A Bug's Life

All sorts of arthropods preserved in perspex blocks or jars. - All sorts of arthropods preserved in perspex blocks or jars.

Last initially checked on 2024-02-21 by Isaac Howell (ih393@cam.ac.uk) and double-checked on 2024-02-21 by John Leung (cfl35@cam.ac.uk).

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Various insects inside perspex blocks. (Specifically, 101 released as part of the Natural History Museum "Real Life Bugs and Insects" Magazine)
- A magnifying glass
- Key with descriptions of each insect (below)
- Jam jar lid
- Hair comb
- Magazine Series (these live in the cupboard usually so don't go mouldy)

Experiment Explanation

*** OVERVIEW ***

Children will look at lots of jars and blocks of interesting creatures, try to identify them, and learn a few things are each one. This is one of those experiments where you'll often get kids who are very interested or not really interested at all, so feel free to vary how long you keep them with you depending on how interested they seem. Don't worry if they only look at one thing then leave!

Tips for demonstrating: 1) Make sure that none of your bugs disappear during the day! I would recommend having a smaller selection out at a time so you can keep an eye on them all (and can remember interesting facts about them all). Some selection ideas are included but feel free to come up with your own sets! 2) If they're young ask them to look at their fingernail or a hair under the magnifying glass – this will give them a better concept of scale and show them how much more detail you can see under the magnifying glass!

*** BASIC PROCEDURE AND EXPLANATION ***

Ask the child to choose a sample on display that looks interesting to them. Then go through the following questions with them: 1) What do you think this is? 2) Do they know anything about the type of bug? (if they recognise it they will often start splurging everything they know about it - just let them talk to you about it!) 3) If they look using the magnifying glass can they see anything interesting (hairs on legs, joints of exoskeleton etc. - talk about the purposes of these things if you know!) 4) For older/very keen kids you can talk about taxonomy (a good website to flick through if you have time before you start: http://www.earthlife.net/insects/classtax.html)

*** About the Insects *** These insects were released as part of a children's magazine series "Real Life Bugs and Insects" which was done in partnership between the Natural History Museum and National Geographic (RRP £5.99 an issue). CHaOS has all 100 issues plus a bonus insect for subscribing to all issues, these were bought second-hand in 2023. All the insects included were (at the time of release in 2016) "not endangered or threatened species". They were also (allegedly) "bred, farmed and harvested in a sustainable way" coming from "specialised, purpose-built farms and the (publishers) can certify that none of these specimens were taken from the natural environment". (Quotes taken directly from the magazine publishers)

There was some controversy at the time of release about how true these statements were. For instance, the stag beetle (sample ID) has a seven-year larvae stage which seems impractical for a magazine gift. You can discuss this if you really want to.

Many children will ask how they are made. The insects inside are all real. They were gassed before being encased in resin.

BASIC INFO

We have a large selection of perspex blocks containing a range of arthropods. Arthropods include: insects; arachnids (spiders, scorpions and mites); crustaceans (including crabs and woodlice); and myriapods (including centipedes and millipedes). The phylum arthropoda also includes trilobites, which are now extinct. Arthropods have existed in some form since before the dinosaurs, with the first arriving ~500 million years ago (dinosaurs appeared ~240 million years ago, and humans about 200,000 years ago).

KEY DESCRIPTIONS FOR PERSPEX BLOCKS

Beetles General Info

The Creator, if He exists, has an inordinate fondness for beetles. - JBS Haldane, geneticist, worked in Cambridge for a time

Beetles are the largest group of insects, with over 400,000 known species (about 4000 in the UK). Insects generally have two pairs of wings, but in beetles the forewings are hardened into elytra that protect the hindwings. Although beetles are still capable of flight, this adaptation allows them to burrow and move around on the ground without damaging their wings, which is what scientists believe to be the reason they are so numerous. With so many species, beetles exhibit amazing diversity – we have a sample of different species here for you to compare.

Large Specimens Box (Box L) and Spider 0) Cuban Tarantula
This isn't in the box but loose and large. Cuban Tarantulas are farmed as an allegedly tasty snack. They don't have a poisonus bite but do have itchy hairs. You can see these clearly on the legs without a microscope. Insert more facts.

1. Giant Scorpion
   Scorpions are arachnids (not insects!). Many people know they use their stinger to inject venom into their prey and for self-defence, but if they have a choice they prefer to use their pincers, because producing venom is costly. While their venom can be deadly, it's also used in biomedical research, with anti-inflammatory properties that make an effective treatment for arthritis. Scorpions also have hairs on their tail which can sense the movement of nearby prey.

2. Spur-throated Grasshopper
   Grasshoppers make their song using stridulation (scraping) - have a comb-like structure and a ridge on each wing and rub the comb of one wing against the ridge of the other (demonstrate using comb) (compare with cicada). They have a thick membrane on their wing which resonates to amplify the sound. Their big legs make them great jumpers, able to jump 25cm vertically, and leap up to a metre horizontally.

3. Rhinoceros Beetle
   Named because of their large horn, which males use to fight over females. Rhino beetles can lift up to 850 times their own weight. They're slow to grow and can spend from a few months up to two years in the grub stage (depending on the species), and can be some of the biggest beetles in the world – the heaviest beetles are a type of rhino beetle called Megasoma, and the longest beetle in the world is the Hercules beetle.

4. Praying Mantis
   Praying mantises are very effective hunters, typically noshing on other insects and the occasional amphibian, but have even been observed capturing small birds. They're ambush predators that blend in with their environment and wait for prey to come close (discuss camouflage appearance with children). They are the only invertebrates to see in 3D, giving them better depth perception.

5. Golden Silk Orb Weaver
   Spiders are arachnids, not insects. They produce silk using special glands called spinnerets at the end of their abdomen. While all spiders produce silk, not all of them create webs, but orb weavers like this one produce beautiful webs.

6. Chinese Stick Insect
   Stick insects are masters of camouflage!

7. Whip Scorpion
   Whip scorpions are not true scorpions, but do have a similar appearance. They are arachnids, and while they are not venomous, they can spray an acidic mix that has a vinegar-like smell – earning them the alternative name vinegaroons. There are about 150 species worldwide, mostly in the tropics.

8. Armoured Cricket
   Armoured crickets are not true crickets (biologists are weird sometimes). They're omnivorous and eat almost anything, from plants to other insects. However, being fat and flightless, they're also on the menu for a lot of other animals. Their first line of defence is their armoured exoskeleton, from which they derive their name, and they have strong jaws to bite with. Males use stridulation to deter predators (see: Large Specimens #2). If all that fails, they can squirt their blood at predators – it is pale green, acrid-smelling, and distasteful.

9. Madagascan Hissing Cockroach
   One of the largest species of cockroach in the world – adults can grow up to 10cm long! They are important for the health of the rain forest, because they are detrivores, which means they eat decaying plant matter and animal carcasses, recycling nutrients back into the ecosystem. They hiss by expelling air from their spiracles – these are holes in the side of all insect bodies through which they breathe.

10. Spotted Black Cicada
    Cicadas are some of the longest-lived insects – nymphs can live for up to 17 years underground before emerging as adults, at which point they scream for three months, mate, and then die. They use tymbals (modified exoskeleton walls on abdomen sides) to produce their loud noise - works by buckling (demonstrate using jam jar lid) (compare with grasshopper, Large Specimens #2)

Box A

1. Manchurian Scorpion
   See Large Specimens #1.

2. Emerald Beetle

3. Giant Froghopper
   Froghoppers are capable of jumping many times their height and length. As nymphs, they suck on plants and encase themselves in foam in springtime, which looks like spit on leaves, earning them the nickname spittlebug.

4. Tropical Black Cicada
   See Large Specimens #10 for cicada info.

5. Giant Wasp
   Native to Asia, but have been sighted in North America, where they are invasive and a threat to bees. Their stingers can be up to 6mm long and deliver potent venom, enough to kill a mouse!

6. Blue Weevil
   Weevils are a type of herbivorous beetle with long snouts (called a rostrum). The weevil family is the largest beetle family, with 45,000+ named species (which also makes it the largest family in the animal kingdom). Some weevil species can be pests. This blue weevil is blue to warn predators that he's not tasty – they eat yam leaves which are toxic to most animals, so eating enough blue weevils can be toxic as the chemicals from the yam leaves build up in them. Being brightly coloured to deter predators is a classic defence mechanism called aposomatism.

7. Giant Forest Ant
   Ants are eusocial (meaning they live in large colonies), usually with a queen and many workers. They build elaborate nests and tunnel systems, and some species of ants even farm fungi. Within a colony, different ants have different jobs: soldier ants are bigger than the others and will defend the nest, whereas worker ants are small and will forage for food or tidy the nest, and the queen lays all the eggs.

8. American Cockroach
   Cockroaches can survive without their heads for over a week - they breathe through spiracles (holes in their exoskeleton) so don't suffocate without heads, but die of dehydration. They also don't bleed to death as they have open circulatory systems (unlike our high pressure systems).

9. Long-horned Beetle

10. Sugarcane White Grub Beetle

11. Wasp Spider

See A6 for aposomatism. Wasp spiders are brightly colored and striped to mimic the appearance of a wasp, but they are not actually dangerous! They're tricking predators into thinking they are by mimicking insects that are dangerous.

12. Giant Shield Bug

13. Brown Grasshopper
    See Large Specimens #2.

14. Exotic Planthopper
    Walks very slowly, pretending to be a leaf; then, if it needs to escape predators/catch prey, it can do big leaps like a grasshopper.

15. Asiatic Cricket
    Crickets are closely related to grasshoppers, and also stridulate. (See Large Specimens #2).

Box B 1) Flower Mantis
See Large Specimens #4. Note the camouflage comparison between the two mantis species – one pretends to be a stick, the other a flower. Different species of flower mantis have different patterns (specific to the area they live in and what flowers are there). They sit very still, waiting for pollinators to come up to them, then strike out with their long forearms.

2. Asian Forest Scorpion
   See Large Specimens #1.

3. Asian Centipede
   Centipedes and millipedes are myriapods (not insects!). Centipedes have around 15-30 legs, whereas millipedes typically have 40-400 legs. If they lose any of their legs, they can regenerate them. Centipedes are much faster than millipedes, despite how many more legs millipedes have! Millipedes are also quite shy, and will curl into a spiral if startled. Centipedes are carnivores, and can bite if threatened.

4. Tropical Mole Cricket
   Mole crickets are burrowing insects, with small eyes and shovel-like forelimbs that are highly developed for digging. They spend most of their lives underground, but adults have wings and disperse in the breeding season.

5. Oriental Flower Beetle

6. Chinese Blister Beetle

7. Paper Wasp
   Paper wasps make their nests by chewing up fibres from dead wood and plant stems, producing large structures that look papery. They generally only attack if their nest is threatened, and are otherwise not aggressive. Like blue weevils (A6) they are brightly coloured to warn predators away, as their stings deliver potent venom.

8. Thai Stag Beetle
   Stag beetles are similar to rhinoceros beetles (see Large Specimens #3), and also spend a long time as grubs and grow to be quite large. Males have huge mandibles that they use to fight other males and throw each other around. Being bitten by some stag beetles would feel like balancing two coke cans on toothpicks on one of your fingers.

9. White Dragontail
   A lovely butterfly. Butterflies have taste receptors in their feet to help them find the best food. Adult butterflies can only feed on liquids, usually nectar in flowers, using a long tubular structure called a proboscis (like a drinking straw); but caterpillars usually eat leaves.

10. Litchi Stink Bug

11. Malaysian Jewel Beetle

12. Pollen Basket Bee
    Bees are eusocial animals (live in colonies) with a queen and many workers. They are important pollinators, and honey bees are kept to produce honey for people to eat.

13. Beautiful Cicada
    See Large Specimens #10 for cicada info.

14. Asian Stag Beetle
    See B-8.

15. Shield-backed Bug
    Named for their shape – closely related to stink bugs.

Box E 1) Asian Water Beetle
Some species of water beetle carry an air bubble under their abdomen to prevent water getting into its spiracles. Other species have a modified exoskeleton which can carry out gas exchange with the water. This particular water beetle is a tasty food in south-east Asia, often boiled or fried whole. The taste is often compared to sweet scallops or shrimp.

2. Damselfly
   Damselflies are closely related to dragonflies, though tend to be smaller, more delicate, and fly weakly in comparison with them. At rest, damselflies hold their wings together and parallel to their bodies, whereas dragonflies keep their wings horizontal and spread apart.

3. Devil Spider

4. Fruit Chafer Beetle

5. African Jewel Beetle

6. Long-nose Jungle Beetle
   Their long nose is for eating pollen out of flowers. Used to think they were pests as they prefer to eat dead flowers and so were always found when there were lots of dying plants - correlation not causation!

7. June Beetle

8. Unicorn Beetle
   See Large Specimens #3.

9. Click Beetle

10. Golden Asian Stag Beetle

11. Formosa Stag Beetle
    See B8 for stag beetles.

12. Orange spotted Cockroach
    A tropical species of cockroach – see A8 for more.

13. Horned Flower Chafer (beetle)

14)Spotted Longhorn Beetle

15. Chinese Lantern Bug
    Lantern bugs are native to China, but are an invasive species in South Korea and the United States. They produce honeydew which they leave behind on plants. Other bugs like to eat the honeydew, but it can also cause sooty mould to grow on plants, inhibiting the plant's ability to photosynthesize and hurting the plant's ability to survive and grow.

*** Interesting Pairings *** In this section we'll pick out a few pairs/groups of specimins from across the boxes which have interesting comparitive elements you can talk about. You will probably want 12-20(ish) samples and this section hopefully helps with some ideas although you are welcome and encouraged to come up with new connections or just talk about them individually.

- Types: Have an assortment of insects (many), arachnids (many), crustaceans (none yet) and myriapods [B3,F?]. You can get people to try and sort them, usually the number of legs is a good hueristic. Including Stick Insect [A6] is good if you want people to guess the types, most people will get arachnids but may struggle on insects, in which case point them to this one.
- Invasive Species: Giant Wasp [A5] and some other wasp (e.g., Paper Wasp [B7])
- Avoiding being eaten: Talk about Stick Insect [A6] which is camoflauged. Compare Wasp Spider [A11] and a wasp (e.g., Paper Wasp [B7]) as disguise. Aposmatism is fairly opposite and is bright colours as a warning (e.g., Blue Weevil [A6] or Paper Wasp [B7]).
- Farming: Cuban Tarantula [L0] is farmed for food (probably several others too). A scorpian (e.g., Giant Scorpian [L1]) may be farmed medically for venom. Spider silk may also be farmed (e.g., Orb Weaver [L5]).
- General similarities: Lots of pairs of closely related insects have very similar features and kids can identify these and figure out they're related. Lots work for this, e.g., Cockroaches [L9,A8,E12].

Some sample sets: - Tom's Selection (17 bugs) - L0, L1, L3, L4, L5, L6, L7, L9, A1, A5, A6, A8, A11, B3, B7, B8, The Millipede from

F?

Risk Assessment

Hazard: Breaking the blocks/jar/magnifying glass

Description: Smashing a specimen block/jar or magnifying glass could cause cuts.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: It is very unlikely that the perspex blocks would break, even with a significant amount of force. However, demonstrators should keep a careful eye on the blocks and jars and magnifying glass, account for all specimen tubes every time a demonstration is completed. Call first aider in case of injury (cut). Clear up perspex (using the dustpan and brush from Set Up and Clear Up), wrapping up in paper or similar so that it won't rip through the bin bag. Place in broken glass box if available at a school. In case of injury, call first aider.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Tripping over blocks

Description: Blocks are quite small and their transparency means that it might be difficult to see them, creating a potential tripping hazard.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Demonstrators should make sure that blocks are not played with by young children without supervision. If a block is dropped, it should be picked back up as soon as the area is safe to do so. In case of a child (or adult) tripping over, call first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Perspex blocks

Description: Kids may throw them or drop them on feet

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Take away from kids if they are being silly with them. Keep all perspex blocks in sight during the demonstration.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Magnifying Glass

Description: Kids (or demonstrators!) may set fire to paper or dry grass if very sunny day.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Take away from kids (and scold demonstrators) if they are deliberately trying to set fire to things

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Preservative

Description: Could escape if jars are broken/opened. Preservative is 1% Propylene phenoxetol, which should not be irritant to eyes or skin at that concentration, but which may be harmful if ingested. (If asked about the toxicity of propylene phenoxetol, mention that it is used as a preservative in personal care products and it is chemically inert).

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Keep a careful eye on the jars and do not let anyone open them. They should all be taped up around the top - if the tape is coming off redo it. If any liquid leaks, clear it up straight away, preferably wearing gloves, then wash your hands immediately. Advise any children to wash their hands immediately if any liquid goes on their skin.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-17 - Michael Darling (md510@cam.ac.uk), **Check 2**: 2012-01-24 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2012-12-24 - Beatrice Tyrrell (bet23@cam.ac.uk), **Check 2**: 2012-12-30 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2013-12-25 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk), **Check 2**: 2014-01-01 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2015-01-05 - Arporn Wangwiwatsin (Koi) (aw584@cantab.net), **Check 2**: 2015-01-06 - Kym Neil (kym.e.neil@gmail.com)

Check 1: 2016-01-07 - Natalie Cree (nc434@cam.ac.uk), **Check 2**: 2016-01-23 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2017-01-13 - Alfred Chia (ac939@cam.ac.uk), **Check 2**: 2017-02-06 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2018-01-08 - Gemma Shaw (gcs33@cam.ac.uk), **Check 2**: 2018-01-29 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2019-01-20 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-01-21 - Amanda Buckingham (abb53@cam.ac.uk)

Check 1: 2019-12-23 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-22 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-01-28 - Sian Boughton (seb216@cam.ac.uk), **Check 2**: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-22 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2023-02-10 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2024-02-21 - Isaac Howell (ih393@cam.ac.uk), **Check 2**: 2024-02-22 - John Leung (cfl35@cam.ac.uk)

Air Rockets

Launching lemonade bottle air rockets along a rope - 5, 4, 3, 2, 1, Lift Off! With a lemonade bottle and a bike pump, we'll show you how to make a rocket! How high can you get it to fly?

Last initially checked on 2023-12-23 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 Timothy Wong (chw55@cam.ac.uk)

Tags

Missiles

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- Pump
- Bung with hole or with valve
- Rope
- Lemonade (or other fizzy drink) bottle with tube attached for the rope to run through (something with low friction so that the bottle will come back down again and fly further)
- Launch stand

Experiment Explanation

Launching lemonade bottle air rockets along a rope (going up at an angle of 20-30 degrees) - this is a less messy version of the water rockets experiment which can be done inside in a suitably large hall.

Setup Set up the rope running from the launch area to a higher point (raising the launch area, e.g. blocks, can keep the rope above head height) - run the rope through the tube attached to the bottle. Jam the bung in the bottle and get kids to pump until the rocket launches up the rope. Hopefully it should come back down to somewhere you can grab it. Keep people out of the area where the rope is so that they don't get hit by the rocket or walk into the rope!

As a further point - it can very occasionally be done without the guide rope pointing vertically upwards, or without a guide rope at all. This is suitable in large sports halls or outside only. Here care needs to be taken that a large enough area is cordoned off so that it does not hit anyone when it returns to Earth. If a guide rope is not being used, it can still be helpful to attach a rope to the rocket, in order to limit its range (such as to avoid hitting people if you can't cordon off a large enough area) - however, care must be taken to ensure the rope itself does not pose a hazard in such cases.

Explanation and Demonstrating

Like the water rockets, everyone likes to play with the air rockets... and they can't fail to notice the experiment since it makes a bang every time the rocket goes off!

If you want to explain the experiment, you'll probably find it best not to let the kids get onto the launch platform until you've talked to them a bit. It's generally best to ask a question first to see what they know already.

There's quite a lot of physics you can explain with the experiment. Firstly the idea of pressure - you can talk about the pump - put your finger over the valve and get them to push down on the pump - they'll find it gets harder as they push down and increase the pressure. So we have the idea that as we pump the bottle up, we increase the pressure and this pushes the bung out. If they understand (ask them to explain it again!) you can talk about molecules. The molecules move at about 500 ms-1, so even though they are light give a good push on the walls of the bottle when they hit (plus obviously there are > 10^23 of them!). So, as you pump up the bottle, adding more molecules, there is a harder push against the wall and the bottle gets harder.

So what happens when the rocket launches? We've said that the bung gets forced out by the pressure in the bottle (what pressure it reaches depends on how hard you jam the bung in each time, and varies, and thus does the height the rocket gets to). You probably don't want to talk about conservation of momentum with the kids - the bung flies out backwards with a certain momentum, and thus to give the overall system zero momentum the bottle gets equal and opposite momentum, sending it up the rope. You can talk about equal and opposite reactions, though. Think about leaning on a wall - does it push back on you? Most kids probably think not. However, if you get one of them to push on your hand, and you push back, you both stay where you are. If you ask them to stop pushing, then you fall forwards (or at least pretend to!) - so leaning against the wall, the wall must be pushing against you! Going back to the rocket - when you pump up the bottle the air is pushing against the bung - when the bung pops out it's like stopping pushing against your hand, so the rocket flies forward. You can show this with throwing a bag of rice; as you throw it it pushes you back. Another example that kids might know about is cannon/ gun recoil which is essentially the same physics as this. The cannon moves backwards and fires the shot forwards and in the same way the bung moves backwards and fires the bottle forwards.

You can also talk about energy - where does the energy for launching the rocket come from, and where is it stored? The more pumping you do, the higher the rocket goes (all else being equal).

Kids will keep coming back to have another go, so each time ask them something about it to see what they've remembered!

N.B. A good trick with families or other groups is to challenge them to get the rocket as far as possible along the string (maybe with only one attempt!) little do they know that the distance pretty much only depends on how tightly you put in the bung, and thus the meekest among them can be the mightiest!

Risk Assessment

Hazard: Bottle

Description: Projectile may hit people

Affected People: All

Before Mitigation: Likelihood: 5, Severity: 2, Overall: 10

Mitigation: Keep people away from the rope (which the rocket travels on) by blocking off any area where the rope is below head height with chairs, hazard tape or similar. Make sure the person launching the rocket doesn't lean into its path (try to keep the pump as far away from the rocket as the hose will allow - we have lengthened the hose to make this job easier). Also locate the experiment sensibly, bearing in mind walkways that people will want to use in the venue, roads etc and wind direction.

If done without a guide rope, cordon off sufficiently large area to ensure it lands within it. Check prevalent wind direction as well by test firing the rocket before people come.

If using the rope to limit range, the areas in which the rocket might land (accounting for prevalent wind direction and lean of the launch stand) must still be cordoned off as there are two hazards - both from the rocket falling on someone and the trip hazard due to the rope.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Bottle (pressurised)

Description: Bottle exploding; debris might cause small cuts or fall on people. Debris may fall into eyes damaging cornea.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Check bottle for cracks and other damage before use. Any damaged bottles should be cut or marked to show they cannot be used if they cannot be disposed of immediately. Only use 2L "fizzy drink" bottles (Coke, Fanta, etc.) with thick walls, not bottles for still drinks which are not (always) suitable for pressurising. If possible, wear safety goggles.

In the event of an accident call a first aider.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Rope

Description: Walking into/tripping on rope.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: The provisions for ensuring people aren't hit by the bottle keep visitors away from the rope. Try using thick/bright-coloured rope so it is easily visible. Keep rope ends tucked away and off the ground if possible. If the ends are on the ground, tape it firmly.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-09 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk)

Check 1: 2015-01-02 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk), **Check 2**: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-13 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2016-12-28 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-01-15 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk)

Check 1: 2017-12-09 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2018-12-12 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2018-12-31 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2019-12-16 - Lucy Hart (ljfh2@cam.ac.uk), **Check 2**: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Vanness Lai Wye Junn (vwjl2@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-12 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2023-12-23 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk)

Air Streams

Balancing balls on upward streams of air, and looking at aerodynamics. - Can you make something float on thin air? Find out how to levitate ping pong balls and why planes can fly in this entertaining experiment.

PLUS experiment includes: Newton's laws, stable equilibria, drag, lift and the Magnus Effect.

Last initially checked on 2024-01-24 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Electricity needed

Physics

Equipment Needed

- Electrical stuff:
  - Big Blower (too big for box, needs 2 people to lift)
  - Stream stabiliser for the big blower (a hollow box open on one end and with a grid on the opposite end)
  - 'Small' blower (in box)
  - 2 x variable power switches for blowers.
- Floating Objects:
  - Beach Balls
  - Ping-pong balls
  - Aeroplane wing
  - Plastic cups and elastic bands
- Also Useful:
  - Screwdriver with haztape streamer (for showing streamlines)
  - Paper
- CHaOS only:
  - Bendy straws (consumable), must have reasonably wide holes.
  - Small wooden rocket puzzle
  - Anti-bacteria wipes (consumable)
- CHaOS+ only:
  - Diagrams of wing cross sections / streamlines around an aerofoil

Experiment Explanation

In a nutshell

Show how flowing air acts on object in or next to it.

How to set up the experiment

IMPORTANT NOTE: All cables for blowers stay in the Airstreams box. They are labelled 'BIG' and 'SMALL'. Please do not return them to Extension Leads and mix them up with the rest. These plugs have a higher fuse rating.

Note: The big blower is not necessary but makes a nice show. It may cause the circuit breakers to go off, so check first so that you don't cause a power outage a the beginning of the session.

Place the blowers on the ground. Make sure they are not in anyone's way, and also check above them to make sure nothing will be disturbed by the fan (such as lightweight ceiling tiles). Put the stream stabiliser on top of the big blower. Plug the cables to the power switches and to the grid.

Note: The switch for the big blower gives full power for a few seconds after switched on. Afterwards you will be able to regulate it.

Blow up the beach balls and have the straws pingpong balls and aeroplane wing handy.

How to proceed

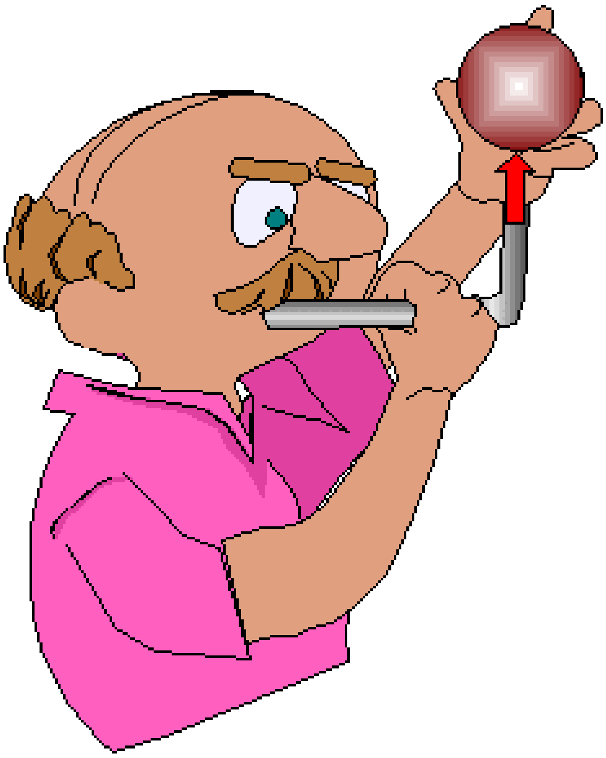
This is a suggestion on how to proceed with the demonstration. The demonstrator should encourage the kids to try and figure parts of explanation out by themselves by asking the right questions, so that they stay focused. There's a lot in here: you may not explain all of it!

Straws and pingpong balls

Take a straw and bend it in right angle. You can start by asking the kids if they can think of a way to balance the ball on top of the short end (not holding it by hand). Two ways are quite good: sucking and blowing. (Simple balancing it is possible but very hard.)

If you suck the air from under the ball, the air pressure from the outside will hold it in place. You can tell them about the air pressure and that we are constantly pressed everywhere and that suction occurs when we reduce the pressure in an area (eg the inside of the straw). (The concept might be hard to grasp so consider the age of the children.) They might already have some knowledge of it if they have seen the Vacuums experiment.

If you blow into the long end and hold the short end upwards, you are able to balance a pingpong ball on the stream. (The straw end needs to be vertical and you have to blow quite hard.) It requires a bit of practice. Let the kids have a go at it. Give each a new straw and dispose of them afterwards to avoid spread of infection. Demonstrating what goes on is easier with the blowers. It's the same on a larger scale.



A bit of theory - what are forces

Hold a ball in mid air and ask them what is going to happen if you let go. Show them that they are right. Now ask them why the ball falls down. You should get to gravitational force. Explain what a force is. That it is what makes things move, for example pushing, pulling, gravity, magnetic force, friction. Explain that if something isn't moving, the forces must be balanced (they are pulled down by gravity but pushed up by the ground). Tell them about Newton's third law - action and reaction. If you push or pull something, you get pushed/pulled yourself. You can demonstrate by letting them push/pull your hand.

Wooden Rocket 'Puzzle'

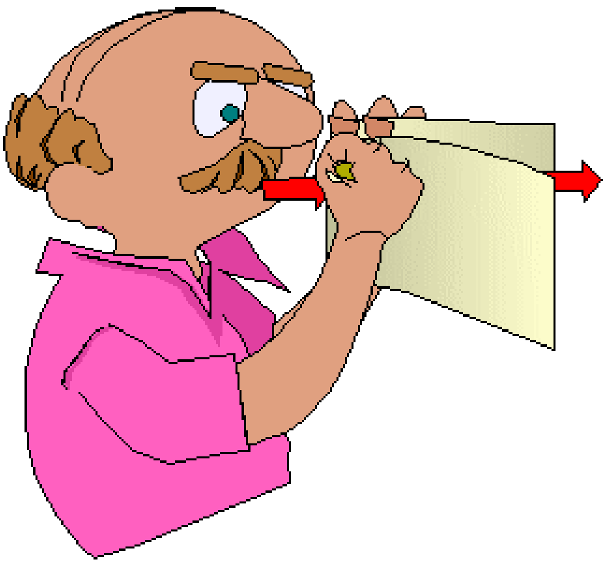
Put the rocket on a flat surface with the tip of the orange 'rocket' pointing upwards. Explain that the aim is to get the rocket out of the container without touching the container. (Hopefully they'll come up with blowing on it after doing the ping-pong straw experiment - though it's really not obvious when you first look at it that it's going to work!). You can then demonstrate that indeed the rocket does jump out of it's container (literally!) if you blow on it. I find that it works best if you blow at about 45 degrees to horizontal - have a practice yourself before hand. (I can generally get it to go the highest when I blow straight across the rocket, but this makes it harder to aim and half the time I just end up blowing the whole thing across the desk). The kids can then have a go themselves. There are some anti-bacterial wipes to use on the rocket afterwards. Explain that the air in the container with the rocket is forced out, bringing the rocket with it - another example of air creating a force. (Air pressure decreases over the top of the rocket when you blow over it creating a pressure gradient, the air needs to be replenished from somewhere and part of it comes from inside the container. The explanation inside the rocket box says 'A short, sharp breath of air directed across the top of the puzzle creates a fierce vacuum, causing the wooden rocket to take off' , however I think vacuum is a bit extreme but if that makes more sense to the group you're explaining it to?)

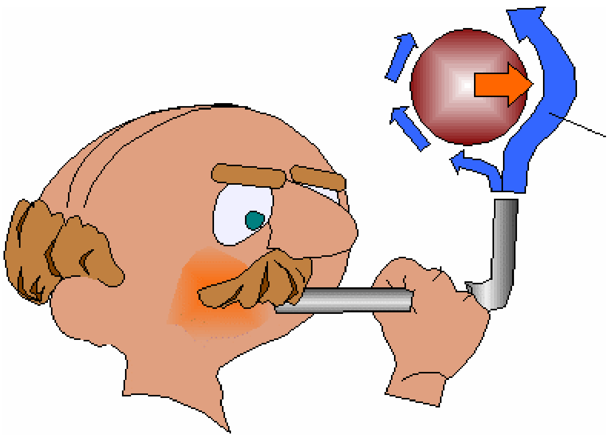
Blowers and beach balls

Preferably use the big blower for this. If you place the ball in the air stream it will balance on it and not fall off. You can demosnstrate that it always balances at the same height. If you hold the ball at the edge of the stream you can feel how it is pulled in. You can let the kids to feel it too. You can use the screwdriver with haztape to demonstrate the direction of the stream.

Explaining why the ball doesn't fall directly down is easy and the kids might tell you that on their own. The tricky part is why is it pulled to the middle of the airstream. There are two ways to go about the explanation. The first is using Newton's third law. When you look at the airstream around the ball when it is at the edge of the stream, you will see that it is bend around the ball. After passing the ball, the stream is not strictly vertical (it is going a bit sideways). That means that the ball effectively pulls the passing air towards itself. The equal and opposite reaction on the ball then is that it is pulled inside. The other way of explaining it is using the Bernoulli's principle - the fact that the pressure is lower where the air has greater speed. (You can demonstrate it by blowing between two parallel sheets of paper hanging vertically next to each other.) So there is atmospheric pressure on one side of the ball and lower on the side of the airstream. The difference in pressure results in a force towards the stream.

This can also be illustrated by tilting the smaller blower, and having it keep the beach ball still, even though it's not blowing from underneath.





A bit on stability

By the time you're reading this we should have a few beach balls of various sizes in the box, if not shout at Zephyr…

Using these we can do a brief discussion on stability of systems and how they will tend to rearrange themselves in the most stable form.

If we put two balls of different sizes into the air stream at once, the most stable configuration is the smallest on the bottom and the largest on top. This is because each ball effectively blocks some of the air hitting it from getting to the ball above (though by no means all, as seen with the bigger at the bottom) and hence there is less upward force on the higher ball.

Thus with the smaller on the bottom, enough air still reaches the second ball to hold it up, whereas the other way up little air makes it to the smaller, higher ball and it is likely to 'fall' off the side of the stream.

Why the quotation marks? Well, if you're lucky (/careful with the settings) the second ball rarely actually escapes the stream, instead the larger ball barges it's way past and then the smaller slots back into place under it. I.e. the system seeks out the most stable configuration.

That said, the smaller ball on top is still an equilibrium state, just less stable, and for more advanced audiences you can talk about the differences between equilibrium and stability.

Note, there is another effect with very small balls, like the ping pongs balls, where they are so light that the force they experience hugely outweighs the difference in amount of air hitting them, so make sure that the balls are of roughly comparable mass, or the lightest will just fly off!

Aeroplane wing

When you tilt the small blower so that the stream of air is horizontal, you can demonstrate the forces acting on the aeroplane wing. Children should be able to feel the air pushing the plane upwards when it is held horizontally. The wings are designed to maximise the upward thrust (which means they push down air significantly) while the backward thrust is minimised (we don't want the wings to slow down the plane too much). Tilting the wing in the airstream results in greater upward force but also greater backwards force. Let the kids feel it but be careful so that the wing doesn't fly off and hit them in the face.

Two possible explanations you can use:

One way to think about this is again with Newton's Third Law. The curvature of the wing means that the wing pushes the air blowing at it downwards, and so the air pushes the wing upwards. The size of the force depends on how fast the air is moving, and therefore how much air it is pushing down - you can show this by adjusting how hard the fan is blowing. This means that a plane has to travel VERY fast to get enough lift to keep it in the air (commercial airliners travel around 500mph).

Or using air pressure to explain: When the plane moves forward it pushes air out of the way, over and under the wing. As the top of the wing is curved more than the bottom of the wing, the air has to go further to get over the top and so it has to move faster. Bernoulli's principle says that the pressure is lowered when the air speeds up, so the air pressure above the wing is lower than the pressure below it, and the wing (and plane) is pulled upward (ie the same way things get sucked into a vacuum), opposing the gravity pulling it down. [note: this doesn't explain *why* the air has to move faster over the wing - the air stream moving over the top of the wing has to move through a narrowing space due to the curvature, but with a constant volume per time (like water through a tube that then gets narrower).]

Other things to talk about:

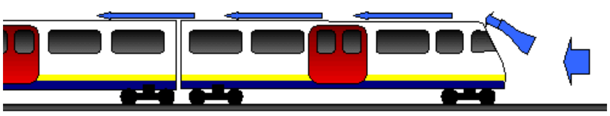
Have you ever noticed your ears going pop as your train goes through a tunnel?

For the train to move forward the air in front of it has to get out of the way, normally there is lots of space for it to do this, but in a tunnel there is just a little gap around the side, which the air has to squeeze through really fast.

This fast moving air sucks some of the air out of the train, which then sucks on your eardrums, making them go pop!

Why do you think they go pop again when you leave the tunnel?

The air isn't going as fast outside so the pressure goes up and the pop back inwards again.



You may notice the ball is spinning sometimes - think about where the air must be flowing to stop the ball falling off.

This happens when the straw is at an angle so the ball drops down a little and the air stream is faster over the top which is what is holding it up.

Try moving your hands across the blower, just above the grill. This will cause the ball to 'dance' as you are changing the air stream so the beach ball adjusts its position to remain in equilibrium.

PLUS Explanation

Aims - Newton's Laws and Stable Equilibria - Drag Forces - Bernoulli's Equation - Lift and Magnus Effect

1 Newton's Laws, Weight and Velocity Profile

What are Newton's Laws? How might they be relevant here?

1 - still or constant velocity if no net force

2 - acceleration proportional to net force

3 - equal and opposite reaction of same type

Here the ball hangs in equilibrium - weight and drag must balance.

How does weight vary with height?

Weight essentially constant over the range of the room compared to the radius of the Earth (if they are familiar with binomial expansions could show this mathematically by expanding $F = -GMm/(r+h)^2$).

How would we expect the velocity to vary with distance? Can we draw a graph of this (i.e. velocity on y as function of height on x)?

Well collimated at exit - velocity gradient 0 - can show this using streamers. Falls to 0 at large distance - wouldn't feel effect of fan far away. Doesn't keep going negative - no bulk downward motion above the fan caused (there may be turbulence or circulation at the sides). Smoothly interpolate. Full solution very complicated.

2 Drag Forces

What factors will affect the drag?

Relative velocity of wind/object (you feel a force from the air if you run as well as on a windy day, easy to run with wind than into it), size of object, shape (streamlined), also properties of fluid - density, viscosity

In fact the functional form is as follows: At high velocities, inertia effects dominate with constant drag coeffcient:

$$F = Cpd^2v^2$$

At low velocities, viscosity dominates. Get Stokes' formula (most likely to have seen this before with Millikan Oil Drop:

$$F = 6 * \pi * \eta * rv$$

(Result of drag coeffcient being inverse in velocity i.e. $C = \eta/(pdv)$)

Note in each case - increasing function of velocity.

Therefore, what would you do if you were building something?

Engineers have to design things to minimise drag by size of area, roughness, stability, smoothness of flow to stop vortices (streamlined tail). Very complicated - get things like vortex shedding which leads to vibration (sounds of wind). Also need to consider laminar and turbulent flow - rough surfaces can actually be better eg golf balls!

Try the "plane wing" (in reality a Pringles tube wrapped in card that you can stick your hand into) in the stream - which way round is it easiest to hold (ignoring the fact it wants to turn a lot) and why? What height is easiest? How does this change when fan turned down?

Should be easier to hold pointing into fan as lower area, more streamlined.

Return to our graph from earlier. Let's assume Stoke's law (where F proportional to v) which means we can relabel y as force. Given weight constant, what should line for weight look like? Where should it be?

Needs to be somewhere between maximum and minimum force such that it crosses the force from the air so we can have equilibrium.

3 Stability

Have a closer look at the graph. When the ball moves above the equilibrium, which is greater and thus what happens? What about the other way?

Up - weight greater - falls. Down - drag greater - rises.

This is an example of being stable, when we move away we return. Also described as negative feedback. What other examples of stability are in this problem? Hint: look for other directions that things can move (ball as a whole has 3 directions it can move, with each point having 3 relative to ball):

- The ball doesn't explode or collapse - e.g. the pressure inside goes up if we try to squeeze it. (Accounts for one degree of freedom - distance from centre of mass.)
- The ball often settles a particular way up with nearish the valve at the bottom. Rotational stability familiar from measuring the centre of mass - if we move away we get a moment that moves us back. (A second degree of freedom - azimuthal angle from centre of mass.)
- The ball doesn't fall out sideways - due to Bernoulli effect which we will come onto. (Accounts for two degrees of freedom - x and y position of whole ball.)

Other examples across the sciences of feedback/stability:

- Populations - predator increases lead to prey decreases which starves predators.
- Homeostasis - e.g. if glucose levels too high, then insulin reduces them and vice versa for glucagon.
- Chemical equilibrium - in reversible reaction, if we increase products, then backward rate increases and we return - relates to Le Chatelier.
- Bond lengths in atoms - balance of electron energies from attraction to two protons to repulsion of atoms. Can be modelled with Lennard-Jones Potential.
- Balls can sit in valleys but not on top of hills!
- Mass on a spring SHM experiment.

With a good group you could go through stable equilibria being potential minima more - but might need building up idea of force as gradient of potential etc. If they know about Taylor series, you can also discuss all minima being quadratic like SHM.

4 Bernoulli's Equation - Lift and Magnus Effect

In steady flow (only) the arrows show both the direction of the fluid at any one point and also where a particle will go over time. Where is the flow around the ball? Try sketching this on paper and confirming hypothesis with streamers.

Important to visualise streamlines using streamers at variety of places - note speed and direction at various heights; distances from centre; bottom, side and top of ball with varying proximity.

Bernoulli's Equation

For a unit volume of incompressible fluid (suprisingly good even for gas), energy conservation gives us (derivation not needed here, we are looking at mathematical reasoning):

$P + \frac{1}{2}pv^2 + pgh$ = constant

What do the terms in this equation mean?

P is pressure, p is the density, v is the velocity, gh is gravitational potential

What happens if the velocity at a given height changes?

Pressure must change to balance.

Thus, why does the ball stay in? Try the ping-pong ball. Why does it not stay in?

Pressure difference between side of ball if off-centre. Pressure difference too small on ping-pong ball.

Shows diagram illustrating how the pathlines/streamlines go around a aerofoil (wing). Where are the lines more spread? What does this mean for velocity? Therefore, how does the pressure vary between sides?

Lines spread below and bunch up above. Mass conservation means that lower velocity below meaning higher pressure - net upwards force - lift. Bird Wings also use similar principles - also have narrow tips to minimise vortices - see cross section comparison.

Magnus Effect

Demo - a pair of plastic cups taped back to back. Wrap (chain of) elastic bands around them. Hold off of one finger like slingshot and release. Have a look at this pair of cups. What does it do immediately after firing?

Cups loop up into air.

Why does this happen? Can we draw diagram of flow lines? Cups drag air as they rotate- adds to motion on one side and detracts on the other meaning there is a velocity and hence pressure difference.

This is known as the Magnus effect. One example is rotor ships. Perhaps more common is the spin on a ball in sports e.g. football, golf, table tennis.

Risk Assessment

Hazard: Blower (intakes)

Description: Trapping fingers/long hair in the intakes/gaps.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Keep visitors away from the intakes. There are guards designed specifically to keep fingers out of the danger area.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Blower (weight)

Description: Injuries from lifting/moving the apparatus from place to place. Also the possibility of falling from a height onto people, causing injuries to the public.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Keep air conditioning generator on floor. Make sure that it is stable in the mount. Take care when moving it (refer to lifting advice on CHaOS website).

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Electrical cables/electrical parts

Description: Tripping over cables. Electrical hazards as detailed in Electrical Parts RA.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Tape wires to floor and lay sensibly (not across the middle of the room). If necessary, attach something brightly coloured so that cables are clearly visible. Ask children to put down cups of water before interacting with blower. Follow electrical parts RA.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Ping pong balls

Description: Slip hazard from ping-pong balls. Risk of child injuring mouth from falling over with a straw in his/her mouth. Also, children are liable to run across people s paths after escaped ping pong balls, which can lead to accidents.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Keep track of where the ping pong balls are and do not leave them on the floor. Get the kids to sit down if possible when playing with the ping pong balls so that they don t run around with the straws in their mouths and fall over. Encourage them not to chase balls. Do not allow young children to take straws away with them after experiment.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Saliva on straws/rocket

Description: Transmission of illness through contact with saliva.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Give every child a fresh straw. Wipe the rocket with anti-bacterial wipes, after attempts at making it take off.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Straws/model wing blown out of child or volunteer’s hands

Description: Injuries as the result of collisions with flying objects, particularly with eyes/face.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Make sure model wing is held securely - do not let small children hold unassisted and avoid using blower at full power for this part. Discourage dropping of straws into air streams. Call a first aider if there is an accident

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Blowing too hard when making air streams

Description: Dizziness, possible collapse

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Warn before blowing into the straws not to blow too hard and to stop if dizzy. Call a first aider in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Wooden rocket

Description: Rocket may hit child in face when it takes off - It s not very heavy nor does it go that high so will probably only be a problem if it hits their teeth. Splinter from wooden rocket.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Make sure the child isn't too close to the rocket when blowing on it. Demonstrator to check for splinters before use and not use if any are noticed. Children should not need to touch the rocket anyway. Call a first aider in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Objects above the fan

Description: Blower, or objects lifted by the blower, may disturb overhead objects such as lightweight ceiling tiles, causing them to fall down and potentially injure someone.

Affected People: All

Before Mitigation: Likelikhood: 3, Severity: 2, Overall: 6

Mitigation: Be careful to check above the blower for anything that might be disturbed when choosing where to place it. If this is unavoidable, then make sure the power is sufficiently low that nothing will be disturbed.

If an incident occurs, turn off the fans, clean up and call a first aider if necessary

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Plastic cups (PLUS)

Description: They may hit someone when launched.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 1, Overall: 4

Mitigation: Only launch cups in a controlled manner where there is a clear area to do so allowing for things veering off course.

Call a first aider in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 1, Overall: 2

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-16 - Jachym Sykora (js973@cam.ac.uk)

Check 1: 2014-01-09 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk)

Check 1: 2015-01-02 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk), **Check 2**: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk)

Check 1: 2015-12-27 - Charis Watkins (czrw2@cam.ac.uk), **Check 2**: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk)

Check 1: 2016-12-28 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-01-25 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2017-12-26 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2018-02-06 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-12-12 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2018-12-12 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-15 - Beatrix Huissoon (beh37@cam.ac.uk), **Check 2**: 2020-01-15 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2020-01-24 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2020-01-27 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2021-01-02 - Lucy Hart (ljfh2@cam.ac.uk), **Check 2**: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-12 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2024-01-24 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Animal skulls (including primate skulls)

Looking at different animal skulls to compare them and see how they differ. - Why do some animals have really long beaks? Why do others have really big TEETH? With our collection of animal skulls, you can find out how different animals evolved to suit their habitats - and how you are a lot more similar to them than you might think!

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-14 by Isobel Gilham (ig419@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Various different skulls and a pile of laminated photos
- Box 1
- Mammals: sheep, dog, cat, fox, mole, rabbit, roe deer
- Birds: magpie, pigeon, oystercatcher, duck (one complete, one in parts), parrots
- Other: gulper shark jaw, striped snakehead fish, snake (some kind of boa), Siamese Crocodile
- (nb: The magpie and pidgeon skulls are sometimes moved into animal cognition)
- Box 2
- Primates: human, chimp, gorilla, orangutan (all models)
- For CBS, some can also be borrowed from the zoology museum.
- Pictures of the animals

Experiment Explanation

OVERVIEW

We have some skulls of different animals. Each has different adaptations relating to the animal's lifestyle and environment. Looking at a skull's characteristics, such as teeth, eye placement and size, scientists can determine whether the animal was an herbivore, carnivore, or omnivore, and if the animal was a predator or prey animal.

SETTING OUT THE EXPERIMENT

In a calm event it can be nice to set out all the skulls on a table, with all the photo cards spread out in front of them so that you can play a matching game. In a busier event or with an excited group of kids it's probably better to have them in the big blue boxes and pull out one skull at a time, or choose a few skulls you like that fit a narrative (e.g. comparing herbivores and carnivores) and have just those out. That makes it easier to control which kids are holding the skull(s) and it makes it easier to control the questions, as you don't have to jump backwards and forwards between lots of different animals!

BASIC PROCEDURE AND EXPLANATION

Unlike some of the other biology experiments, the animal skulls experiment has no fixed story line. This makes it much more flexible, so you can talk about the skulls that you find cool or know more about. (No-one will know which ones you've left in the box!).

Our advice is to start talking about one skull in detail, then compare other skulls to the first one you picked. It's easier to pick one of the bigger/ less fragile skulls first, such as the human (made of plastic!) or the sheep skull. Make sure that you've established what a skull is on the first one- it's not as obvious as you might think that it's the boney stuff that is inside our head/ protects our brain. You might also want to briefly talk about what bones are for/ made of - an explanation of hard stuff that holds our bodies up is probably enough detail for the youngest kids!

- Start by asking the child if they recognise any of the skulls - they will probably recognise the human one at least
- On the human skull - can ask if they know the names of any parts of the skull (can help them out by providing a couple - remember to use simple terms e.g. teeth, eye sockets)
- Point out interesting points on the skull that you might know e.g. foramen magnum where the spine attaches to the skull and through which the spinal cord runs, or the holes on either side of the skull where the inner ear goes
- Once you've established the names of a few of the skull's main features, ask the child if they know what each of these features does or what they're for
- Point out that the jaw isn't fixed to the main part of the skull - apart from anything else we wouldn't be able to open our mouths to eat if it was stuck (fused) to the rest of the skull.
- Holes for nerves, such as at the back of the eye sockets. These allow the brain to connect to send and receive signals from the rest of the body.
- Can then move onto the other skulls - discuss the features of the skulls and how these relate to the demands that the animal has to cope with in its environment. Why might the adaptations help the animal to succeed in its environment/why might the animal have developed these skull features? You might want to discuss each skull in turn, or you may prefer to talk about a particular 'theme' i.e. teeth, brain size across a number of skulls at once
- Make sure you get child involved i.e. get them to (gently!) handle skulls so they can feel how delicate/sturdy they are, ask lots of questions. Remember to use simple language and explain difficult words in simpler terms (e.g. 'animals that come out at night' rather than 'nocturnal animals') Particularly delicate skulls have a small piece of red gaffa on their boxes - only let children handle these if you think they will be careful enough with them!

Interesting features/comparisons include:

TEETH

The type, shape and number of teeth an animal has can help determine its diet.

- Incisors are the front teeth. They are used primarily for cutting and grasping.
- Canines are the teeth next to the incisors. The canine teeth typically are large in a predator and are used for tearing and grasping.
- Premolars are the teeth behind the canines. These teeth have sharp edges for crushing food.
- Molars are the very back teeth. They are broad and flat and are used for grinding.

If a mammal has long, sharp canines, it is most likely a predator. Canines are used for grabbing, holding and killing prey. Some meat-eating mammals (carnivores) have sharp shearing cheek-teeth called carnassials. These teeth act like a scissor to cut through tough flesh and to break it into smaller pieces for swallowing and digestion. The fox is mainly carnivorous, although they also gather a wide variety of other foods like fruit and berries. The European Mole is also carnivorous, and feeds on invertebrates e.g. earthworms, insects. Ask the child if they can think of any other carnivores (cats and dogs are just two familiar carnivores).

Plant eating animals tend to have teeth specialized in chewing various parts of plants. Some plant eaters eat grasses (grazers e.g. sheep, using incisors to nip plants close to their bases), some eat twigs, leaves and berries (browsers e.g. goats/deer) while others eat only specific plant parts (i.e. roots, fruit, etc.). In order to properly digest vegetation, an animal must chew its food to help break down the plant. Most herbivores have cheek teeth called molars. These molars help grind leaves, stems, grasses, fruit and even seeds before the animal swallows them. Examples of herbivores in our skull collection include the hare (hares eat grasses during the summer and twigs/tree bark etc. during the winter, and also commonly re-ingest their faecal pellets…) and the sheep (these mainly feed on grasses, have a large and complex stomach which is able to digest highly fibrous foods that cannot be digested by many other animals). Sheep, cows, llamas and alpacas all don't have top inscisors! Instead they have a thick, hardened gum line (called the dental pad) which they use to pinch off blades of grass against.

Some animals (omnivores) eat both plants and animals, and have both types of teeth. The primates and magpie are omnivores (although obviously the mapgpie doesn't have any teeth). Interestingly though, recent studies have shown that chickens (and possibly other bird species) still retain the genetic blueprints to produce teeth in the jaws, although these are dormant in living animals. These are a feature from primitive birds such as Archaeopteryx, which were descended from theropod dinosaurs. Other examples of omnivores include pigs and bears.

Fish - some fish have teeth, others don't. They tend to all be small and sharp if they have them and are mostly found in carnivorous species. This fish eats frogs, insects, and smaller fish. It has small and large teeth but they are all the same shape.

Snake - snakes have long sharp teeth. Venomous species have venom teeth which have either a groove or a hole running through the tooth, through which the venom is injected. These are the only specialised teeth in snakes.

Shark - sharks have many sharp teeth. Their teeth often fall out as they grab moving prey and so they have a continuous 'conveyor belt' of teeth growing from their jaw. The new teeth that aren't needed yet lay flat against the jaw until the tooth in front falls out and they they move up into the normal tooth position. You can see the new teeth ready to move up on the inside of the jaw.

Crocodile - the crocodile can also replace it's teeth when it loses them but rather than having a 'conveyor belt' system like the shark, it has permanent teeth buds (which are what your teeth develop from) under each tooth which are stimulated by the tooth falling out, causing another one to grow.

BEAKS

You might want to talk about how birds such as the chicken use their beaks to feed, and talk about how other birds have adapted their beaks to help them eat their chosen food.

The beak of a bird is an extension of its skull and is designed for feeding. Some beaks have evolved to specialize for feeding on specific items.

Duck: wide flattened "bill" used for eating aquatic plants and mosses - specialised for "dredging" type jobs. Dabbling ducks, which feed on the surface of the water (or as deep as they can reach by upending without completely submerging) have a comb like structure along the edge of their beak called a pectin - this strains the water squirting from the side of the beak and traps any food. This can be seen on one of our duck skulls. Also used to preen feathers.

Parrots: seeds are the most important part of their diet, which has led to the evolution of a large and powerful bill which is primarily an adaptation to opening and consuming seeds.

Oystercatcher: bill shape varies between species, according to diet - birds with blade like bill tips pry open or smash mollusc shells, and those with pointed bill tips tend to probe for annelid worms.

Pigeons: homing pigeons have iron containing structures in their beaks which may enable the birds to use the earth's magnetic field for navigation

Other birds (which we don't have, but that you could discuss) include - the hawk, which has a sharp hooked beak used in tearing flesh from its prey or carrion. A hummingbird uses its long narrow beak to lap nectar from flowers and a sparrow has a small powerful beak used for picking berries and cracking seeds.

NOSES

Possibly start by asking what is missing (nose, ears, eyes and other soft tissues) - they are not part of the skeleton, made of either cartilige or muscles and nerves. The kids can think about the differences in nose sizes, do they think that cats have a better sense of smell than dogs? etc (dogs are 10,000 times more sensitive to odors than humans). Apart from food, what else do animals need noses for? (smelling mould, predators, recognising family members, detecting when another animal is in heat). The sheep skull has large nasal cavities, with delicate rolls of (turbinate) bones, which support a large area of nasal epithelium (skin inside the nose) for many, many scent receptors and to reduce heat/moisture loss.

Nose length varies in dog species-

Dolicephalic- long nosed breeds like greyhounds

Brachycephalic- short nosed breeds like pugs

Mesocephalic- medium nosed breeds like terriers

EYE PLACEMENT AND SIZE (particularly relevant to mammals)

Large eye sockets suggest an animal is active at night (nocturnal). In this case, a larger eye has evolved to allow the animal to see better at night. Moles and cats (very obvious large eye sockets) are nocturnal, hunting prey and remaining active at night.

Eyes that face forward on a skull suggest a predator ('an animal that hunts other animals for food'). Forward facing eyes allow for binocular or stereoscopic vision, which allows an animal to see and judge depth. Predators need this depth perception to track and pursue prey. The fox is an example of a predator in our collection. The orangutan also has forward facing eyes that give it depth perception needed to swing and leap in their tree top habitat. Humans have forward facing eyes as well (you could talk here about us being descended from apes).

Animals with eyes that are located on the side of its head would suggest a prey animal. Side eye placement allows for greater peripheral or side vision. This enables the animal to see predators approaching from the side as well as from behind. This vision is very important for protecting an animal when it is grazing or feeding. The hare is an example of a prey animal in our collection. Other examples include deer and rabbits.

"Eyes in the front, the animal hunts. Eyes on the side, the animal hides."

CRANIUM

The size of an animal's cranium (relative to its body size) can give you an idea of how well developed its cerebral cortex (the part of the brain that contributes to 'intelligence') is. The size of an animal's cerebral cortex can be used as a rough indicator for how 'intelligent' it is as a larger brain gives more processing power. A good way to compare the size of the brain cavity is to look at how big it is relative to the rest of the animal's skull. Generally, social animals such as monkeys, apes (including humans), dolphins, and elephants have large cerebral cortices. This is because keeping track of social relations within the group requires a great deal of 'processing power'.

Magpies are a member of the corvid family - group of birds including crows, jackdaws etc. - these birds are thought to be the most intelligent of all bird species, and have larger cerebral cortices than would be expected for their body size. This intelligence is demonstrated in several ways e.g. European magpies have shown self awareness (i.e. recognising themselves) in mirror tests, crows and rooks have tool making abilities (e.g. hooks to 'fish' for grubs) - things that people generally associate with higher mammals such as ourselves and other apes. These birds also have highly complex social lives, just like apes (need to have large brains with lots of computational power to keep track of what other animals are doing, understand their relationships with other animals in the group etc.).

Parrots also highly intelligent and have high brain size to body ratio - some have been shown to be able to associate words with their meanings and form simple sentences (e.g. Alex the African Grey), some species of parrots are highly skilled at using tools and solving puzzles.

Pigeons, by contrast, seem to be less "intelligent". If a pigeon is taught that doing something (e.g. pecking at light A) leads to reward, and doing something else (e.g. pecking at light B) doesn't, then they can learn these rules, but if you change the rules around (e.g. pecking at A doesn't lead to a reward, and pecking at B does) they find it difficult to "reverse" their behaviour (whereas corvids and humans manage easily!) As pigeons are a similar size to magpies, comparing the size of these 2 skull's craniums is a good example of how cranial size can indicate intelligence. Another good comparison is the human and the chimpanzee.

NB Unlike most other apes, orangutans are shy, solitary animals. They live alone in large territories. This is probably due to their eating habits; they need a large area in order to get enough food and too many orangutans in one area might lead to starvation. However, they are very intelligent. They have been known to use found objects as tools; for example, they use leaves as umbrellas to keep the rain from getting them wet. They also use leaves as cups to help them drink water.

OTHER THINGS TO TALK ABOUT

Can the child think of any other distinctively-shaped skulls that animals have, and why might they have developed to be like that? E.g. crocodile, hammerhead shark, elephant (tusks)...

Crocodile things - so from the crocodile skull the bones look fairly different (part of this is as the skull is beetle cleaned vs chemical cleaning on other skulls). Crocodiles have spiraled bone fibres to help them resist torsion, allowing them to death roll and resist forces from fleeing pray which could break their skull. Crocodiles are also diapsids. These have two 'temporal fenestra' or holes in each side of the skull, these are positioned above and below the eye. This allows for larger stronger jaw muscles and wider movement than a single hole. On the human skull you can see the single bony arch behind the eye where the ear would be. The original classification was complicated as, other than crocodiles, many diapsids have lost these additional holes since the Pennsylvanian period. Lizards (lost one hole), snakes and turtles (lost both) and birds (heavily restructured skull) are also in this class.

If the child is old enough and seems keen, you might want to touch on the concept of natural selection (survival of the fittest) and how this drives development of the peculiar features that some animals have. For example nocturnal animals will have more success catching food and escaping predators if they have large eyes that let in as much light as possible in low light conditions. Animals with smaller eyes than average will find it more difficult to do this and are less likely to survive than animals with larger than average eyes. The animals with larger eyes will therefore be more likely to survive and have babies, who will in turn also have big eyes like their parents (you will need to briefly touch on genetics here too – has the child noticed that they share the same eye/hair/skin colour/nose shape etc with their parents?)

PLUS Explanation

Animal skulls experiment is flexible and you can talk about the skulls that you find cool or know more about.

You could start talking about one skull in detail and how it is suited to its function. Then you could move on to comparisons with other skulls to the first one you picked. It's easier to pick one of the bigger/ less fragile skulls first, such as the human (made of plastic!) or the sheep skull.

- Start by selecting a skull of a species that you are going to focus on.
- Discuss what the skull is made of- bone. The skull is made up of flat bones. Bone is made of 1/3 organic type 1 collagen and 2/3 hydroxyapatite with adsorbed calcium carbonate. Skull bone is formed from condensed sheets of fibrous tissue- cancellous bone and marrow sandwiched between two layers of compact bone and periosteum - this is called a diploë (Compare this to long bones which are different. Long bones are made up of osteoblasts and osteoclasts. Osteoblasts are uninucleate cells that live as long as the animal and are responsible for formation of the bone matrix. Osteoclasts are myeloid derived blood cells which are multinucleate, short lived and are in control of bone destruction. Together these types of cells are in charge of bone formation and destruction. This is a feature of bone in general and applies to the skull as well under the control of parathyroid hormone, calcitonin and vitamin D. Another example of a flat bone is the scapula)
- Discuss how the skull bone is formed developmentally- it is formed from pharyngeal arches. The toothed, upper and lower jaws are dermocranium- they form around viscerocranial cartilage templates from pharyngeal arches.
- The skull is made up of lots of different bones: premaxilla, maxilla, vomer, nasal, palatine, lacrimal, frontal, parietal, interparietal and tympanic bones. There are also also teeth.
- On the skull you have taken- can ask if they know the names of any parts of the skull. Key features to notice:
- The cranium contains a cavity that has the main function of containing the brain.
- Eye sockets- supports the eye balls. There is a nasolacrimal fossa for the sac and the duct. There is a hole at the back of the socket through which the optic nerve runs
- Tympanic bullae are the bulges associated with the auditory canal- these have the function of amplifying sounds and particularly low frequencies.
- Nasal conchae are scrolls within the nasal canal and these increase surface area for the olfactory epithelium to cover which
- The foramen magnum is the main cavity at the back of the skull and this is where the spine attaches to the skull. The spinal cord runs through this hole and connects to the hindbrain.
- The mandible is used for creating a hinge join at the temporomandibular joint which allows jaw movement
- The mandibular symphysis is the joint in the chin where the two bones of either side of the mandible are fused– note that this is one of the most common 'fractures' to result from cat/car impacts. The symphysis fuses in horse around two years of age and may also fuse into a 'synostosis' late in life in ruminants.
- Other holes in the skull are for nerves e.g. the supraorbital foramen which you can feel in the middle of your eyebrow and which carries the supraorbital nerve, part of the frontal nerve, in tern part of the opthalmic nerve (1/3 of the trigeminal nerve) which carries sensory information (touch, heat, pain etc) from the eye region (but not the image from the retina, which is transmitted via the optic nerve). This nerve is particularly prominent on the horse skull (see below).

The cranial nerves are:

I- Olfactory nerve II- Optic nerve III- Oculomotor nerve IV- Trochlear nerve V- Trigeminal nerve VI- Abducens nerve VII- Facial nerve VIII- Vestibulocochlear nerve IX- Glossopharyngeal nerve X- Vagus nerve XI- Accessory nerve XII- Hypoglossal nerve

These allow the brain to connect to send and receive signals from the rest of the body.

- Can then move onto the other skulls - discuss the features of the skulls and how these relate to the demands that the animal has to cope with in its environment. Why might the adaptations help the animal to succeed in its environment/why might the animal have developed these skull features? You might want to discuss each skull in turn, or you may prefer to talk about a particular 'theme' i.e. teeth, brain size across a number of skulls at once
- Allow the students to handle skulls so they can feel how delicate/sturdy they are
- Note that delicate skulls have a small piece of red gaffa on their boxes - only let children handle these if you think they will be careful enough with them!

Basic information about the skulls is as in the regular explanation. Extra things to mention for CHaOS+ are:

TEMPOROMANDIBULAR JOINT

This is the 'jaw joint between the cranium and the mandible. In carnivores it is quite limited to a dorsoventral hinge movement (in badgers the lower jaw is so firmly hinged that it cannot be detached). In contrast, in herbivores there is much lateral grinding movement as well. The temporomandibular joints each contain a disk similar to the menisci of the stifle, and like the menisci, the disks may help to partition the movements of the jaw joint into compartments (hinge-like between disk and mandible, translation between disk and skull)

It may also be helpful to draw out these comparative anatomy points from domestic breeds: 1) Cat: Note the domed cranium, huge orbits and short snout. 2) Pig: exhibits dramatic specialisation for rooting It is extremely tall caudally for the attachment of strong neck muscles. Also, in life there is an extra bone in the snout - the os rostri 3. Ruminants: Have distinctively domed crania, although this may be obscured by the horns . The horns are frontal in position in sheep and goats and more temporal in cattle. Also, the ruminant basi-cranial axis appears rather 'bent'. There is no alar canal for the maxillary artery in ruminants. The nasal bones often fall off. 4. Horse: Extremely long and the origin of the jaw muscles is extended cranially from the zygomatic arch by the long facial crest . There is a supraorbital foramen dorsal to the eye through which passes the supraorbital artery (used for arteripuncture) and supraorbital nerve (used for nerve blocks). 5. Rabbit: Extremely delicate skulls– sometimes the occiput falls off, which is the bones at the back part of the skull

Risk Assessment

Hazard: Teeth or beaks.

Description: Some skulls have sharp teeth or beaks, which can cut/stab children and demonstrators.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Remind children to handle skulls carefully; in particular, be careful not to pinch fingers/hands in the jaw.

Demonstrator should visually inspect skulls before use - any skulls with sharp edges may need to be smoothed off or replaced.

Call first aider in event of incident.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Shattered skulls

Description: If dropped, skulls may fall on feet or shatter, causing cuts and other injuries.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Demonstrator only have a few skulls present at a time to minimise risk of children picking up or playing with skulls. Demonstrator to keep an eye on anybody holding skulls. If a skull smashes, clear it up immediately with dustpan and brush. Any damaged skulls with sharp edges should be repaired as soon as possible - demonstrator should notify committee if this is needed.

Call first aider in event of injuries.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Unsanitary skulls

Description: Possible infection risk from bone if skin is cut by touching the bone.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: We have boiled the skulls we found in bleach for a few hours to sterilise them. Please note, however, this does not necessarily mean that the skulls are completely sterile now. One could give the skulls a gentle clean with disinfecting wipes if they're on hand.

Call first aider to properly dress and sterilise wounds. Warn parents of the possibility of infection if a child does cut him/herself on the skull. Advise parents to take child to a doctor if the cut looks infected.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-17 - Michael Darling (md510@cam.ac.uk), **Check 2**: 2012-01-24 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2012-12-22 - Beatrice Tyrrell (bet23@cam.ac.uk), **Check 2**: 2012-12-30 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2013-12-25 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk), **Check 2**: 2013-12-27 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2015-01-08 - Kym Neil (kym.e.neil@gmail.com), **Check 2**: 2015-01-24 - Chloe Hammond (cjh214@cam.ac.uk)

Check 1: 2015-12-26 - Natalie Cree (nc434@cam.ac.uk), **Check 2**: 2016-01-04 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2017-01-03 - Sarah Wiseman (sw628@cam.ac.uk), **Check 2**: 2017-01-11 - Roxanne Armfield (rea41@cam.ac.uk)

Check 1: 2018-01-08 - Gemma Shaw (gcs33@cam.ac.uk), **Check 2**: 2018-01-25 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2019-01-08 - Amanda Buckingham (abb53@cam.ac.uk), **Check 2**: 2019-01-09 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-23 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-24 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-30 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-12 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-01-23 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-01-29 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2023-02-05 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-02-06 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Isobel Gilham (ig419@cam.ac.uk)

Arch Bridge

Building an arch bridge, and then walking over it. - Can you build a bridge strong enough to walk on?

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-01-23 by Lauren Mason (llm34@cam.ac.uk). ## Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Engineering

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **This experiment can take place outdoors**
- Bridge Base (flat board and two triangular pieces, they attach together with wing nuts)
- 5 Blocks (all the same)
- 2 wooden supports (scaffolding to assist the building process)

Experiment Explanation

Overview:

This is an arch bridge built of 5 identical blocks, which the children can then walk over.

Possible activities: 1. Build bridge. 2. Walk over it.

Other things to talk about: Forces on blocks.

Tips for demonstrating: The blocks are quite heavy for small children, so you may need to lift them for them/get parents to help. Don’t let them jump on the bridge/too many on at once - jumping off sideways may cause the bridge to fall to the side, too many children on at once may push each other off.

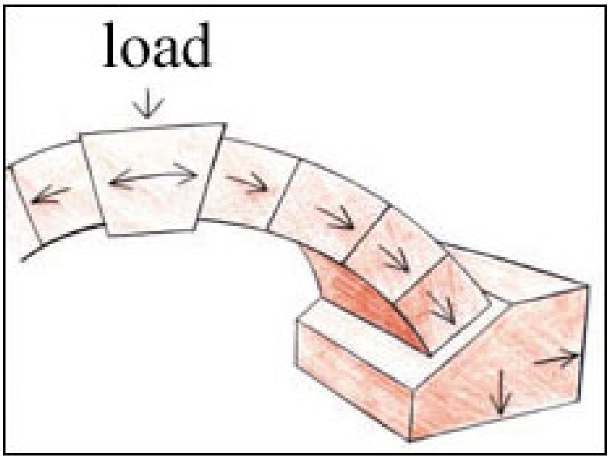
Basic procedure and explanation:

To build the arch bridge, get the children to place the wooden supports between the ends of the bridge (say there like the scaffolding used around the edge of buildings or under bridges), then get them to add the blocks, starting at the ends. If they have trouble working out which way round to put the blocks try showing them the trapezium shaped side of the block. Ask them whether the longer or shorter side needs to go on top to make the arch shape.

Check that the blocks are all lined up straight and that the tops of the blocks all meet. Ask them what will happen when you take the wood away - will the bridge stay up? Why?

Take the wood away - the bridge stays up! Talk about how the shape of the brick means that they are being squashed in from the sides (‘in compression’) and they can’t fall down. Ask if they think the bridge is strong enough for them to walk over (subtly check that the bridge is sturdy first) - take care that they don’t fall when they do this.

When the child is standing on the middle of the bridge, ask them what is stopping them from going straight down. Depending on the child’s age, could talk about the force of their weight, and explain how it is pushed out sideways and that it is because the ends of the bridge cannot move away from one another that they don’t fall down.



Explain that this is how real arch bridges work - the mortar ‘gluing’ the bricks together isn’t very important, all the strength is due to the bricks being squashed together horizontally. Bricks are strong in compression, but no good in tension.

It can be useful to ask the children how the other blocks would have to move to allow one of the blocks to fall, to get them to see the arch as a lot of wedges jammed in between the piers. Very wide stone arches have a tendency to force apart their piers and collapse.

Risk Assessment

Hazard: Blocks

Description: May fall on feet and injure people.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Blocks are designed to be fairly light and covered with rubber. Demonstrators may need to help younger children carry the blocks. When taking apart ensure feet are sufficiently far back.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Bridge Collapse

Description: Bridge may collapse due to instability. Blocks may become smooth over time and slip against each other causing bridge collapse. Could result in people falling off bridge or being hit by falling blocks.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Demonstrators should test the bridge by walking over it before any children do. Children should not be allowed to jump off the bridge sideways, as this may cause the bridge to fall. Blocks should be checked for smoothness at the beginning of the event. Demonstrator should remain vigilant for blocks slipping during the event.

Demonstrator must stop experiment if they suspect that the blocks are getting smooth.

Call first aider in the event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Blocks

Description: May trap fingers between blocks during construction.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Demonstrators may wish to help small humans when placing the blocks. Mention that it is better to hold them across their sides rather than ends.

Call a first aider in the event of an emergency.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Blocks

Description: Being hit by carried blocks.

Affected people: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Small or overexcited children should be supervised when moving blocks. Demonstrator should volunteer to do it themselves.

Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Built bridge

Description: Children/demonstrator falling off the bridge.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Make sure that the bridge is erected somewhere the floor is flat, with no sharp corners or objects to fall on. Don't let kids jump up and down on the bridge (both because the blocks can slip and the child can fall off). Children should only go on the bridge one at a time. Don't let children crawl under the bridge. Demonstrator to check the bridge is stable before allowing children to stand on it.

Call first aider in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2011-01-22 - Anna Kalorkoti (anna.kalorkoti@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk), **Check 2**: 2012-01-26 - Rosy Ansell (rosemary.a.r.hunt@gmail.com)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-18 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2014-01-22 - Brett Abram (ba305@cam.ac.uk)

Check 1: 2015-02-01 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2015-02-11 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2015-12-27 - Andrei Ruskuc (ar720@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-02-01 - Joanna Tumelty (jt574@cam.ac.uk)

Check 1: 2018-01-07 - Joanna Tumelty (jt574@cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-20 - Yaron Bernstein (yb258@cam.ac.uk), **Check 2**: 2019-01-30 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-01-03 - Oliver John (oaj24@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-27 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-17 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-01 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-17 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2023-01-14 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-14 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-01-23 - Lauren Mason (llm34@cam.ac.uk)

Bubbly Crystals

Modelling crystals with soap bubbles - Using a raft of tiny bubbles, see how materials are made up of crystals and watch the atoms move when the material is deformed! (Or it's just fun for little kids to play with the bubbles)

Last initially checked on 2023-02-04 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2023-02-15 by Chiara Delpiano-Cordeiro (cd796@cam.ac.uk)

Frequency of use: 4

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

CHaOS+ (More complex explanations suitable for older children are available)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Materials Science

Requires Water

Equipment Needed

- Black Tray
- Gas Generator (two bottles stuck together with their bottoms chopped off, and a thin tube – made from the insulation of an electrical cable – coming out with some Blu-tack on the end. The upper bottle should be full of rice or something else to weigh it down)
- Base of clear plastic bottle to put gas generator in
- 2 wooden skewers for manipulating bubbles
- Spare tube, rice and Blu-tack
- 7 plastic cups (or other equally-sized round objects)
- Quartz prism (example of a crystal)
- Laminated printouts of figures
- Fairy liquid (consumable) – note that cheap washing up liquid doesn't work very well!
- Kitchen roll (for popping bubbles and cleaning up)
- Requires ~100 ml of water (not included)

Experiment Explanation

This experiment is based on a classic demonstration originally devised (and filmed!) by Sir Lawrence Bragg: Nobel laureate, former director of the Cavendish Laboratory and co-discoverer (along with his dad) of Bragg's Law of Diffraction. His video is available here: https://youtu.be/UEB39-jlmdw; if you have an internet connection then watching this is recommended (though not strictly necessary) before demonstrating this experiment.

The following explanation includes quite a lot of detail: how much of this you include depends on your audience. For younger children, it might be better just to let them play with the raft, and you can point out anything interesting you see.

A CHaOS+ explanation is available for this experiment; see additional details in italics.

Set-up

Set the tray on a flat surface, and, using another container or bottle, fill it with water to about 5 mm depth. Add a small squirt (~1 ml) of liquid soap. Stir with your finger until the soap is mixed in, being careful to avoid making bubbles. Also fill the clear plastic half-a-bottle with water, to between the first and second lines from the bottom. Place the gas generator into this water.

Put the end of the green tube into the tray of soapy water so that it sits flat on the base of the tray – don't let it poke up to the surface. Move the gas generator around and squash the blu-tack to help it stay down (though note that it won't stick properly underwater).

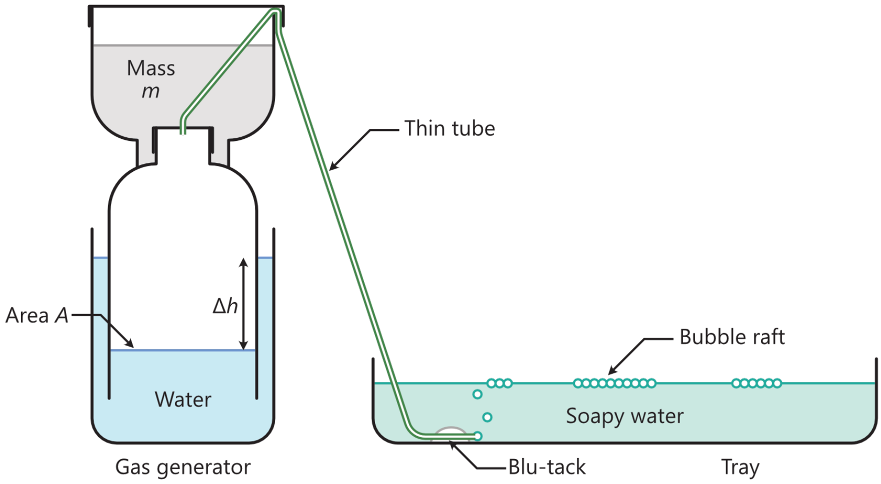


Fig 1: the setup for the experiment.

Making Bubbles

The weight of the gas generator causes it to sink into the water, pressurising the air inside the green bottle.
(CHaOS+: calculate the pressure using $\Delta p = \rho_w g \Delta h = m_{\text{gas gen}} g / A$*)*
This can escape (very slowly) through the small tube and into the water, making bubbles.
Q: What will be the effect on flow of increasing the pressure Δp */ radius of tube* r */ length of tube* L */ fluid viscosity* μ*?*
A: Flow rate Q *calculated using Hagen-Poiseuille Equation:* $Q \approx \pi r^4 \Delta p / 8 \mu L$ *(Not exact as air is compressible). As the air is used up, the bottle sinks lower, maintaining a constant* Δh *and therefore flow rate, so the bubbles stay the same size.)*

If all is well, small bubbles should now be coming out of the tube and settling on the surface of the water. If not, try pressing down on the gas generator – if this works then you might need to add more weight so it works automatically. Otherwise, try checking the seal of the cap on the green bottle in the gas generator.

This experiment works best if the bubbles are all a uniform size, which they should be if the generator is working properly. If you ever need to take the tube out of the water, wipe the end before putting it back in – otherwise larger bubbles will have built up there. Any spurious large bubbles can be popped by using a small piece of kitchen roll to absorb their water.

The bubbles should be able to stick around for minutes to hours once made – if they are popping too quickly, add more soap to the water. If too many bubbles have built up, empty the tray and refill with fresh water and soap (a quick fix is to push them to the edge and then fish as many of them out as you can).

The experiment uses a single layer of bubbles: if they stick around near the tube for too long, they can start forming a double layer, so waft them away from the tube with a skewer.

Some people might ask why the bubbles stick together: if you look at the water surface around a bubble it dips downwards slightly (surface tension makes it behave a bit like a trampoline with a weight on it) - when two bubbles approach they 'fall into' each others' dips.

Forming Crystals

The bubbles will aggregate to form a regular pattern, analogous to a crystal lattice. **Crystals** have a regular structure or pattern that repeats in space, though made of atoms/ions/molecules rather than bubbles. This particular arrangement is known as **hexagonal close packing** (HCP) – ask children if they can identify the hexagons. HCP is the most space-efficient way to arrange a sheet of spheres, which is why HCP structures occur in nature (e.g. honeycomb, and graphite; Fig 2). *(It is also the lowest energy and therefore most thermodynamically favoured: the tension in the walls of the bubbles creates elastic potential energy, and having an HCP arrangement enables the greatest length of these walls to be shared with adjacent bubbles, minimising the energy per bubble)*

You can use the seven cups to let children work this fact out for themselves. Arrange them randomly on the table, then ask a volunteer to imagine they are all attracting each other like the bubbles are, then to push the cups together so they occupy as small a space as possible. This should have naturally made a HCP arrangement.

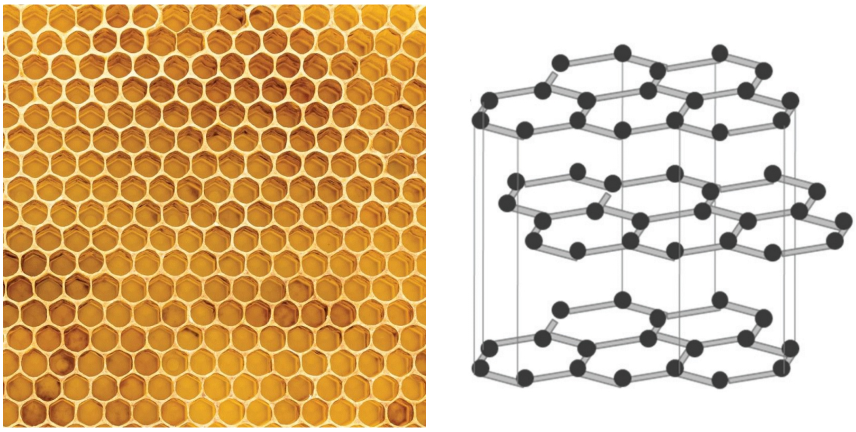


Fig 2: naturally-occurring hexagonal close-packed structures: honeycomb and graphite. The bubble raft is most similar to graphene – a single sheet of graphite.

Q: How would you extend this into 3D?
A: By putting the next layer of spheres in the gaps between those in the first layer, then filling the gaps in the second layer, etc. You can demonstrate this by allowing a double layer of bubbles to build up near the tube. There are two options for repeating this tiling in the z direction: ABAB… (3D HCP, e.g. zinc) or ABCABC… (Cubic close packing, aka face-centred cubic, e.g. copper). See Fig 3.

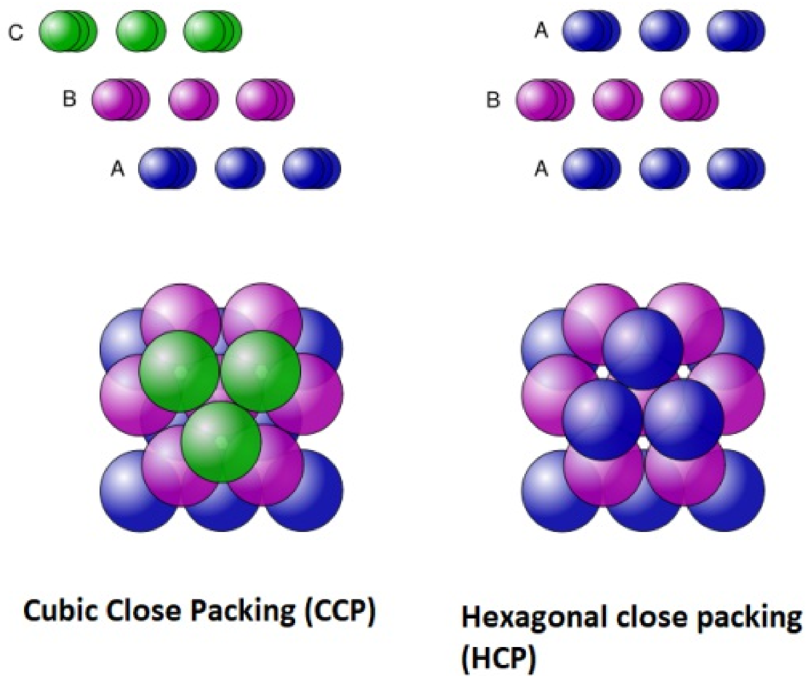


Fig 3 : 3D close-packed structures

Crystal growth can be observed by two methods. Addition of one bubble at a time to an existing crystal is analogous to the 'classical' view of crystal growth, ion by ion. The addition is favoured at any 'kink sites' with missing bubbles on the outside of the crystal. Crystals can also grow by the formation of smaller nuclei (made of several bubbles, often with a more irregular structure), followed by their aggregation and alignment with the crystal lattice. This is known as 'oriented attachment' – such 'non-classical crystal growth' has been the subject of much research in materials science and mineralogy in the last decade.

Polycrystalline Materials

After enough bubbles have accumulated, you should see that the lattice is not going in the same direction throughout the raft. Instead, there will be regions where the lattice is in different orientations – each region is a separate crystal, or **grain**. The **grain boundaries** separating crystals of different orientations are characterised by a series of defects in the lattice. Ask the children to point out some separate grains, and they can attempt to make their own grain by pulling in a new cluster of bubbles with a skewer. Most metals, rocks, etc are made up of multiple crystals in this way.

*A 2D lattice can be described by two **lattice vectors**, $\mathbf{a}$ and $\mathbf{b}$. Translation by either of these (or a linear combination of their integer multiples) will leave the lattice invariant. Ask the student to point out the lattice vectors, maybe on a scaled-up drawing of the lattice. The misorientation between two grains is the smallest angle between equivalent lattice vectors in each grain.*
Q: What is the maximum misorientation in this HCP lattice?
A: 30°. A rotation of 60° will bring the lattice back into alignment.

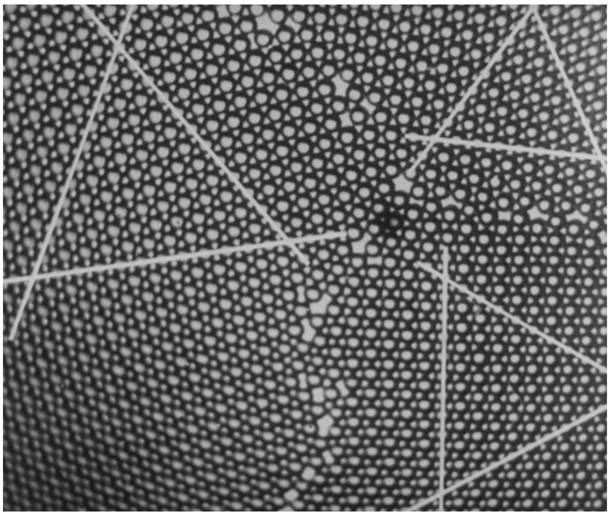


Fig 4: three grains, with the lattice orientations for each drawn. Note the defects on the grain boundaries. Screenshot from the Bragg video.

Deformation and Dislocations

Take the two skewers (or have a child do it) and constrain two edges of the raft with them. This works better once there are a lot of bubbles. Then move one skewer relative to the other to stretch, squash or shear the raft and see how the deformation is accommodated. There are three ways in which a polycrystalline material like this raft can deform:

Elastic deformation: If the skewers are only slightly moved, the whole raft can stretch or squash like a spring. No bubbles move relative to their neighbours. When the force is released, the raft returns to its original shape.

Moving the skewers more results in...
Grain boundary sliding. As the name suggests, this is when crystals slide past each other along their boundaries. This deformation is now permanent (*plastic deformation*): the grains will not slide back when the force is removed. Grain boundary sliding allows dry sand to be poured like a fluid, *and is the dominant method of deformation in fault zones in the upper crust.*

The grains themselves can also change shape (also permanently/plastically). This is done through...
Movement of Dislocations. You might have spotted little defects in the crystal lattice (e.g. a row that stops suddenly), even within a single grain. These defects are known as **dislocations**.

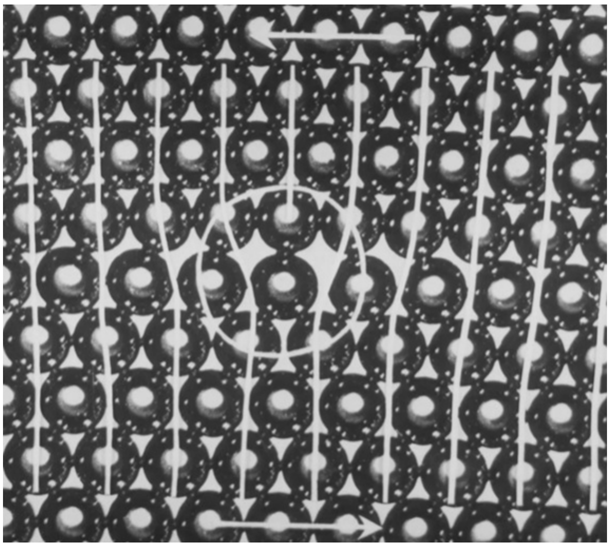


Fig 5: Dislocation within a bubble 'crystal'. Note how there is an extra column of bubbles on the top compared to the bottom. This dislocation has a Burgers vector of 1 bubble diameter to the left, and will move to the left to relieve the applied stress. Screenshot from the Bragg video.

When the crystal is deforming, you can see the dislocations zipping from one side of the grain to the other. They are created where the stress on the lattice is greatest (at irregularities on the grain boundaries), and when they reach another grain boundary they get stuck and may contribute to some grain boundary sliding. They leave the grain permanently deformed in a way that reduces the stress that acted on it. When the direction of stress is reversed, the dislocations start moving the other way.

Q: Why do crystals deform in this way?
A: Compared to moving a whole row of bubbles/atoms at once, moving a dislocation has a much lower energy barrier as only a few bonds need to be strained at a time compared to the hundreds (or millions in real crystals) in a row of a crystal lattice. However, once the dislocation has made it to the other side, the net effect is the same.

The direction a dislocation will move in can be calculated by counting the same number of bubbles horizontally and vertically in a circuit around the dislocation: the offset that is left over is the ***Burgers Vector****. Dislocations can combine, adding their Burgers vectors together. The stress field around a dislocation can also influence other dislocations, causing them to attract or repel each other. See the Bragg video (5:35 to 12:07) for more details on this.*

In addition to elastic deformation, grain boundary sliding and dislocation creep, real crystals can also deform by ***diffusion creep****, where individual atoms/ions move from one side of the crystal to the other. However, I have not seen a good analogy for this in the bubble model.*
Q: What conditions would favour diffusion creep?
A: High temperatures (more thermal movement of ions); presence of a solvent (e.g. water) that can dissolve the ions and help them move.

The bubble raft experiment was developed in 1952 to study dislocations, which at the time were only theoretical predictions. Real dislocations were first observed four years later (Hirsch *et al.*, 1956) after the development of high-resolution transmission electron microscopy, and were found to behave almost exactly as the bubble raft experiment predicted!

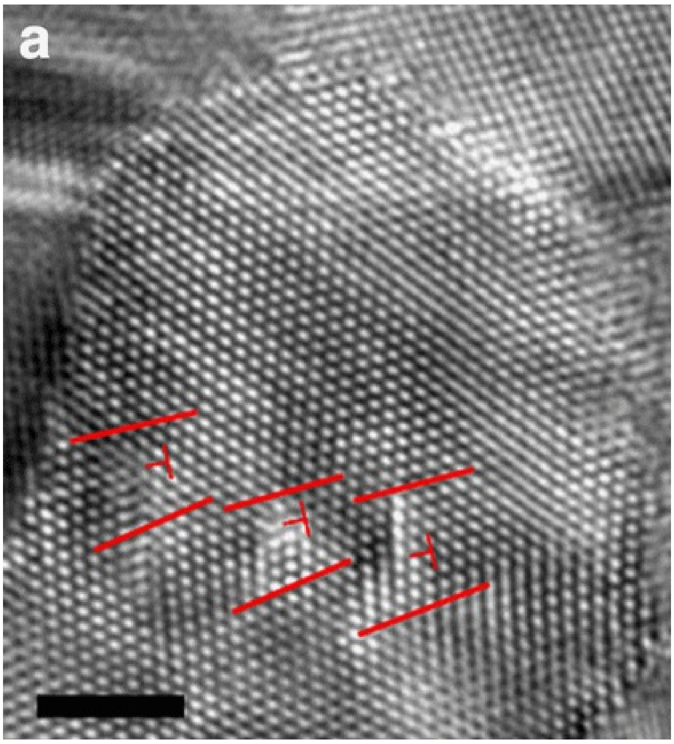


Fig 6: Electron microscope image of real grain boundaries and dislocations (marked in red) in a crystal of platinum. Scale bar is 2 nm (that is 0.000000002 m!) From Wang et al. (2014).

Vacancies and Impurities

As well as the dislocations and grain boundaries, you may be able to see other types of defects in the crystals.

A **vacancy** is a site where a bubble is missing. They often occur naturally but, if not, you can create one by popping a bubble with kitchen roll. A passing dislocation can fill in a vacancy, jumping over a row in the process.

A bubble of the wrong size resembles an **impurity**, e.g. an atom of carbon in a lattice containing mostly iron. Impurities stress the surrounding lattice, and cause passing dislocations to get stuck.

Q: What are the implications of this for how easy the crystal is to deform?
A: Since the movement of dislocations is hindered, the crystal becomes harder to deform, and the material is therefore stiffer. This is the principle behind **alloying** metals: the deliberate introduction of impurities (e.g. carbon in steel) makes the metal less soft and bendy.

Recrystallisation

Stir up some of the raft using the skewers or an enthusiastic child's hand! This destroys the regular crystal structure and is analogous to damage caused by quick deformation (**work hardening**) of metals, or radiation damage in minerals.

However, the bubbles will soon rearrange themselves into a regular lattice again, forming new grains and grain boundaries. The grains will be small at first, but get bigger over time (**annealing**), especially if the tray is shaken to simulate thermal agitation.

Q: Why does this happen?
A: To minimise energy. A perfect crystal structure has lower energy than a random arrangement of bubbles, as each 'bond' between the bubbles is an optimal length. The mismatch at grain boundaries also increases energy, so energy is further minimised by minimising the total length of grain boundaries. However, doing this requires rearranging the bubbles, which is only possible if there is enough 'thermal' agitation to move them.

Q: Therefore, under what conditions is a coarse-grained metal / metamorphic rock formed, compared to a fine-grained one?
A: A coarse-grained texture requires the material to be held at a high temperature for a long time, to give the ions the chance to move into the most thermodynamically-favourable arrangement.

Packing away

Carefully empty the tray and gas generator and dry with the paper towel provided. Stack up the cups. Put everything back in the box.

Risk Assessment

Hazard: Pointy skewers

Description: Getting poked (particularly in eyes); splinters

Affected People: Demonstrator and demonstratees

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: No pointing skewers near people's faces. Don't let young children hold skewers (they can use fingers if not allergic to soapy water); sand down any rough and sharp bits before use

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Soapy water

Description: Skin irritation for people with cuts / eczema / allergies

Affected People: Demonstrator and demonstratees

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: I would advise against demonstrating if you are irritated by soapy water. Ask parent/ responsible child if OK to put their hands in soapy water. Otherwise, can do as demo only or only let them touch the water via the skewers. Do not let children drink the soapy water.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Soapy water

Description: Eye irritation

Affected People: Demonstrator and demonstratees

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Don't let anyone who touched the soapy water with their fingers touch their eyes without drying their hands first. Know where the nearest eye wash is (there should at least be some in the Safety box).

Summon first-aider to wash eyes if necessary.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Open containers of water

Description: Trips / slips / electrical shorts from spillages.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: I would advise doing this experiment outside or in a room with a wipeable floor. Do not put near electrical equipment. Do not use more water than is necessary (5mm depth is fine), and if possible fill the tray using a water bottle and then don't move it. Keep the gas generator in a place where it is difficult to knock over. Warn people of any spillages and clear them up promptly using the kitchen roll.

Summon first-aider in event of someone tripping and hurting themselves.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Small Quartz Crystal

Description: Choking hazard

Affected People: All but particularly young children

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Use a larger crystal for demonstrations if possible. Don't let young children hold it, and if you do hand it out then keep an eye on it and don't let it go near anyone's mouth!

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2022-06-06 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 22-06-09 - Emma Crickmore (elc75@cam.ac.uk)

Check 1: 2023-01-13 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-01-17 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2023-02-04 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-02-15 - Chiara Delpiano-Cordeiro (cd796@cam.ac.uk)

Cantilever Bridges

Building a series of cantilever bridges - Can you build bridges across wider and wider rivers?

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-01-24 by Lauren Mason (llm34@cam.ac.uk).

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Engineering

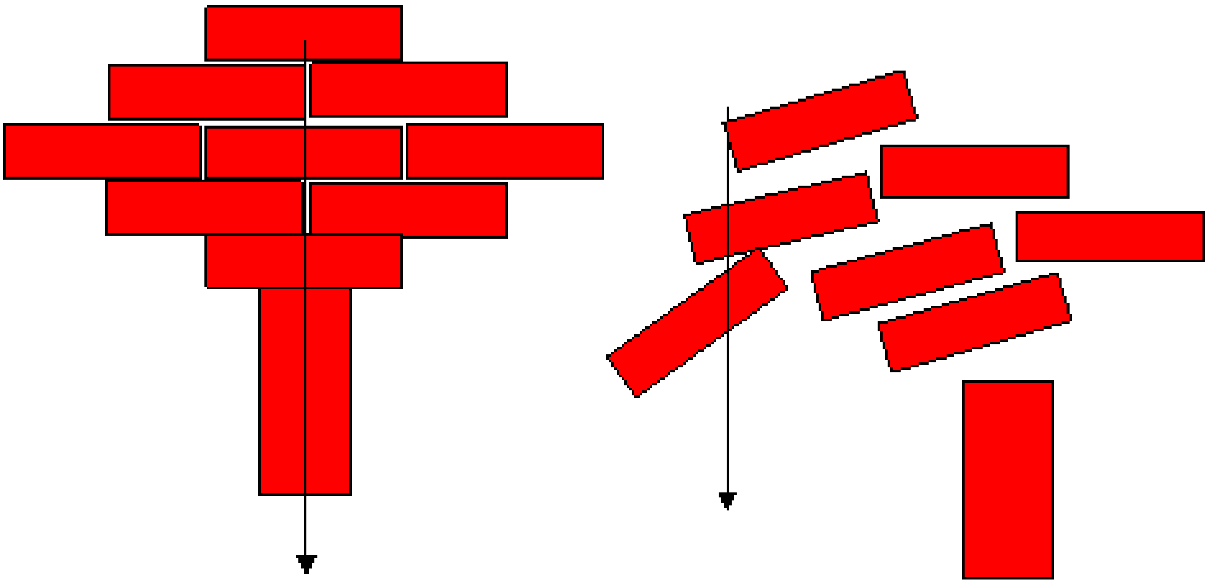
Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **This experiment can take place outdoors**
- Base boards
- Small blue box of blocks
- Laminated photos

Experiment Explanation

Basically you want to get across that you have to balance everything, and if the centre of balance goes over the edge of any support it will fall over.



Setting up the experiment:

Kids: works best on the floor, as the blocks don't fall too far when stacks topple! Get everyone to sit on the floor around the board/ pile of bricks Grown ups: we've run this at an adults-only science evening, on a table, which worked fine. But adults are much less confident about stacking blocks than kids are!

The challenge:

The challenge is to build three bridges across the river. There are two rules... 1) You're only allowed to use the wooden blocks 2) The wooden blocks can only stand on the support blocks, not on the land (it's marshland, too soggy!) or in the river (cheating!)

The first bridge (smallest gap)

Start with this one, as everyone can do it! The first gap is easy, as you can just put a block across it.

Extension: Why does the block not fall into the river? One answer is that the block is being pulled down (by gravity), but is being pushed up the same amount by the supports at each end. This balance (of forces) is why it stays still.

The second bridge (bigger gap)

Do this one next, once they've succeeded at the first bridge. This gap is the width of three bricks. If you hold a brick partially across the gap/on the end of the support and let it go, it falls- why? (The brick/the forces acting on the brick aren't balanced.) How can you balance the blocks? (Think of a see-saw.) How can you get more of the block to go across the gap? (Balance it on the other side).

Try to do this yourself before you demonstrate the experiment. The most obvious design uses 8 blocks (2 towers of 1;2;1), the fewest we've see it done in is 5, but this doesn't look much like any bridge we've ever seen! It's not as stable - why?

Look for mirror lines/symmetry: this is a simple way of making sure the towers are balanced. For the most common 8 block design the two towers are symmetrical, and each tower is symmetrical in the line above the support/ along the middle layer of bricks. (This is also true of the most common version of the third bridge).

It can be a bit of a surprise to find out how much of this is not obvious to some children. Many will start trying to build something like an arch, or want to put supports in the river. The first thing is to get them to see that combining bits of structure that tip over in opposite directions can produce something that balances.

The real trick is knowing how long to let them try to build the bridge without telling them how to do it. It's much better if they figure it out for themselves, but you want them to be able to build the bridges even if they can't spot the balancing trick! You want to give them a clue *just before* they get bored of trying - the real pro demonstrators can do this without being obvious that it's a clue, but that takes practice!

Once you've got to the end of this second bridge don't forget to tell them "well done" for completing a tricky challenge!

Here's an alternative version of our explanation for engineers/those used to thinking about moments: The second bridge requires you to start cantilevering. Get the kids to show you where they want to put the next block - and why it won't work - suggest that they need to counterbalance it with weight - another block. Making the smallest bridge from 2 balancing blocks can help to get them started on the others. Then get them to see that things further from the fulcrum have more tipping power (moment). You can demo this with the bricks, using one as a fulcrum another as a beam and more as weights. Or get them to hold the heavy mass from the spinny chair (another CHaOS experiment that may be nearby...) close to them, then at arms length. Comparison with see-saws might be useful, as most children should have played on one of these).

The third bridge (biggest gap)

This builds on the ideas in the second bridge - take how long that took as an indication for how quickly to go through this. If they really struggled on the second bridge you don't have to make them do this one themselves. Get them to help you do this one, as you can't hold all the blocks yourself (which is usually true - two pairs of hands makes it much easier!)

You can use the same idea as the bridge above to go across a bigger gap, but this time the towers need to be wider (which ends up making them taller if you pick the simplest design). The most obvious solution is 2 towers of 9 blocks (1;2;3;2;1), but we've seen it done in as few as 7 blocks. What's the smallest number you can build it in? (We're mainly aiming that challenge at you demonstrators, but you might also want to give it to kids that have figured out the first challenge quickly!)

Extension: If you add more blocks to the top, to look something like the Corbeled arch below, the bridge appears to be more stable. Why is that?

For engineers: The third gap is more difficult, with the number of blocks you have, you can't just pile up a counterweight near the fulcrum, you have to get some of it further out to counterbalance the bridge.

These bridges exist in reality!

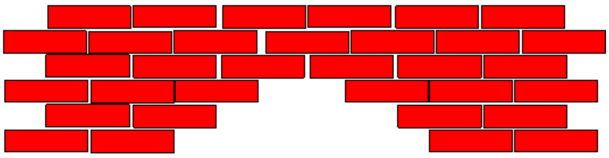
Note: some of the pictures in the box are arch bridges that go with the arch bridge experiment (which doesn't have its own box). Try not to confuse the two - the forces aren't the same in each.

You can compare the bridge to the Forth Bridge: a real example of a cantilever bridge. There are photos in the box. This bridge is in Scotland, and is famous for being so long that by the time you've finished painting one end that you need to go and start painting the other end!

Look for the picture of the bridge in construction - here you can see the cores of the towers before sections were added to each side. That's analogous to our supports before we add sideways with extra blocks.

Two questions that seem to come up quite often with the bridge photos: Why isn't it solid like the blocks? The Forth Bridge is made out of metal, this behaves differently to wood, and if you can fix the pieces of metal together you can get away with less metal than something completely solid. Apart from anything else, that saves money on metal? Is our bridge weaker than real ones? Yes, because the blocks aren't joined. But it's very solid considering!

A primitive form of arch was called the Corbeled arch, this is basically two of the balanced cantilevers next to each other with the wall acting as the counterweight.



This was used in passages and tombs, before the true arch was developed.

Risk Assessment

Hazard: Tower of blocks

Description: A very tall tower may mean bricks have enough energy to bruise when the tower falls down.

Affected People: All (especially children)

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Demonstrator to monitor building, anticipate collapse, and get children to stand back.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Board/ Blocks on floor

Description: There is a trip hazard from the board or blocks placed on the floor.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Don't put the experiment in an area which is likely to be used as a thoroughfare.

Call first aider in the event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Gaps between boards

Description: Children may pinch their fingers in between the boards on the floor.

Affected People: All (especially children)

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Demonstrator to ask children to not place their fingers where they can be pinched between the boards. Tape gaps between boards and boards and floor.

Call first aider in the event of an accident.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Blocks

Description: Possible splinters from the wooden blocks.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Demonstrator to make sure only wooden blocks with no splinters coming out are used. Report any blocks that aren't smooth/sand them smooth.

Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk), **Check 2**: 2012-01-26 - Rosy Ansell (rosemary.a.r.hunt@gmail.com)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-18 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2014-01-22 - Brett Abram (ba305@cam.ac.uk)

Check 1: 2015-02-01 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2015-02-11 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2015-12-27 - Andrei Ruskuc (ar720@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-01-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-07 - Joanna Tumelty (jt574@cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-08 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-01-20 - Yaron Bernstein (yb258@cam.ac.uk)

Check 1: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-24 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-01 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2022-02-04 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-01-14 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-14 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-01-24 - Lauren Mason (llm34@cam.ac.uk)

Cornflour

Explore the remarkable properties of cornflour mixed with water. - Slimey, gooey and messy: cornflour is one of our favourite experiments! Come and stick your hands in, and figure out if it behaves like a liquid or a solid...

Last initially checked on 2024-01-01 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

CHaOS+ (More complex explanations suitable for older children are available)

Chemistry

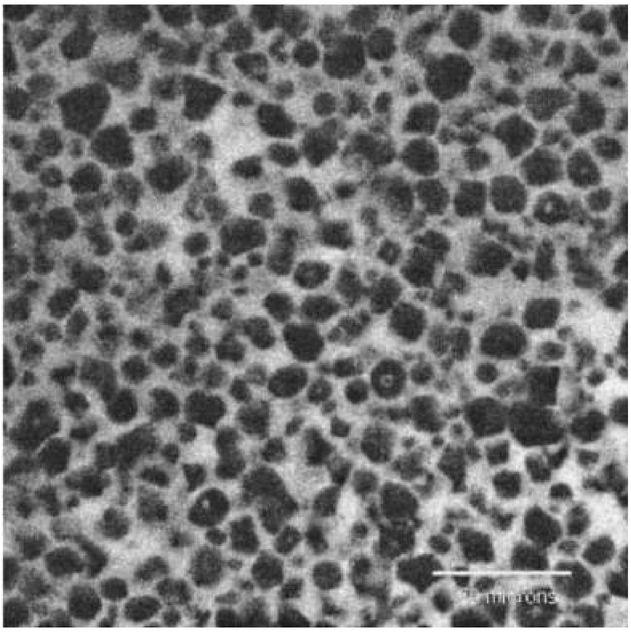
Equipment Needed

- **This experiment can take place outdoors**
- Washing up bowls 3-4 or large plastic trays
- Cornflour 3kg min
- Water
- Laminated cornflour picture

Experiment Explanation

In a nutshell

You and the children play with the gooey cornflour/water mix, exploring the concepts of solids, liquids and substances that have properties of both. Cornflour is lots of irregular shaped particles that are separated by water normally so are lubricated and can move. If you squash them together it will push the water sideways a little bit and let them touch - now they lock together and behave as a solid.



Cornflour under a confocal microscope, which takes a 2-D slice through an image rather than looking at the surface.

How to set up the experiment

Putting down a tarpaulin or taping bin bags to the floor first may make cleaning up easier. If possible set up near a sink or have an extra bowl of water nearby for hand washing.

Put about one packet of cornflour into a bowl or bucket. Slowly add water to the cornflour until it works - ask a committee member for help if you're getting stuck. A ratio of 2.5 parts cornflour to 1 part water is suggested, but the ratio may vary. Note that on a hot day the water will slowly evaporate so it will eventually need to be topped up.

Packing away

Let the cornflour settle to the bottom of the bowl. Tip away any excess water and let the cornflour dry out (if there is time; otherwise throw it away). It can then be returned to its container. Other cornflour-contminated things should be washed down with plenty of water.

What you need to know about the experiment

1. Cornflour is shear thickening. This means the higher rate of shear, the higher the viscosity (i.e. the thicker it is). (Note: Shear can be explained by considering 'layers' of cornflour particles sliding past each other.)
2. Try asking them whether it is a solid or a liquid. You may want to get them to come up with definitions of the terms solid and liquid - e.g. "what do we call hard things / things that flow…?" Cornflour is like a solid and a liquid - Acts as a solid under stress and a liquid otherwise
3. It's like a room full of people and when you try and make it move quickly, everyone tries to move at once (while also moving closer together) and they all get in each other's way and so no one can move anywhere. And when you do stuff to it slowly, everyone has time to move out of the way and file out.

Want to know more?

Shear thickening is a problem in the oil industry, as when they are drilling they are getting rock fragments in the mud coming back up, if there are too many they behave similarly to the cornflour, with catastrophic results to pumps. Some people are talking about making liquid body armour using this effect, to make the body armour more comfortable. The opposite of shear thickening is shear thinning. Many substances are shear thinning because the higher rate of shear can break up interparticular interactions and reduce the viscosity - e.g. shampoo, toothpaste - when you shear them by squeezing them out of the tube, it flows, but when there's no shear, it sits quite happily on the toothbrush without flowing anywhere.

Explanation warnings

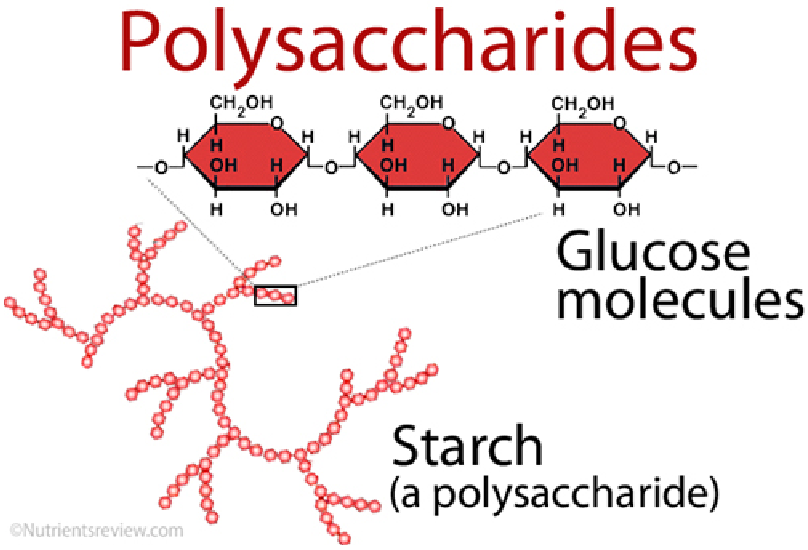
THICKENING SOUPS IS DIFFERENT: the cornflour grains open up when heated and release long starch molecules that tangle together forming a gel-like substance. THIS IS NOT THIXOTROPY, which is concerned with time related effects. Thixotropy is a long word and shouldn't be used with children. Adults should be politely and gently explained the difference! The longer you shear a thixotropic fluid the lower the viscosity (the thinner it becomes) - e.g. paint - as you progressively break up interparticular interactions. Many fluids that are shear thinning are also thixotropic. Rheoplexy / Anti-thixotropy is the opposite - i.e. the longer you shear a fluid the higher the viscosity (the thicker it becomes). Xanthan gum might do this under certain conditions, but it's very rare for substances to do this.

PLUS Explanation

The above explanation works well even with sixth-formers (they often just like playing with the cornflour). Perhaps focus more on real applications (e.g. the bullet proof vests, oil etc), and then add in some discussion of the points below.

CHaOS Plus Further Ideas

The starch granules themselves are composed of a mixture of long-chain polysaccharides - essentially lots of "sugar molecules" (glucose) stuck together.



The starch granules themselves are composed of a mixture of long-chain polysaccharides - essentially lots of "sugar molecules" (glucose) stuck together.

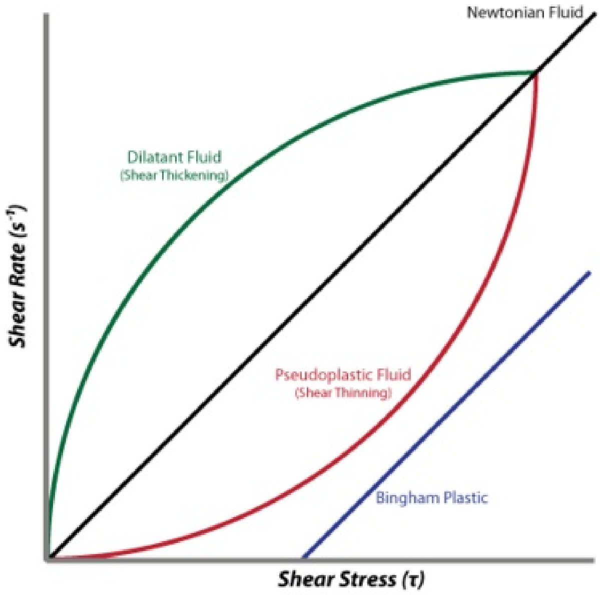
A simple model for describing a non-Newtonian fluid is

$$\eta = k\left(\frac{d\gamma}{dt}\right)^{n-1}$$

Here η is the viscosity (how "thick" the fluid is) and γ is the shear (how much the material is deformed). The differential with respect to t tells us we're interested in the strain rate (how fast you're shearing). k is a constant.

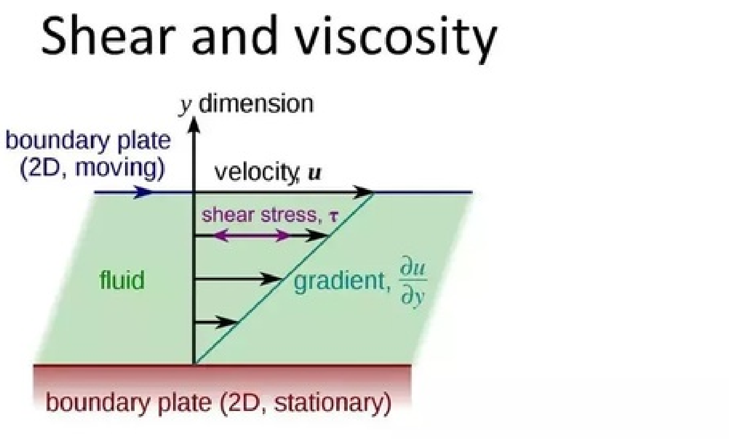
If $n = 1$, we get classical Newtonian behaviour (no dependence on shear rate). If n<1, then the viscosity decreases with increasing shear rate (shear thinning) and if $n > 1$, then the viscosity increases with increasing shear rate (shear thickening).

Below is a schematic shear rate vs stress graph for various materials (labelled). The gradient gives the inverse of viscosity:



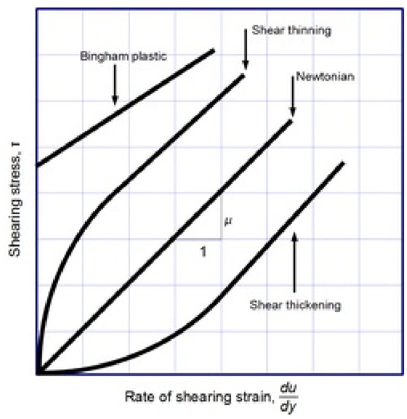
The “proper” definition of viscosity is the ratio of the shear stress γ to the velocity gradient $\Delta u/\Delta y$ in a fluid from a stationary boundary:

$$\eta = \frac{\gamma}{\Delta u/\Delta y}$$



Higher viscosity means a larger stress is needed for a given velocity gradient to be achieved (basically need to push harder to move a viscous fluid).

Another graph of shear stress vs velocity gradient (this time the gradient is the viscosity):



A Bingham plastic is one which is solid up until some yield stress, and then subsequently deforms with increasing stress. Mayonnaise and toothpaste are examples.

There is no “one” theory for why shear thickening happens - there are a couple of mechanisms... Talk about intermolecular forces (e.g. van-der-Waals forces), which hold molecules in suspension.

For large shear rates, intermolecular repulsion can be overcome, and the molecules are pushed out of their equilibrium positions and “mosh” together. This essentially makes the suspension “less ordered”, and hence increases the viscosity (less easy for molecules to move past each other).

Another mechanism involves the molecules joining to form small groups (“hydroclusters”), which may be thought of as long rods of particles that cause a “traffic jam” and increasing viscosity.

Risk Assessment

Hazard: Cornflour

Description: Powder may trigger asthma attack.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Clear up spilt powder. Where possible, do the experiment outside. Do not allow children to help to mix in new powder without first checking that they do not suffer from asthma. In the event of an adverse reaction, move child out of area and sit them down. Call first aider.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Water/water-cornflour mixture

Description: Minor slip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Clear up spills promptly; if the floor is smooth, ensure that a mop is available for this. Put wet floor sign down on cleaned floor. Set up near a sink or have a bowl of water for hand washing nearby so children don’t drip cornflour on their way to a sink. Call first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Cornflour

Description: Irritant to eyes.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Avoid contact with eyes and tell children to as well. Know where the nearest eye wash is (there should at least be some in the Safety box). Call first aider in event of injury, who may perform an eyewash if trained and happy to do so.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Old cornflour mixture

Description: After a while, the mixture accumulates some dirt, which is not recommended for consumption.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Encourage children to wash hands after use. Do not allow children to ingest the mixture.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-21 - Catherine Collett (chc47@cam.ac.uk)

Check 1: 2012-12-12 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2014-01-23 - Peter Maynes (peter.maynes@cantab.net), **Check 2**: 2014-01-23 - Vamsee Bheemireddy (vrb23@cam.ac.uk)

Check 1: 2014-12-27 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2014-12-31 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2015-12-28 - Haydn James Lloyd (hjl43@cam.ac.uk), **Check 2**: 2016-01-02 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-01-22 - Haydn James Lloyd (hjl43@cam.ac.uk), **Check 2**: 2017-01-23 - James Nicholas (james.nicholas@cantab.net)

Check 1: 2018-01-01 - Georgia Harris (grh37@cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-13 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2020-01-09 - Holly Smith (hs606@cam.ac.uk), **Check 2**: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-17 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-18 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2023-01-12 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-01-12 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2024-01-01 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk)

Ear switching hat

This magical hat will confuse your senses! - Sound cues can help us figure out where things are located in the environment - try confusing your brain with the Ear-Switching Hat!

Last initially checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk) and double-checked on 2024-02-01 by Margaret Johncock (mllyj2@cam.ac.uk)

Tags

Busking

Floating

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- **This experiment can take place outdoors**
- One piece hat

Experiment Explanation

The hat switches sounds from the left hand side to the right ear and vice versa. This leads to a couple of cool effects and is great as a way of attracting people who would otherwise pass by without stopping.

What to do (1):

Put the hat on a child or other volunteer - if they are very small you might have to get them to hold the ear defenders on. Fairly quickly get them to shut their eyes, then go to one side or another and ask them to 'point where it sounds like I am standing' (these words partially get around the effect of the cunning kid who catches on very quickly and consciously changes where they are pointing).

You have two main ways of telling which direction a sound is coming from, volume and time delay. Which one you use depends on the frequency of the sound. Below 80Hz there isn't really an effective method; between 80Hz and 800Hz humans use the phase difference between their ears to determine location; between 800Hz and 1600Hz we're again a little lost but above 1600Hz we start using volume to locate the source of the sound. What about telling the difference between in front, behind or above us? That's the shape of our ears and heads that make sounds slightly different if they come from a different one of those positions. It's not perfect though, and a new noise in front of us sometimes sounds like it's behind.

What to do (2):

Put the hat on a volunteer (as before). Instead of getting them to close their eyes, get them to look (with their eyes only) to one side (right for the sake of description, although this works the same reversed). Stand more two people one either side of the volunteer. The person on the volunteer's right (who they are looking at with their eyes whilst keeping their head pointing forwards) mouths a simple sentence (for example: "My name is …". They do this when counted in by the person on the left, who speaks the same words. For maximum effect, choose people with different voices/accents/genders and hopefully the person on the right will sound like they are speaking with the person on the left's voice. Maybe practice with some other demonstrators beforehand.

More information:

The brain integrates a range stimuli from the environment to help ascertain one's relationship to these. Particularly important is the processing of auditory cues - hence the vast majority of animals employ a 'two detector', i.e. two ear, system to pick these up. By comparing the input from one ear with that on the other side, special centres in the brainstem figure out the 3D origin of a sound wave - at its most simple level by comparing the intensity (volume) of the input to each side and the delay from one side to the other, but also by the more complex changes in pitch (frequency) that occur due to a 'acoustic shadowing' effect (different frequencies are affected differently by passing through your head) that the head getting in the way of a sound wave has!

The importance of this is huge - as predators this may help us to hone in our prey, rustling in the undergrowth, or in the converse situation, helping us figure out how to avoid being someone's next meal! This is evident in how most predators typically have relatively small external ear parts compared with many more 'docile' creatures with very large external ears (pinnae) that in many cases (such as rabbits and hares) can even be directed (kids might then ask about elephants - their ears are large for a very different reason, for cooling, much as the 'sail' of some dinosaurs is speculated to be) to help them localise sounds better (and I can't begin to imagine how complex the neural network integrating ear position with auditory input must be.)

In theory, if someone wears the hat for long enough, processes of synaptic plasticity will take place in the brain re-mapping inputs so someone can adapt to respond to sound cues in the correct direction. But even in the short term people can get used to the switched inputs and respond appropriately, much like an experiment that involved volunteers wearing prism glasses that inverted their environment - they were asked to throw a basketball into a net, which initially was impossible for most, but over time, presumably through cerebellar motor learning they adapted to their new state and were able to function perfectly normally despite seeing everything upside down! (intriguingly, when the prism glasses were removed, although it still took them time to adapt back to 'normal' again, it took less time than it did to learn when they tried the glasses for the first time).

So in people who have reduced hearing on one side, it's often still possible for them to discriminate whether sounds are coming from one side or the other due to these plastic changes, although it may not be as accurate.

Hearing is even all the more clever when you take into account how the hair cells of the cochlea can 'tune in' to certain frequencies and desensitise to others. Insect hearing is rather different to the above but (I think!) a basic intensity compatator is still employed, together with other clever mechanisms to distinguish externally-produced sounds from internal ones via a mechanism of 'corollary discharge'.

Risk Assessment

Hazard: Loud noises

Description: Risk of hearing damage

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Warn children not to shout loudly into ears, and make sure you talk quietly into the ears.

Call a first aider in the event of an injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Hat

Description: Risk of disorientation and falling over, especially if they have closed their eyes.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Tell child to sit down if they feel disorientated/dizzy. Before letting the child close their eyes make sure the area has no sharp objects, near sharp drops and isn't too crowded.

Call a first aider in the event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Tubing

Description: Tubing may get caught on wearer

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Warn child not to pull hat off quickly to avoid injury, especially with long hair.

Call a first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Hat sharing

Description: Risk of transfer of hair infestation (e.g. headlice).

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Visually inspect hat between use.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-16 - Jonathon Holland (jaah2@cantab.net), **Check 2**: 2012-01-23 - Ashley Smith (ashley.smith@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-06 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-22 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-06 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-09 - Kym Neil (kym.e.neil@gmail.com)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-07 - Natalie Cree (nc434@cam.ac.uk)

Check 1: 2017-02-09 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-10 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-27 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2019-01-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-24 - Jennifer Simpson (jks61@cam.ac.uk)

Check 1: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-24 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-22 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-01-23 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-18 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-18 - John Leung (cfl35@cam.ac.uk)

Check 1: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk), **Check 2**: **Check 1**: Margaret Johncock (mllyj2@cam.ac.uk)

Electrolysis

Splitting water into hydrogen and oxygen, and using the recombination of these to launch ping-pong balls. - Electrolysis in the process of splitting water into hydrogen and oxygen using electricity, and then recombining them explosively! We'll use talking about energy as an excuse to launch a ping pong ball into the air…

Last initially checked on 2024-02-14 by Timothy Wong (chw55@cam.ac.uk) and double-checked on 2024-02-15 by Vlad Penzyev (vp410@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Chemistry

Requires Electricity

Equipment Needed

- **Electricity needed**
- Electrolysis tower (~ 6' tall, white cover, don't drop it - you will need 2 people to move it)
- 0-15V variable power supply OR Power pack of doom
- Small red box (approx. contents): Water models, small air blower, $MgSO_4$, deionised water, funnels etc. power connectors, green trigger button, silencer, ping-pong balls)

Experiment Explanation

In a nutshell

Water is split into hydrogen and oxygen, which are then recombined explosively at different concentrations to launch a ping pong ball into the air. This means that you can investigate energy conversion, stoichiometry, what is an explosion, etc. etc..

Setting up Electrolysis

Note: Please do not attempt to set up or pack up electrolysis unless you have been shown previously how to do it and are confident you know how (one of the committee members at the event will be happy to show you what needs to be done) - if you get tap water in the electrolysing chamber you will get some very strange results (mainly due to metal oxide formation removing the oxygen as you make it), and the chamber may need to be cleaned.

1. Ensure the tower is secure, having been tightly roped to a fixed support, and won't fall over.
2. Attach the power cable to the current controller
3. The wires are connected (those with tape on inserted first, and the sparker can have its wires go in any way around, for the electrolysis apparatus itself, connect red and red, and black and black)
4. Ensure that the apparatus is not on wet ground (if outside use separate upside-down trays for the apparatus, and for the power supply and sparker)
5. Use a funnel to pour the $MgSO_4$ solution into the back chamber (such that it goes to the electrolysis chamber), ensuring that no water enters the sparking chamber

6. Use a gravity siphon (use plastic tubing to suck some water, preferably not with your mouth, to insert the tap water into the front (mixing) chamber, again ensuring no water enters the sparking chamber)

To be safer, you can use deionised water in the front chamber (this is not strictly necessary, but it is a good precaution in case any gets into the electrolysing chamber), however try not to lose too much whilst setting up/packing up so we can reuse it.

How to run the experiment

1. Double check the tower is secure, having been tightly roped to a fixed support, and won't fall over. There is a sound muffler (the top of a plastic bottle) in the box, that fits over the ignition chamber. It is strongly advised that you use it if you are going to be demonstrating this for any length of time/are indoors.
2. Using the power supply, pass current between the platinum wires in the reaction chamber at the bottom, this splits water into hydrogen and oxygen, which are collected by two inverted burettes. ***Do not use too much voltage for the water splitting, as you may start causing some strange by-reactions.***
3. Holding the mixing chamber valve shut, release hydrogen and oxygen from their burettes in an appropriate ratio into the mixing chamber.
4. Release the mixing chamber valve to let the gas mixture into the explosion chamber, then use the green trigger button to fire it (some off the gas will vent out around the ping pong ball - this is ok).
5. The electrodes that make the spark are now wet; if you need to repeat the explosion quickly the air blower may be used to dry them more quickly - in practice by the time you've done the introduction again the electrodes may be dry.

What you need to know about the experiment

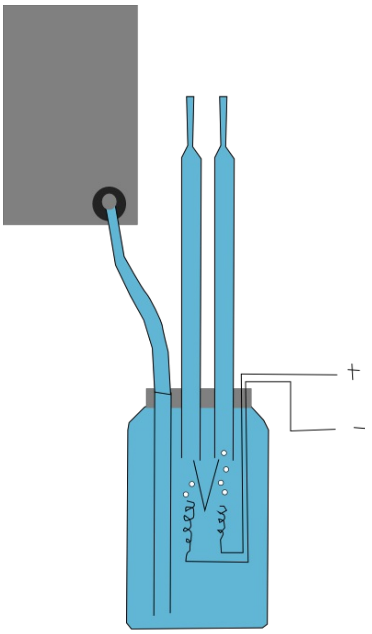
Water is H_2O and, if you apply enough energy (needed to break bonds), it can be split into its constituent parts (there should be some models).

You should be able to see that there is twice as much hydrogen as oxygen.

You can get the energy back out rapidly → heat → expansion → acceleration of the ping pong ball.

The sparking electrodes become wet: you've made water! (most of it in vapour form but it condenses on the electrodes and the combustion chamber walls)

If the concentration and ratio is right, the hydrogen/oxygen mixture will **detonate** – a detonation is an explosion which travels at supersonic speeds (you should hear it!)



Want to know more?

The main point to get across is that water is made out of hydrogen and oxygen and these are gases. But as you go on you can also describe the energy in → energy out aspect, stoichiometry and molecular structure and also relate it to how we would have to make hydrogen for cars.

In starting the explaining at the bottom of the apparatus you can ask what the children can see in the bottle at the bottom. Water and wires. I then go on to say I'm going to put some electricity in the wires, now what can you see? Bubbles. What's in the bubbles?

I then explain how were are turning water into what it's made out of. So what's it made out of? Excellent if they can answer this. Otherwise, do you know another name for water? It's surprising how many kids get H_2O. Why is it called H_2O? Because it's made out of hydrogen and oxygen - "Hydrogen times 2, H_2 and oxygen O."

Once that's settled, you can go for the molecular models. Breaking two water molecules up into two H_2 and one O_2 molecules. While this is in I explain what we're going to do next in recombining the molecules back to H_2O giving them a good shake. Random collisions aren't a bad model for a chemical reaction.

Now is also a good time to talk about the energy in/out business if you're going to. Though for years 6 up really. Energy from electricity is used to split the O and H and is then stored in the O_2 and H_2 molecules. When they recombine the energy is released as heat. Cycling up a hill is the clear analogy, I always like pointing out that as you come down the hill you think that it's "speed for free" but it's not really, you're getting the payback for all the effort you put in cycling up the hill.

We then try some logic and I turn the power off and draw their attention to the bubbles at the top of the tubes. One is twice the size. Which one is the Hydrogen? Next explain how you're going to mix the gas and arrange your volunteers and check the trigger works.

As you mix the gases you can say, if we need 8 ml of hydrogen, how much oxygen do we need? Then we're pretty much onto the pop. Once that's gone grab the ball quick. With luck there should be some water on the bottom. Show them this, as this is your opportunity to hit home. "Can you see that? You've that made water!" Which is cool.

Parents and teenagers will be interested in the hydrogen cars angle. With this audience I probably would have started with the hydrogen cars. Anyway, you can be a bit environmental pointing out we have to use energy to make hydrogen, and it is only ever an energy store. you can also burn the hydrogen in an internal combustion engine (like at the top) or in the exact reverse of what happens on the electrodes at the bottom, to make electricity right out of the hydrogen and oxygen in a fuel cell, then driving a motor.

Risk Assessment

Hazard: Electrolysis chamber

Description: Explosion in the electrolysis chamber (shrapnel injury, hearing damage).

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Designed so any excess gas vents to the outside, so even if the power is left on there will be no major build-up of gas. The chamber is made out of a tough plastic (PET) that won't shatter. There is a polycarbonate blast shield in case something does go wrong.

Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Mixing chamber

Description: Explosion in the mixing chamber (shrapnel injury, hearing damage).

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: The valve at the top of the mixing chamber is designed so it defaults to be open, so gas won't build up when you are not paying attention. The explosion is separated from this chamber by water so it shouldn't ignite. There is a polycarbonate blast shield.

Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Chlorine

Description: Emission of chlorine gas.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Use deionised water (chloride ions have been removed), and use $MgSO_4$ as an electrolyte as this will not decompose before the water. Experiment must only be set up by a demonstrator familiar with the apparatus and the solution required.

In the event of an incident, turn off power, remove any casualty from area, call first aider and ventilate the area.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Explosion noise

Description: Loud explosion. Possible hearing damage.

Affected People: Demonstrator mainly (repeated exposure)

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Ignition is by modified kitchen lighter. Is on the end of a long wire, allowing everyone to stand well clear of the explosion (energy dissipates as r^2. A sound muffler can be attached to the top of the column. Use hearing protection if available, especially if demonstrating this for a long time.

Use less gas if the explosions are too loud.

Seek GP's advice in the event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 3

Hazard: Ping pong ball

Description: Being hit by ping pong ball.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Make the explosion chamber quite high, so you can't look in the top. Ball is very light and would not hurt much.

Call first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Mains electricity

Description: Increased hazard from mains electricity due to presence of high ionic strength solution.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Ensure that apparatus is secure and tightly roped to a fixed support before filling (also prevents risk of tower falling). Do not fill/top up apparatus whilst power unit is nearby. Keep power unit raised above level of base of apparatus.

If solution splashes onto power supply turn off immediately at mains and close experiment.

In case of injury call a first aider (and turn off power if safe to do so).

See electrical parts RA.

After Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Hazard: Tower

Description: Tower falling

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Ensure the tower is stable (i.e. on level ground). Do not allow children to climb/push the tower.

In the event if an injury, call a first aider.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Water models and ropes

Description: Trip hazard from balls or ropes being left on the floor. Risk of children running into inappropriately placed ropes.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Do not leave these “loose” parts of the experiment lying around.

In the event if an injury, call a first aider.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-21 - Catherine Collett (chc47@cam.ac.uk)

Check 1: 2012-12-16 - Rachel Chapman (rc506@cam.ac.uk), **Check 2**: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2014-01-23 - Peter Maynes (peter.maynes@cantab.net), **Check 2**: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk)

Check 1: 2014-12-27 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2014-01-02 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-12-13 - Tim Morgan Boyd (tmb58@cam.ac.uk), **Check 2**: 2015-01-02 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2017-01-23 - James Nicholas (james.nicholas@cantab.net), **Check 2**: 2016-01-09 - Haydn James Lloyd (hjl43@cam.ac.uk)

Check 1: 2018-01-30 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2017-02-09 - Haydn James Lloyd (hjl43@cam.ac.uk)

Check 1: 2019-02-05 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2020-01-18 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2022-01-30 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-01-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-01-16 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-14 - Timothy Wong (chw55@cam.ac.uk), **Check 2**: 2024-02-15 - Vlad Penzyev (vp410@cam.ac.uk)

Electromagnetism

Making electricity, and using it to spin a motor. - Generate electricity and learn all about how it works!

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Electricity needed** for some parts of the experiment, but you can still demonstrate the rest without power!

Generating power

- Small ammeter and coil. Bar magnet of some sort that fits through the hole
- Green rotating generator. Clamps to attach it to a table.
- Wooden box with bulbs/handle/generator

Dropping magnets

- Metal ‘coin drop’ setup, separate wooden base (base in box, the rest is separate)
- Two pipes, one copper, one plastic.
- Green ‘iron filing’ paper
- ‘Stripey’ magnet for use with green paper
- Selection of coin magnets (don’t get more than a couple out an once).

Motors etc.

- Motor
- Power pack (stored in separate power pack box)
- Real motor (non-functional)
- Magnet/wire with ‘indicator lights’
- Nail with coil of wire.

Experiment Explanation

AS 2023 - Practically speaking this is still done all as one with Renewable Energy and Lenz’s Law. I personally think we might want to keep it together. There are also several bits of this that we are missing or are broken such as the coin magnets, motors, nail etc. Personally I think a good story is: Start with Lenz’s Law with the magnets in the perspex and copper tubes. Get a surprising result! Why might these be different? Let’s try and see... Move onto the black box generator with the switches and bulbs. Turn the handle with increasing amounts of bulbs on. Where do the lights get their energy? From electricity in the wires, b ut ultimately from you! Note that the more bulbs the harder you have to work ie the more energy needed. Lets look inside (use the big green one to demo, its a bit temperamental to use actively to turn the handle) - note the magnet inside and the copper wire - almost like our Lenz's Law demo. The magnet turning and moving past the wire is creating electricity in the wire. But we also see this electricity flow is creating a force to make it harder to turn the magnet. The magnet falling in the copper tube works the same way by creating swirls (eddies) of electric current that resist its motion. In reality, if you wanted to watch TV, you wouldn't want to sit there turning a handle so where does power in your home come from? They usually say from the wall, try to question where does the wall get it? They might know about pylons etc. Segue to energy generation through renewable. Except solar cell, mostly just ways to turn a handle (steam turbine, wind turbine etc). They will often have seen "windmills" in fields and many homes and even schools now have PV cells on the roof.

TW 2018 - There are many bits to this experiment and it's reached the point we sometimes get two people to demo it at CBS and also lots of the bits don't work. I've moved it to minor repairs needed however I've begun the process of splitting out several ideas and strands into new experiments, see Lenz's Law, Renewable Energy so far and then Induction, Coils and Transformers, Sparks and Motors experiments soon.

There are lots of things to do, there are 2 nice stories, going through the generation and motors stuff, and some extra odds and ends. You shouldn't usually attempt to get through all of this in one go!

1. Generating Power

There are 3 different power generating bits, in increasing level of usefulness.

Magnet, coil and ammeter

This has a coil of copper wire attached to a small ammeter. When you wave a magnet through the hole in the middle of the wire you get a reading on the wire. Some things to talk about/do with it are: - What are the objects? Coil is made of copper wire, this is a good electrical conductor. The setup as a whole is an electrical circuit (components linked together in a circuit). The meter looks like it might measure something (cf weighing scales), it measures the amount of electrical current (or just electricity) going round the circuit. - Do we get more electricity by moving fast or slow? Does it work if we're not moving at all? - Is this very much electricity? The scale on the ammeter is microamps (the funny squiggle is the Greek letter mu), talking (or asking questions about) millimetres, metres and kilometres is a good warm-up to explaining that microamps is a small unit. Older kids might know that fuses have amp ratings on them. - What do the positive/negative readings mean? It tells us which way the electricity is going round the circuit, notice that it changes if we move magnet in a different direction, or swap north/south poles. - How can we get more electricity? Good ideas are moving faster (and moving in circles is easier than up/down), stronger magnet or more coils.

This then leads nicely onto the next bit...

Rotating generator (green)

This has most of the improvements suggested above (show to them the larger magnet, more coils), and if you spin the handle fast enough it will give you enough electricity to light a bulb. Things to talk about:

- The faster you spin it, the brighter it is.
- Does it matter which way round you turn it? No.
- (more advanced) Rather than a filament bulb, the lights are two LEDs, connected with opposite polarity. Each LED will only light half of the time, with frequency=rate of turning the handle. This is because the current is alternating ('going backwards and forwards') and it only lights when the current is going one way.

Generator in a box

This is a better version of the previous one, but it's all hidden in a box which means visitors can't see what is going on as well. There are two bulbs that can be switched on or off, and also a voltmeter/ammeter. Things to do:

- Start someone off turning the handle and then increase the wattage of bulbs turned on gradually. They will find that it gets harder to turn as you do this. Talk about needing to put extra energy in to get more light out (the energy is coming from them, **not** from the magnet/coil which just convert kinetic/moving energy into electrical energy)
- Power generation: How many watts are the bulbs you have at home? If it's this hard to turn a handle to make 10W of bulbs light, how hard would it be to power all the bulbs in your house? How about all the bulbs, TVs,... in town X? This is really where our power comes from, what better ways are there of turning the handle (wind farms are the easiest example for small kids)
- (More advanced) Look at the ammeter/voltmeter. When a bulb is fully lit how do those readings compare to the wattage of the bulb ($P = IV$).

2. Dropping magnets

This uses the last part to do a neat trick. The three columns in the coin drop are made of plastic, aluminium and copper. None of these are magnetic, but a coin magnet will fall more slowly through the metals.

This is because the moving magnet is inducing an electrical current in the metal (like the magnet past the coil in part 1). There are two ways to explain why this causes it to slow down: 1. (easier) Some energy is needed to make the electrical current (like turning the handle before). This time the energy comes from the falling magnet, and when it loses kinetic energy it slows down. 2. (harder) Eddy currents of electricity are formed, and these create an electromagnetic effect opposing the motion of the magnet, hence it slows down.

You can also do this with the perspex and copper pipes (get a volunteer to hold the pipe, with their other hand below it to catch the magnet), the slowing effect with the copper pipe is really huge.

There is also green ‘iron filing’ paper, which shows up the movement of a magnet through it. You can use this to ‘see’ the movement of the magnet inside the copper pipe.

3. Motors etc.

There are various bits here, you probably won’t want to do all of them. This is the opposite of what we have been doing so far. Now we are using electricity to make magnets, or electricity and magnets to make something move.

Compasses around a magnet/wire

Show what a magnet/current carrying wire do to a compass, compare the two.

Electromagnetic Nail

Wrap wire around a nail attach it to a power supply and see how it affects paper clips, with and without the power, try picking up a matchbox car as a use for electromagnets.

Jumping Wire with indicator lights

Put a current through the wire on top of the magnet, you should notice the wire is pushed by the magnet. If you reverse the direction of the current the direction of the force reverses.

Simple motor

This is a simple toy motor. There are two commutators one which keeps the polarity the same - you can show that you can get some movement but not rotation, and one which swaps the polarity, that will make it turn nicely.

- Have a look at the motor there are a load of wires near some magnets, so there will probably be some forces going on from the Jumping wire experiment.
- Using the first commutator, you need to keep swapping the polarity as when the motor gets half way round the direction of the current has essentially reversed (you are using the other half of the coil), so it gets pushed back again. You can get it to keep turning, by reversing the current. This however gets a little tedious…
- Luckly the second solves the problem, everytime the motor turns halfway round the two contacts swap, so it keeps turning. This is how all DC motors work, some AC ones use the changing direction of the voltage instead of a commutator, so have fixed speeds.

Tricks: It works best on the 7.5V range with the motor wired from the +ve side to the -ve side. The brushes should be touching the commutator, on either side (top and bottom won’t work)

There is a real motor in the box too, which you can compare it to.

Risk Assessment

Hazard: Hot coils and wires

Description: Possible overheating could result in burns. Motor can short-circuit and get hot.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Do not put too much current through a coil/wire: if it is getting hot, turn it down. Demonstrator to turn off power supply to motor when not in use. If there is a burn, run under tepid water for ten minutes. In the event of any injury, turn off electricity at mains, and call first aider. In event of fire, follow procedure in venue RA (raise alarm, evacuate).

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Powerful magnets

Description: Magnets may shatter, possibly leading to cuts. Magnets may trap fingers if mishandled.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Warn visitors if you give them a magnet. Use the minimum number of free magnets. Keep the magnets under control. Cover with tape to reduce impact, and contain any shards. Pad edges of magnet to reduce finger trap. Call first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Copper pipe

Description: Copper pipe hitting people in face.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Demonstrator should hold pipe for younger kids and monitor use for others. Call first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Hazard: Heavy generators/motors

Description: Can fall off tables and land on children/demonstrators, causing injuries.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Use clamps to keep generators and motor firmly attached to table. Call first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Rotating motor

Description: Children could trap fingers in the rotating parts.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Keep kids' fingers away - if it needs pushing it should be done on the axle, not the armature. Call first aider in the event of injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Generator

Description: Visitor or demonstrator catching fingers in generator as they turn the handle on the generator.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Place generator on flat surface so visitors can't catch their fingers underneath so easily. Tell visitors to hold only the rotating part of the generator handle and not the entire handle. Keep control of the visitors at all times and don't let them get overexcited while turning the handle. Call first aider in event of injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-16 - Jachym Sykora (js973@cam.ac.uk)

Check 1: 2014-01-22 - Brett Abram (ba305@cam.ac.uk), **Check 2**: 2014-01-26 - Zephyr Penoyre (jp576@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-22 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-28 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-01-29 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-01 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-01 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-14 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2020-01-22 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk), **Check 2**: 2022-02-09 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2023-02-18 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-02-18 - Timothy Wong (chw55@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Engines

What are the different types of engine, and how do they work? - Have you ever wondered what an engine is? Learn about how various types of engines work from the ubiquitous Internal Combustion Engine found in almost every car ever made to a small engine which runs on nothing but hot water!

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-01-30 by Lucy Bland (lb831@cam.ac.uk).

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Engineering

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **Electricity needed**
- Internal combustion engine model, Jet engine model, Stirling engine model, soft pencils, kettle, mug.
-
- WARNING: STIRLING ENGINE MUST NEVER BE LUBRICATED WITH OIL. It will gum it up. Lubricate bearings with graphite from soft pencil only.

Experiment Explanation

Engines Experiment - Explanation Last Update - Gareth Funk, April 2015

************** INTRODUCTION ************** I like to start with the Stirling Engine whirring away whilst I give the following introduction. To do this, the Stirling Engine should be placed on a mug of freshly boiled water and given a push to get it going. It will only go one way for reasons which should become clear.

Before looking in detail at any of the models, it is worth asking the question “what is an engine?”, or alternatively, “what do you know that has an engine?” and as a follow-up “why does it need an engine?”. Many of the children will not be able to give a good answer to the first, but can answer well enough the second two. The key thing about all engines is that they turn energy from one form into mechanical (or kinetic) energy and an engine is simply any device that does that. Examples of engines are: - Electric motors - Jet Engines - Steam Engines - Internal Combustion Engine - Stirling Engine

Excluding the Electric motor, all the above are heat engines: they use heat energy as their input. Obviously this energy usually comes from burning something, but thermodynamically the input to the engines is heat. It is worth noting that the jet engine is also, strictly speaking, an type of internal combustion engine. Similarly it is worth noting that the steam engine and the stirling engine are examples of external combustion engines.

The Stirling Engine is the best one to demonstrate because it best exemplifies the idea of a thermodynamic cycle and gives a real-life demonstration of an engine in action. The Internal Combustion Engine and the Jet Engine models are just models and a lot of children can’t see past the fact that a battery and an electric motor are what is making them turn. However, if there is time left after the Stirling Engine demonstration, feel free to move on to the others if you have time.

************** STIRLING ENGINE ************** The Stirling Engine we have is one of three commonly seen implementations of the Stirling Cycle. Out of interest, ours is a Gamma Configuration Stirling Engine. Most Stirling Engines used in practice are of different configurations but the thermodynamic processes they undergo are the same.

The following explanation requires that the children are familiar with the concepts of pressure and volume. A good, quick way to explain pressure is to get them to consider running around in a room with their eyes closed. They'd bump into walls every so often. They'd bump into walls more often if there were more of them in the room, or if the room got smaller.

Before we proceed, the following things need to be pointed out concerning the names we will use for the various different parts of the engine. Point out the two different pistons. Note that the black piston simply moves the gas to the hot space (when it lifts up) and to the cold space (when it comes back down). It is as such termed the "displacer piston" however during the demonstration I tend to stick to "black piston" but it is nonetheless worthwhile to show them that is simply moves the gas around and does NOT compress it. The glass piston at the top changes the overall volume of the chamber: when it lifts up, the volume increases (expansion) and when it descends, the volume decreases (compression). The hot space of the engine is the metal surface in contact with the hot steam (please stress that this is not a steam engine!) and the cold space is the upper metal surface in contact with the surrounding air. Also tell them what the flywheel is and point it out (it's the large gold-coloured wheel which spins). The flywheel is there mainly to store the mechanical energy we extract but also to tip the pistons from one phase to the next.

Stop the Stirling Engine by keeping your finger on the flywheel so that we can slow the process down and step through the stages in turn. Let the engine get to the point where the black piston is about to come up and then proceed with the following explanation.

The idealised Stirling cycle consists of four thermodynamic processes acting on the working fluid (in our case, the air trapped inside the chamber):

Constant-Volume (known as isovolumetric or isochoric) heat-addition: The glass piston is staying roughly still at the bottom of its stroke during this process which means that the volume of the chamber is remaining constant. The big black piston is moving up which moves the gas into contact with the hot space and so it heats up. During this process, the pressure will also increase.

Isothermal Expansion: The small glass piston rises up thus expanding the hot fluid meanwhile the gas continues to be in contact with the hot space as the black piston is staying roughly still. It is NOT important to stress the constant temperature; the expansion of the gas and the intake of thermal energy are the key points.

Constant-Volume (known as isovolumetric or isochoric) heat-removal: The glass piston stays still (now at the top of its stroke), hence constant volume, and the black piston moves down moving the gas from the hot space and into contact with the cold space and so heat is lost.

Isothermal Compression: The glass piston now moves down and compresses the gas. The black piston stays still so the gas continues to lose heat at the cold space.

The cycle repeats: Now we are back where we started but in getting back to where we started we made the wheel spin! Now the cycle will continue over and over again until we run out of heat. This is the really important point to stress: by doing those four thermodynamic processes we extracted some mechanical energy!

Note here that these processes have to happen in this order hence why the wheel only spins one way.

To finish off, take the stirling engine off the heat, let it stop, and then ask "what would happen if we were to spin the flywheel in the opposite direction to the way it normally spins?". Think about the system we had before: Heat was added at the bottom, the wheel turned round. The answer to the question is that the opposite would happen if we were to spin the wheel in the opposite direction the bottom surface would heat up. This will not be practical the demonstrate as it's difficult to spin the wheel sufficiently fast but it is nonetheless true. Some children will instinctively get this without much prompting but in my experience most struggle with the concept.

************** INTERNAL COMBUSTION ENGINE **************

Our particular model is of a four cylinder, four-stroke engine. The piston completes four separate strokes which together comprise a single thermodynamic cycle. A stroke refers to the full travel of the piston along the cylinder, in either direction. The strokes are as follows: INTAKE: this stroke of the piston begins at top dead centre. The piston descends from the top of the cylinder to the bottom of the cylinder, increasing the volume of the cylinder. A mixture of fuel and air is forced by atmospheric (or greater) pressure into the cylinder through the intake port. COMPRESSION: with both intake and exhaust valves closed, the piston returns to the top of the cylinder compressing the air or fuel-air mixture into the cylinder head. POWER: this is the start of the second revolution of the cycle. While the piston is close to Top Dead Centre, the compressed air–fuel mixture in a gasoline engine is ignited, by a spark plug in gasoline engines, or which ignites due to the heat generated by compression in a diesel engine. The resulting pressure from the combustion of the compressed fuel-air mixture forces the piston back down toward bottom dead centre. EXHAUST: during the exhaust stroke, the piston once again returns to top dead centre while the exhaust valve is open. This action expels the spent fuel-air mixture through the exhaust valve(s).

Focus on one cylinder when explaining these but make sure you are pointing out the correct stroke! Check the valves to check you're telling them the right stroke at the right time: If the valves are open then the stroke is intake or exhaust, depending on which way the piston is moving. If you get this wrong the spark won't be at the right time and the valves will be open when you're saying the fluid is being compressed etc.

Note that the cylinders are not all moving together and even those that are do not fire at the same time. This is in order to deliver the power more smoothly with four smaller bursts per two revolutions than one large burst per two revolutions. Most cars have 4 cylinder engines like our model.

Side Note: The model can be switched off and on such that it gets out of sync with the spark. If it does this, turn it off and on again, stopping at a different point in the cycle, until it gets back in sync.

************** JET ENGINE ************** As of this update, the Jet Engine model has not been built yet. This section will need updating once the model is finished and I have decided what can be demonstrated with it.

The following is from wikipedia:

A turbofan engine is a gas turbine engine that is very similar to a turbojet. Like a turbojet, it uses the gas generator core (compressor, combustor, turbine) to convert internal energy in fuel to kinetic energy in the exhaust. Turbofans differ from turbojets in that they have an additional component, a fan. Like the compressor, the fan is powered by the turbine section of the engine. Unlike the turbojet, some of the flow accelerated by the fan bypasses the gas generator core of the engine and is exhausted through a nozzle. The bypassed flow is at lower velocities, but a higher mass, making thrust produced by the fan more efficient than thrust produced by the core. Turbofans are generally more efficient than turbojets at subsonic speeds, but they have a larger frontal area which generates more drag.[11] There are two general types of turbofan engines, low bypass and high bypass. Low bypass turbofans have a bypass ratio of around 2:1 or less, meaning that for each kilogram of air that passes through the core of the engine, two kilograms or less of air bypass the core. Low bypass turbofans often used a mixed exhaust nozzle meaning that the bypassed flow and the core flow exit from the same nozzle.[12] High bypass turbofans have larger bypass ratios, sometimes on the order of 5:1 or 6:1. These turbofans can produce much more thrust than low bypass turbofans or turbojets because of the large mass of air that the fan can accelerate, and are often more fuel efficient than low bypass turbofans or turbojets.

Risk Assessment

Hazard: Hot Water and Hotplate

Description: Risk of burns

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Warn of hot water (and steam) before experiment starts, keep hot water away from easy reach of children's hands. Mark mug as "HOT". If any burns occur, run under tepid water for an appropriate amount of time.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Water

Description: Spilled water is a slipping hazard

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Use stable mug for water. Do not over-fill. Clean up spills immediately.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Sharp edges

Description: Sharp edges may cause injuries if Stirling engine is dismantled.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Do not allow children to play with Stirling engine. If flywheel becomes detached, demonstrator to reassemble.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Fly wheel

Description: Fingers could get trapped or caught in fly wheel

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Flywheel is very light and has little angular momentum, even at high speed. Do not let children put their fingers near the flywheel.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Small parts

Description: Choking risk from small parts

Affected People: Children

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep away from very small children. If engines break, close experiment and put parts in box.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2014-02-23 - Philip Garsed (pgarsed@gmail.com), **Check 2**: 2014-02-24 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2015-02-12 - Sarah Wiseman (sw628@cam.ac.uk), **Check 2**: 2015-02-12 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2016-01-02 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2018-02-06 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-12-29 - Käthe-Marie White (kmw54@cam.ac.uk), **Check 2**: 2020-01-24 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk), **Check 2**: 2022-02-09 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2023-02-17 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-18 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-01-30 - Lucy Bland (lb831@cam.ac.uk)

Exercise and Heart rate, Stethoscopes and Heart Model

When you exercise your heart beats faster! - Why does your heat beat faster after exercise? Come and find out why in this demonstration where you are the subject.

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- Stopwatch.
- (When done on tour, this experiment is often integrated with the Stethoscopes experiment. The Stethoscope experiment requires stethoscopes and antibacterial wipes/disinfectant and tissue, and also lives in a small blue box, often with the stopwatches. If using the stethoscopes, ensure you read the separate risk assessment for Stethoscopes).

Experiment Explanation

Exercise and Heart Rate - Check for asthma. If child is asthmatic, check with parents (or teacher) about severity, and if the child can do five minutes of fairly heavy-impact exercise. If they can do it, ensure they have an inhaler, and ensure they don't push themselves too far.

- Take child's pulse (radial side of forearm), and write it down.
- Make child run on the spot 3 mins and then do starjumps for 3 mins or any other combination of the above.
- Check pulse again.
- There should be a difference. If not, it's an anomaly, and you can make them do the experiment again.
- If you're doing this experiment by taking the radial pulse, you need to start by asking questions ("Have you had your pulse taken before/seen it done on TV?" and "Why do doctors take your pulse?") to make sure they know that your pulse reflects your heart rate, and if they don't, make sure to explain it before carrying on!

So, why does your heart rate go up?

- What is the heart for? - They will usually say say pumping blood around the body/beating.
- My favourite question after this is "What is blood for?", to which the answer is always "It keeps you alive".
- You can then progress from here by asking why (which they often will not know, even in surprisingly old children), and then explaining why we need blood.
- I usually go along the lines of "What do we need to do to stay alive?", get them to work out that we need to breathe, eat

and drink, then think about where air and food go into our bodies, and then how might we be able to transport these things from your lungs/stomach to wherever they're needed, like your muscles to jump around or your brain to think - and then you have ended up working out what blood does! (You can use the analogy of lots of lorries (blood cells) driving along roads (blood vessels) carrying cargo (oxygen/food). You can go further into the idea of cells needing energy from glucose and oxygen with older/interested kids.)

- With older/interested children you can then develop the idea by talking about the heart as a double pump and the pulmonary and systemic circulatory systems - this works well if you've got the heart model to hand (on tour), or if someone else has just explained the heart model to them!

- Then you can talk about how your muscles are more active when you're doing exercise so they need more 'fuel' (oxygen and glucose), therefore you need to get more blood to them in a shorter space of time, therefore the heart beats faster!

- You can also talk about breathing rate (are they panting?) and recovery times and fitness if you wish to. You need to breathe at a higher rate and more deeply to get more oxygen into your lungs, and then move it to the muscles more quickly, because they need more energy and so are using up oxygen faster.

(N.B. I find this experiment is quite useful with groups of lively children, as provided you can get them to be reasonably sensible and you have enough space, they can jump up and down until they're quite tired and then they will often sit down calmly and listen to the explanation afterwards!)

Heart Model and Diagrams

ACTIVITIES - Let the kids take the model apart and let them figure out how it all fits together

THINGS TO TALK ABOUT - What is "circulation" and why do we need it (see below) - Structure and function of the heart - Things that can go wrong (valve defects, heart attack etc)

TIPS FOR DEMONSTRATING - It is quite surprising how little most people know about circulation. It is therefore very important to find out how much the kid knows already and work from that. - I have included a very basic script for explaining circulation below - you would obviously have to adapt that to the age of the kid and to what he/she knows already.

BASIC PROCEDURE AND EXPLANATION

A. BASIC CONCEPTS

Look at the whole model. Ask the kids what it is (heart) and what it is used for (they will usually say that it pumps blood). Now comes the tricky bit: Why does the heart pump blood? It is quite surprising that many kids (and parents) have no idea about why we might want to pump blood through our body. If this happens, here is an explanation you could use to explain the basics of circulation (I have used a very simple one that even young kids can understand- you would have to adapt that for older kids/parents):

- Our body is made out of loads of little building blocks called cells. Each cell is like a small factory and it needs two things
- Get the kids to think about what these two things may be; i.e. why do we breathe (to get oxygen); why to we eat (to get food/nutrients)
- So the factories in our body need food and oxygen
- Where do they get that from? Ask them where the food they eat goes (stomach); similarly, the air they breathe in goes to the lungs
- So if the food is in the stomach and the oxygen is in the lungs, how can it ever get to all the "factories" that make up the brain, your toes etc.
- You need something like a street- these "streets" are your blood vessels
- You also need something to transport the food and oxygen, i.e. a lorry –this "lorry" is the blood
- So our blood transports food and oxygen to all the cells in our body
- But there is a problem - blood is a liquid - ask them what happens when you pour water/get water from the tap (water always "goes down" - so if this happens to our blood as well, it would all end up in our toes).
- So you need something that makes the blood go to the cells in the brain as well; i.e. you need an engine to drive a lorry or in other words, you need the heart to pump the blood through your body

B. STRUCTURE OF THE HEART

Let them take the heart apart and get them to think about what the individual bits may be and what they might be used for. Here are some things you could point out:

- Can they see the big blood vessels ("streets") that come into and out of the heart; get them to think where they might come from and where they may go to; i.e. some go to/come from the lungs and others go to/come from the body (having explained circulation beforehand helps; i.e. the blood has to go to the lungs to pick up oxygen)

- Let them guess which ones might be the vessels that go to the lungs and which ones are the ones that go to the body
- The heart has chambers – can they see them? How many are there?- how does the blood travel through the heart?
- Do they think that the blood can go back to the chamber it just came from? No; point out valves; if the kids are older, get them to figure out why this "one way" system is important
- The heart is a muscle; it contracts, when it contracts, the chamber gets smaller, this squeezes the blood in that chamber into the next chamber/ into the body/ to the lungs; valves prevent backflow

C. OTHER THINGS TO TALK ABOUT

- Can they see the small blood vessels going into the heart itself (coronary arteries etc)?
- Why is this important? – the heart is a muscle, that has to work all the time for all your life - it needs a lot of food and oxygen, too!!!
- What do they think happens if you block one of these vessels? - Ischaemia, angina, heart attack (Parents are usually quite interested in this)
- What can you do when this happens? - Open up vessels (stents), make vessels bigger (drugs; vasodilators), but most importantly, remove anything that can block those vessels- this is why a healthy diet, exercise and stopping smoking are so important!
- Other things that can go wrong: Valve defects, heart failure
- When the heart pumps, it makes a noise - this is what you can hear with a stethoscope; refer them to the stethoscope experiment
- For older children - noise heard through the stethoscope is actually the closure of the different valves in the hear

Stethoscopes Using a stethoscope to listen to the heart and find out how it works Use the 'heart rate and exercise' explanation too!

1. Do they know what it is?
2. Do they know what it's used for?

- Use it to listen to: Lungs, Heart, Bowel sounds, Bruits (noise due to turbulence in blood vessels for various reasons) in the following vessels:
- Carotid
- Femoral
- Thyroid
- Hepatic

3. What makes the sound?

Normal Lungs: - Normally turbulent air going in and out of bronchi. - Sounds different over bronchi/trachea and lung fields. - Same noise, but in the lung fields it is heard through large amounts of other tissue and so is soften (I think it cuts out specific frequencies - high or low -but don't quote me on that).

Abnormal Lung (probably talk about Asthma as most kids now about it)

1. Bronchial breathing over lung fields. Due to consolidation - solid debris in lungs with pneumonia- or fribrosis. Means sound can't 'disperse' (I'm sure physicists would have better description).
2. Wheeze (can demonstrate this one). Due to narrowing of the tubes. Asthma wheeze, COPD gives polyphonic. Tumour wheeze gives monophonic (because only blocks one tube).

Heart. 1. Have brief discussion about what heart does (see Heart Rate and Exercise or Heart Model explanations). Where is your heart? It is surprising how many children seem to think it's somewhere in their left shoulder!

2. What makes noise in heart?

- Valves - with older kids a discussion about why we have valves may be useful.

3. Normal heart sounds.

- Lub-dub.

4. Extra heart sounds:

- Note, can have third and fourth heart sounds.
- If you have both they make noise like train going over tracks - du-dub-du-dub.

5. Abnormal:

- Due to turbulent flow through valves (make the noises).
- Why do you get turbulent flow? - Valve doesn't fully open (stenosis) or Valve doesn't fully close (regurgitation)

Risk Assessment

Hazard: Over-exertion

Description: Asthma attack.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Check child's asthma status with parent or teacher (or with child themselves if old enough) before doing experiment. Do not allow child to exercise if asthma is severe, and DO NOT ALLOW AN ASTHMATIC CHILD TO DO EXPERIMENT IF THEY DO NOT HAVE AN INHALER.

In case of an attack, sit child down, keep them calm, locate inhaler for child to self-administer. Call first aider.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Running children

Description: Child running into things/people.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Make sure exercise area is clear, use on-the-spot exercise e.g. star jumps if space is limited.

Call a first aider in the event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Exercise

Description: Physical injury e.g. falling.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Demonstrator to ensure floor area is clear and dry. If area becomes wet, locate a mop and dry the area.

Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Small Parts in Heart Model

Description: Small parts could be swallowed.

Affected People: Public (especially small children)

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: (The heart model is suitable for older children, so hopefully shouldn't be an issue). Do not let children play with experiments unattended.

Call first aider in case of ingestion and encourage the child to cough.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Pointed Parts in Heart Model

Description: Some parts have fairly sharp points - risk to eyes/skin.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Sharp points filed down to be as safe as reasonably possible.

Call a first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Earpieces of Stethoscopes

Description: Transferring infection via ear pieces.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Wipe ear pieces with antiseptic wipes or tissues and disinfectant before use and after you or a child has used it.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Stethoscopes

Description: Yanking or swinging of stethoscope causing injury

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Ensure stethoscopes are removed before doing exercise. Keep children under control, and if children are misbehaving, don't give them a stethoscope.

Call first aider if necessary.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Stethoscope

Description: Choking from stethoscope being tangled around neck.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep children under control, and if children are misbehaving, don't give them a stethoscope. Ensure stethoscopes are removed before doing exercise.

Call first aider if necessary.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2012-01-05 - Ashley Smith (ashley.smith@cantab.net), **Check 2**: 2012-01-25 - Daniel Obute (rdo23@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-09 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-22 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-06 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-10 - Alisha Burman (arb95@cam.ac.uk)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-14 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2017-02-09 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-10 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2018-02-06 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-02-02 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2020-01-26 - Samuel Amey (sra44@cam.ac.uk), **Check 2**: 2020-01-27 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-19 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2021-01-20 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-26 - Hayoung Choi (hc585@cam.ac.uk), **Check 2**: 2022-02-09 - Sian Boughton (seb216@cam.ac.uk)

Check 1: 2023-01-20 - Emily Wolfenden (elw74@cam.ac.uk), **Check 2**: 2023-01-31 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Exploring Nanoscience

Activities to discover the nanoscale

Last initially checked on 2024-02-13 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-02-15 by Isobel Gilham (ig419@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active

Chemistry

Water needed

Equipment Needed

- Teacup
- Tiny teacup
- Bowl of water
- Sand
- Hydrophobic sand
- Kinetic sand
- Three trays
- Paper
- Graphite pencil (6B is best)
- Two wires with crocodile clips
- LED
- 9V battery

Experiment Explanation

In a nutshell.....

This experiment explores how nanoscience differs to science on a "normal" scale by demonstrating the effects of nanomaterials.

Tiny teacup

Fill both teacups with water, then let the children attempt to pour them out. The water shouldn't leave the tiny teacup. This is demonstrating two competing forces: gravity and surface tension. Gravity is more important on a larger scale, whereas surface tension is more important on a small scale. The point of this experiment is to show why nanoscience is its own area of science - different forces and mechanisms become important on a nanoscale.

Sand

There are three types of sand: normal, kinetic and hydrophobic. Let the children play with sands and notice their different properties.

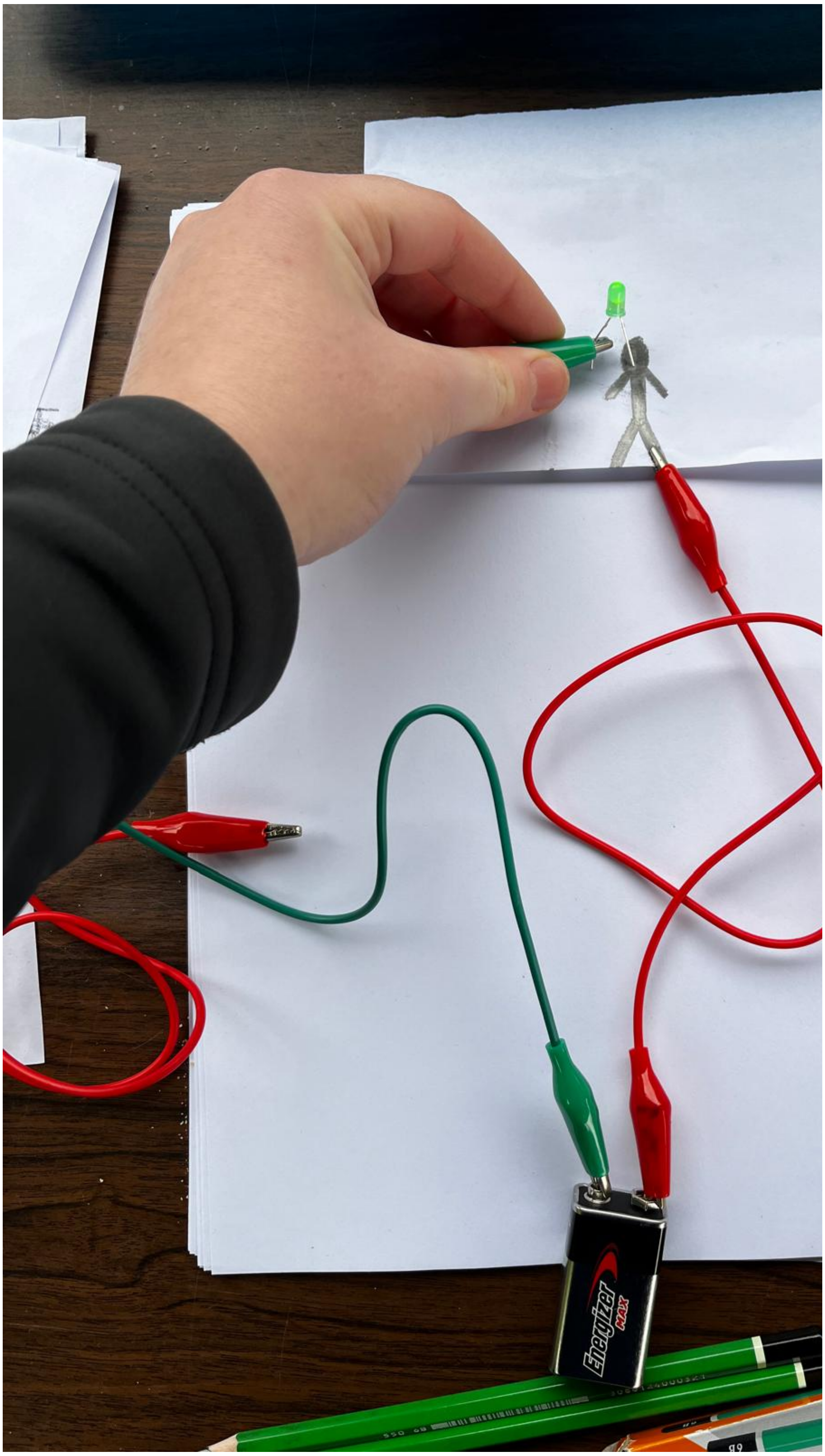
Kinetic sand is covered in a thin polymer layer (polydimethylsiloxane, PDMS), which makes the sand stick to itself. The polymer layer is too small to be noticeable to us, but it has a big effect on the properties of the sand.

Hydrophobic sand is coated with a silicon compound that is one nanometer thick. A nanometer is one billionth of a meter - your fingers grow one nanometer per second! Like the kinetic sand, this tiny change makes a big difference.

You can pour water on the hydrophobic sand to show how it repels water, but avoid getting water in the kinetic sand as it will change its properties.

Battery and bulb circuit

Draw a picture on a piece of paper. Connect the picture with the edge of the paper and draw with heavy, thick lines. Clip one wire from the negative terminal of the battery to the edge of the paper, so it's touching the drawing. Clip the other wire from the positive terminal to the long leg of the LED. Touch the shorter leg of the LED to the drawing. The LED should light up. The brightness should increase as the leg is moved closer to the clip, and decrease as it's moved away (don't directly touch the other clip with the LED leg, or touch the LED directly on the battery, as this will apply too much voltage and the LED will blow).



Graphite is made of many layers of carbon atoms and conducts electricity, so completes the circuit between the battery and the bulb.

You could also talk about how we can take a single layer of graphite, called graphene. This was first discovered by using ordinary tape to strip apart layers of graphite. Graphene is a nanomaterial.

Risk Assessment

Hazard: Small parts (tiny teacup, LED)

Description: Choking on small parts.

Affected People: Small children

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Watch small children carefully. In the event of a piece being swallowed, encourage child to cough. Call a first aider, who may perform the Heimlich if trained and happy to do so.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Sand

Description: Getting sand in eyes.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Discourage children from throwing sand. Ask them to wipe their hands after playing with the sand.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Water

Description: Slipping in split water.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Take care when pouring water than it doesn’t go on the floor. Clean up any spills immediately.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2024-02-23 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-02-15 - Isobel Gilham (ig419@cam.ac.uk)

Giant Breadboards

Make circuits using giant components - Explore circuit basics, different components, logic gates, speakers, buzzers and build your own heat alarms and more.

Last initially checked on 2024-03-15 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-03-15 by Margaret Johncock (mllyj2@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Computer Science

Equipment Needed

- **Batteries needed**
- Boards with pins to attach components to
- Selection of clip-in components:
  - Battery boxes
  - Wires
  - Switches
  - Resistors
  - Capacitors
  - Diodes
  - Light bulbs and LEDs
  - Motors
  - Inductors
  - Light sensors, microphones, etc.
  - Various ICs (the big square boxes)
- Fans to attach to motor
- Spare fuses, batteries, etc.
- Instruction manual with example circuits
- Ready-made kits containing similar components to above
- Old/WIP stuff (currently unused)
  - Giant breadboard
  - (Selection of wooden components)
  - (Material samples)
  - 4mm banana plug wires
  - Spare banana plugs and components.

Experiment Explanation

The experiment (and this explanation) is still in the process of being finished; it currently consists of a whole bunch of electronic components to make circuits and demonstrate various properties of electricity.

Particular recommendations for circuits to make and demonstrate (from the Hot Wires book) would be:

- Experiment 2: Powering the motor and fan (**using only one battery pack**) - the fan will take off when you switch the current off, so be prepared for that! Make sure people stand well back!
- Experiment 5: Simple LED circuit - make sure to include a ≥ 100 Ω resistor in series with LEDs
- Experiments 7 and 8: LEDs in series and parallel
- Experiment 11: Variable brightness LED (only use one battery pack!)
- Experiment 12: Charging a capacitor (PLUS)
- Experiment 14: Dark sensitive LED (PLUS)

The experiments marked with PLUS have more complex explanations and are more suited to an older audience.

Feel free to try other things with the clip-in components, but I wouldn't touch the other parts with loose wires as they are unfinished, and some have sharp points which can cause injury

Packing Away

Remove batteries from battery box and store in separate bag. Separate components and return to bags, loosely sorted into wires, bulbs, switches, resistors, etc.

Risk Assessment

Hazard: Quickly spinning / flying fan in Experiment 5

Description: Getting fingers trapped in blades or being hit by the flying fan, leading to injury

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Tell people to stand well back before powering the fan, and only use one battery pack to limit the speed and the height it reaches.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Batteries

Description: Potential for battery corrosion, releasing acids that can irritate skin and cause eye damage.

Affected People: All, particularly demonstrators

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Remove batteries from the battery boxes when not in use.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Using excessive voltage or current.

Description: This could cause components to get damaged and have to be replaced. In the worst case, an overvolted capacitor could explode causing injury, although this is very unlikely with the small capacitors and voltages used.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Only use one battery pack at a time wherever possible. Preferentially use the grey battery packs with the built-in 500 mA fuses. Always install a 100 Ω current-limiting resistor in series with any LED.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Small/sharp pieces in old set of unused components.

Description: Choking hazard, potential for minor cuts on sharp edges.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: Do not use this equipment out until it has been made into something more complete. Leave it in the bag.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Electric current.

Description: Electric shocks

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Only use 1.5V AA batteries, not power supplies and definitely not mains power! Where possible, use only one battery pack and preferentially use the ones that have integrated 500 mA fuses.

After Mitigation: Likelihood: 2, Severity: 1, Overall: 2

Risk Assessment Check History

Check 1: 2024-03-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-03-15 - Margaret Johncock (mllyj2@cam.ac.uk)

Giant intestine model

Functional model of the intestine - Everyone knows that your intestines are long, but how long is long? Find out with our scale fabric model, and you might be surprised!

Last initially checked on 2024-02-15 by John Leung (cfl35@cam.ac.uk) and double-checked on 2024-02-15 by Isobel Gilham (ig419@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- Model of the intestine, which can be used to explain the digestive process to children.
- May also include tube made from chopped-off tights and a smooth plastic ball.

Experiment Explanation

ACTIVITIES:

- Show the model to kids, let them feel it and ask them to guess what they think it may be
- Illustrate the length of the intestine: get a kid to stand up and use the model to illustrate how long the intestine actually is (you can hide it in the bag and give the child one end to gently pull out and walk across the room until the whole thing is stretched out, if there's enough space and the child is sensible about it). Get them to imagine that such a long tube is actually rolled up within the small space of their tummies…
- Get them to feel the inside - there are ridges. You could use this to discuss surface area (i.e. "what would happen if all these ridges were smoothed out?")
- Use the plastic ball as a bolus of food and squeeze it through the tights tube to describe peristalsis.

THINGS TO TALK ABOUT:

- Basic theory of digestion, i.e. "what happens to the food once we've eaten it?"
- What you need to make digestion effective: surface area of the intestine; how to increase surface area (ridges, length of intestine- use model to demonstrate)
- Things that can go wrong: diarrhoea, constipation, etc.

TIPS FOR DEMONSTRATING:

The idea is to get the kids involved as much as possible. The best way to do this is by using the model as much as possible when you explain things. Let the kids play with it as well- and get them to figure out things for themselves.

BASIC PROCEDURE AND EXPLANATION:

What do we use our intestines for?

- Our body is made up of loads of small factories, called cells

- What do they think these factories need? – Food (That's why we eat…)
- However, the food we eat is very big and these cells are really small (so small that you can't usually see them with the naked eye!)- so the food needs to be broken down
- What do they think breaks down the food? Talk about teeth, stomach, also your intestine
- The pancreas secretes a special liquid that breaks down the food (If the kids are older, they will often have heard of enzymes, so you can expand on this point as much as you - and they - like…)
- So, once the food is broken down, how does it get to cells in the body? Via the blood (for young kids: the blood is a bit like a lorry - it can pick things up and bring them somewhere else)
- The intestine is the place where the food gets taken up into the blood (for older kids, talk about absorption etc.)
- How does food move through the intestine? Use the ball and tights tube to explain peristalsis - there are muscles in the intestine walls that contract to squeeze the food along (use your hands to represent the muscles)

What makes the intestine so good at what it does?

This point is all about absorption and how you can increase the latter by increasing the surface at which it can occur.

For young kids:

- Get them to imagine how long the intestine is by using the model.
- Can they imagine that such a long tube is actually folded up within their tummies (see activities)?
- So there is a lot of space for the food to get into the blood…

For older kids:

- Talk about the length of the intestine as before.
- Also get them to feel the ridges inside - what do they think would happen if they were all smoothed out?
- Just for reference, the surface area of the small intestine in an adult person is about 250 square meters – that's about the same size as a tennis court!
- How can such a large area fit into our tummies - by folding it up (so all the ridges are folds of the intestinal wall…)

What happens to the food we don't absorb?

- It moves through the intestine and leaves our body as poo - small kids often find this strangely fascinating.

OTHER THINGS TO TALK ABOUT:

- There are two types of intestine (small and large) - they have different functions (parents may ask you about this.)
- Things that can go wrong: diarrhoea, constipation, malabsorption, inflammatory bowel disease etc… see below for ideas:

Diarrhoea – ask who knows what this is?!

- It's watery, frequent stool.
- Very important to kids in developing countries especially – losing so much water (and you can lose blood too – this is called dysentery, which happens with Shigella and Amboebiasis) can be fatal.
- With cholera you are losing so much water so quickly that it is pretty much literally a battle to give the patient enough water.
- Common agents:
- Bacterial: E. Coli 0157 (the E Coli K we have on display is entirely safe though), Salmonella
- Protozoa (one-celled, primitive, parasites in this case): Amoeba, giardia - much commoner in the third world.
- Viruses: rotavirus (most common in kids), Norwalk virus (causes diarrhoea and vomiting on cruise ships, calling for impeccable hygiene standards).

Older kids might understand the principal of isotonic drinks for rehydration – the ions are needed because so many are being lost, and the water enter cells more quickly due to osmotic attraction and as some ion channels co-transport water. Explain that ions are chemicals like sodium, chlorine, and potassium, and that they spread themselves out in the body into all the cells, with water following them. Ask them if they think it's important that you keep your cellular ions at a constant level. Ions are lost into the intestine because inflammation at its mucosal surface makes it leaky.

Malabsorption:

- What if a surgeon cuts out half your small intestine because it got damaged in a skiing accident or whatever?
- Do you think your intestine will work as well?
- What do you think happens if your villi are destroyed?
- This is what happens in celiac disease – it is an inappropriate immune reaction to gluten in the diet.
- The patient (usually a child) becomes thin and malnourished, slows down their growth and can become deficient in

micronutrients, eg. vitamins, which are usually absorben in the small intestine.

Villi are also destroyed in Inflammatory Bowel Disease (these diseases are Crohn's disease and Ulcerative Colitis).

- Ulcerative colitis tends to affect the large bowel almost exclusively, decreasing its ability to absorb water. Therefore someone with Ulcerative Colitis will get watery stools. The tissue gets so inflamed (or I guess you could say "attacked" to younger kids) that it bleeds, which can be noticed in stools.
- Crohn's can affect the small intestine and cause malabsorption of lots of nutrients, carbohydrates, and lipids.

We mentioned that the pancreas makes enzymes – I like to describe them as being like tiny scissors which chop up the smallest nutrients up into a form which they can just nicely be absorbed into villi. If someone's pancreas isn't working properly (eg. it gets clogged up in cystic fibrosis, or if they have a gallstone obstructing its outflow) they can't absorb a lot of things like lipids, proteins and fat-soluble vitamins (A, D, E, K).

Bacteria in the intestines- these play an important role too in breaking down components in your food. There are about 100 trillion bacteria in your intestine, more in the large intestine than the small intestine. Some of these are beneficial, others are pathogenic. Probiotics are to help encourage growth of bacteria that are beneficial. Examples of bacteria that are damaging in the gut include Campylobacter and some types of Salmonella.

Risk Assessment

Hazard: Tube

Description: Risk of strangulation if model or tights tube is wrapped around neck.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Supervise children carefully and do not allow them to wrap model around neck.

Call first aider in case of accident

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Stretched intestines

Description: Risk of tripping and falling if child runs across room to stretch the intestine out (especially if stopped suddenly by reaching the end of the intestine); risk of other people tripping on stretched intestines.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Supervise children carefully, only allow them to walk (not run) across the room and do not allow it at all if there is insufficient space or the room is busy.

Call first aider in case of accident

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Plastic ball

Description: Risk of tripping on escaped plastic ball

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Only have one ball out at a time and keep an eye on where it is. Pick up ball if it falls on floor.

Call first aider in case of accident

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-05 - Ashley Smith (ashley.smith@cantab.net), **Check 2**: 2012-01-25 - Daniel Obute (rdo23@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-09 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-23 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-06 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-23 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-14 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2017-02-09 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-10 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-02-02 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-01-12 - Beatrix Huissoon (beh37@cam.ac.uk), **Check 2**: 2020-01-27 - Samuel Amey (sra44@cam.ac.uk)

Check 1: 2021-01-07 - Jennifer Simpson (jks61@cam.ac.uk), **Check 2**: 2021-01-20 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-02-09 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2023-01-22 - Emily Wolfenden (elw74@cam.ac.uk), **Check 2**: 2023-01-30 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-15 - John Leung (cfl35@cam.ac.uk),**Check 2**: 2024-02-15 - Isobel Gilham (ig419@cam.ac.uk)

Hand Model

Large working model of a hand and forearm, with all the tendons to show how a hand works. - Take control of an *enormous* hand, playing the part of the muscles that control it! Can you work out how to make a fist? Why are there tendons running down both sides of the fingers? And exactly how are your thumbs different to your fingers?

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- Working hand model (“Emily”).
- Short lengths of string (optional)
- Small Paper Hand (stored in wallet attached to box)

Experiment Explanation

This experiment is a bit of a crowd-pleaser. There is a subtle technique of keeping kids’ fingers out of the wooden joints, and after this has been achieved, all ages will be amused by playing with it.

Explanation

1. Guess what the model is of – nice and easy start!
2. Ask what do the pieces of wood represent = bones, and where in the body they are.
3. Talk about moving your fingers, and ask what in the body moves them = muscles (after several shouts of veins, ARGH!!), then where are the muscles that move your fingers = forearm not in the hand, and the fact the muscle belly mostly ends quite before the wrist. You can get them to wiggle their fingers and see if you can see the muscles moving in the forearm, but not above the elbow (this is often more visible on demonstrator/parent than child!)
4. Leads onto the fact that muscles are in forearm, but need to join onto fingers in order to move them – how? Gives off strings that run along fingers and attaches to the bones (show on model) – what are the strings called? = tendons (after more shouts of veins!!). So, to move, muscles contract (tighten up/become shorter), and pull the tendons, which pull the bones.
5. Then let them play around a bit – I usually get them to pick a pink string (but avoid thumb for now), and then a purple string, and see the difference between them. Pink string goes all the way to the end bone, so can bend the end joint, whereas purple string can’t because it doesn’t attach to the end bone.
6. Get them to bend all the fingers (tests if they’ve remembered which strings bend the fingers).
7. Then ask how to make the fingers straight again. Most will try to push the pink/purple strings – tell them that doesn’t work because muscles can only pull. Get them to look at fingers closely and spot any other strings. Eventually they’ll realise to pull the green/blue strings.
8. Ask them why green/blue strings makes the fingers straight. If they struggle, get them to see the difference between pink/purple and green/blue = different sides of the hand. Therefore muscles on front of arm (flexors) pull pink/purple

tendons on that side, which flex the joints, and vice versa with other side with the extensors.

9. So, all around the body, muscles work in pairs to do opposite actions. Point out biceps on you and say it bends the elbow, then ask where the muscle will be to make it straight = on the other side, triceps.
10. Then ask what's telling the muscles to contract and pull the tendons = brain. And how = send messages = nerves, and briefly explain concept of nerves sending messages.
11. I usually end by saying that to play the piano for example, or type on a keyboard, your fingers have got to move in lots of different ways, so your brain has got to send all those messages in the right order to the right muscles, to pull on the right tendons. So, it's actually really complicated just to move your fingers.

Thumbs

The yellow string pulls the thumb across the palm. You can use this to talk about how thumbs can move in an additional special way so you can pinch things - show them how you can oppose the pads of your thumb and fingers, but not of your fingers. They may have heard of opposable thumbs - some will tell you the word, others will recognise it. You can talk about different animals not having opposable thumbs and thus not being able to use tools etc.

If you've got the short (c. 6 inches) lengths of cord, you can challenge them to tie a simple knot in one. When they triumphantly present you with the resultant knot, get them to do it again without using their thumbs (police this vigilantly, people cheat without even noticing!). Usually this is much much harder. If somehow they do it easily, tell them to undo it without their thumbs. This is more challenging!

General stuff

– Useful to refer to your own or their hand while describing stuff, for example show the extensor tendons on the back of your hand (they're a lot easier to see in adults than on themselves). Get them to feel the muscles working on themselves or on you. Do this by getting them to place their whole hand over their arm (both sides!) and then wiggling their fingers! Then they have to believe you!

- This can be a good experiment to do with really quite small kids, but keep it nice and simple with them (i.e. I wouldn't bother talking about tendons, just say 'stringy like things that pull on our bones to make them move'!)

- This is a great "How-Science-Works" experiment even if you don't know the biology. Ask about how we can find out about how our hands work, we have hands so look how they work. We can feel muscles moving and see tendons. We can get an X-Ray to see the bones, an ultrasound gives us more information on muscles. We can do a dissection too. Then we build a model to test our theory. The paper model is a nice simple model, what can't we do with it? We don't have as much movement, bones aren't as accurate, make the wooden model with more motion.

Additional stuff:

1. Carpal tunnel syndrome:

- Carpal ligament bridges wrist bones, making a small tunnel for nerves and tendons to go through.
- Median nerve goes through – sensation to most of hand (not little finger), and muscle control of some thumb muscles.
- Compression of tunnel walls (due to repeated wrist movements) or swelling (due to injury/arthritis), causes pressure on median nerve.
- Symptoms – aches, pins+needles, pain, numbness, loss of fine finger movements e.g. writing.
- Treatment - stretching exercises, anti-inflammatory drugs, surgery (cut carpal ligament = relieve pressure).

2. Difference between ligaments and tendons

- Explain that a joint is where 2 bones come together and they can move. But the bones need something to hold them in place, this is what ligaments do, connect bones to other bones. Tendons connect muscles to bones so they can move the joints.

Risk Assessment

Hazard: Joints

Description: Finger traps.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Do not allow the kids to touch the hand itself when someone is pulling the tendons.

Call a first aider in case of accident.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Wooden corners

Description: Splinter risk.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Hand is sanded and shaped to try to reduce this.

Call a first aider in the event of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Model (weight)

Description: Heavy model which moves easily when strings are pulled.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 1, Overall: 4

Mitigation: Do not let the people pulling the tendons get too violent. Hold on to the model to prevent it from sliding along the desk, or place it on the floor if possible.

Ensure kids are behaving sensibly. Inform people to be away from the hand model while someone is pulling the tendons.

Call first aider in case of injury.

After Mitigation: Likelihood: 3, Severity: 1, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-05 - Ashley Smith (ashley.smith@cantab.net), **Check 2**: 2012-01-25 - Daniel Obute (rdo23@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-17 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-23 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-06 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-09 - Kym Neil (kym.e.neil@gmail.com)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-07 - Natalie Cree (nc434@cam.ac.uk)

Check 1: 2017-02-09 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-10 - Jessica Gorman (jrg63@cam.ac.uk)

Check 1: 2018-01-27 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2019-01-24 - Jennifer Simpson (jks61@cam.ac.uk), **Check 2**: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-07 - Samuel Amey (sra44@cam.ac.uk), **Check 2**: 2021-01-22 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-01-26 - Hayoung Choi (hc585@cam.ac.uk), **Check 2**: 2022-02-09 - Sian Boughton (seb216@cam.ac.uk)

Check 1: 2023-01-20 - Emily Wolfenden (elw74@cam.ac.uk), **Check 2**: 2023-01-20 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

You could ask the kids to think of something powered by hot air (many get it straight away, some need a remarkable amount of prompting and loads say aeroplane…).

To make a balloon fly:* Put the cardboard shield around the toaster, it's easiest if you turn it on first. - Put the bag over the shield, pull it all of the way down to the bottom (or, hold on to the top, and hold it about as high as possible - this way the top of the balloon is further from the heat source and less likely to melt and deform). - Let the air inside heat up and off it goes.

You can get sensible kids to do this themselves.

PLEASE TRY TO SET THE EXPERIMENT UP TO AVOID OVERHEAD STRUCTURES SUCH AS LIGHTING RIGS

Things to talk about include:* What is at the bottom of a hot air balloon? Aside from the basket with people in, there is a burner that heats the air, and gives it more energy. - Pretend that the bag is air tight (actually not far off being true, very little air escapes out the bottom), thus it only has a finite amount of air in it, which initially weighs the same as all the surrounding air. When heated the gas expands, which can be seen as the balloon puffs up slightly (although the effect is subtle sometimes) and hence there is the same amount of weight spread over more volume, so each "bit" of air i.e. fixed volume element, weighs less than it did before, thus less than the surrounding air and the balloon experiences buoyancy (you could use an analogy about the difference between a sponge and a brick of similar sizes dropped in the bath and say that if you expand the brick it would become more like a sponge). - Now pretend like air is lost. Where does the air go when it expands? It fills up the bag then escapes out the bottom. This makes the bag lighter, so it floats up to the ceiling. N.b. either explanation works, the first is more thorough but the second may be more intuitive especially for younger children. They are both in part true, though the first is probably dominant. If they all say "it rises", you can explain that we're trying to understand why it rises, or hold the bag down and say that it can't be rising because there's a bag in the way! - Get them to make a prediction for what will happen - it's usually a balance of the bag will explode or the bag will rise up - you can then test their competing scientific hypotheses! - Why do we have the bits of tape on the bottom? They are weights helping the bag go up in a straight line, if it gets tipped over sideways a bit then the weight pull it back straight again (hold the bag over your arm and tip it to demonstrate this). Some kids will know that real hot air balloons carry sand bags as ballast, this is more to help them control their height than to stop tipping, the weight of the basket/passengers is enough for this. You can try launching a bag without any weights, you should find that it tips over and falls back down quite quickly, though you need a relatively high ceiling to see this. Even with the weights, the bag often tips over with the opening at the top - here is a good chance to prove that the hot air is what gives it buoyancy (not the bag itself) because the bag quickly deflates (as the air can now rise out of the hole) and sinks back down. - How can we make it go higher/faster? Heat up the air more at the beginning by holding down the bag. Be a bit careful doing this, you can melt the plastic bag quite easily and it all gets quite hot. Different sizes of bag would be an option as well - some definitely fly better than others!

Further discussion:* What difference does the temperature of the room make? - Will the balloon stop going up? Would this balloon work in space, why not? What would happen as it approached space? (tip: as it rises density of surrounding air drops until the weight of displaced air = weight of balloon and it stops rising) - How does this relate to buoyancy in water? Can lead into some great discussions about how fish and submarines change depth (by expanding and contracting their volume, one way or the other)

*(We used to have a vacuum chamber as well as the spheres and bazooka, this allowed you to show that air does have some mass, so the bag does really get lighter when you lose some air, this will surprise most children and their parents. With good groups this is best done after the balloons, though less attentive children may lose interest once they've seen the exciting bit. Vacuums can however be used to start off the theory and lead into the idea of gas particles.)

Risk Assessment

Hazard: Heat

Description: Heat may cause burns from direct contact. Tube or crumbs may catch fire. Bin liners can be melted.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Make the tube out of card, which isn't very conductive and will not melt and stick to people. Use a cool-wall toaster which will therefore not get too hot. The tube should make it very difficult to put fingers in the hot parts of the toaster. The tube is supported so it can't fall over easily. Use a toaster that hasn't been used to toast bread so there are no crumbs. The card is white so will go brown before it burns - if it goes brown turn it off. If there are burning smells turn it off! Do not hold bin liner over toaster for longer than a few seconds or use multiple bags. In case of burns run under tepid water for at least 10 minutes. In case of fire, turn off electricity then follow procedure in venue RA (raise alarm, evacuate…) Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Toaster cable/electrical

Description: Electrical hazard and cables present a trip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Use a new or PAT tested toaster. Ensure cable is either positioned where people will not be walking or taped down. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Bin liner

Description: Risk of suffocation if it lands on a child's head.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Make sure spectators are not standing too close where the bag could land on their heads, and try to catch before it can land on them. Suspend experiment if the children are getting silly and trying to catch it with their heads. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2012-12-16 - Rachel Chapman (rc506@cam.ac.uk), **Check 2**: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2014-01-10 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-01-17 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-07 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-01-29 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-01 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-01 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-05 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2021-01-17 - Sian Boughton (seb216@cam.ac.uk), **Check 2**: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-22 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-01-28 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-12 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2024-01-06 - Lucy Bland (lb831@cam.ac.uk), **Check 2**: 2024-01-23 - Lauren Mason (llm34@cam.ac.uk)

Kiwi DNA

Breaking open cells of a kiwi fruit and making the DNA inside visible to the human eye - In this experiment we get DNA out of living cells in kiwi fruit. The DNA can be made fully visible to the human eye - no microscopes or magnifying glass needed! Done in less than 5 minutes in front of your eyes.

Last initially checked on 2024-02-04 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 Isobel Gilham (ig419@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **Electricity needed**
- *Consumables*: Kiwi fruit, salt, washing up liquid, 96% ethanol or 99% isopropanol (*caution*)
- *Equipment*: Slow cooker, plastic pint glasses, half rolling pin (for mashing), sieve, plastic champagne flutes, ice bucket, bowl (for liquid waste), cloths (it's generally messy), sharp knife (*caution*), chopping board, spoon/fork/cocktail stick/pipette, model of DNA, posters about DNA and proteins
- *NB. Ethanol/isopropanol need to be kept out of reach of children, as does the sharp knife. If possible, keep the knife and any spare alcohol in the box when demonstrating*

Experiment Explanation

Kiwi DNA repack for the 2011 Summer Roadshow

- Slow cooker, run on high for 30 mins in setup, then turn down to "warm" heat before visitors arrive.
- Stores box (small blue) has spares of most of the kit in the kiwi DNA box.
- Please use only 1-2 cm3 of ethanol/isopropanol per experiment to conserve our supplies for the whole roadshow. There are some plastic pipettes to help you with this.
- Poking the DNA at the end. As well as the cocktail sticks described in the main explanation we've now got some clear plastic cocktail stirrers, which are easier to get into the cocktail glasses when you're getting the DNA out.
- RNA model: in a plastic Tupperware tub in the main box, and new for 2010. Don't feel you have to use this, but if you want to talk about DNA being used as a template to make proteins it's a nice prop, and has the same colour coding.
- Laminated sheets: provide some useful images, and there's a wheel to show how DNA code is used to encode amino acids. Please try to dry these if they get damp during the day.
- DNA model in box. Roughly 1.4bn times bigger than real life (if my maths + memory is correct).

Overview

Breaking open the cells of a kiwi fruit to extract the DNA. You can demonstrate it to one family or a whole crowd as a show, discussing cells, DNA and proteins!

Tips for demonstrating:

- It's difficult for the audience to participate in the practical activities, so it's more of an interactive show with lots of questions and answers.
- Do the preparation work before the audience arrives! I work the experiment as a continuous process and maybe use five kiwis in the day.
- Be aware that young children won't know a lot of science. For instance, don't assume they know about cells (most don't), they know about humans being animals and that plants and animals have a lot in common. They might not even have reached the stage where they relate the idea of parts of the body having different structures and functions.

Preparation

You need to have:

- Isopropanol or ethanol on ice (as it works best when cold). If no ice is available, isopropanol seems to work better at room temperature than ethanol.
- Water bath heated to "warm"
- Use masking tape or similar to divide the water bath into pint-glass sized sections so that the glasses don't fall over when you put them in the water bath
- A kiwi or two peeled and cut into 1 cm chunks
- A bottle of lysis buffer - contains washing up liquid, salt and water. As a general guide, in a bottle, put about 1/8 volume salt and dissolve in 3/4 bottle of warm water, then top up with washing up liquid and invert a few times to mix. You don't want it particularly thick, so err on the side of less washing up liquid - you can always add more.

Basic procedure and explanation

The steps of the experiment are below in bold, with an example way of talking through the experiment for younger children. It includes questions and answers (of course if you get the right answer modify your reply). Try and use simple words and up the language as you deal with older kids or adults. You can use this experiment as a basis for talking about scale, with respect to cells and molecules and also as a basis for discussing what DNA does, and how similar our DNA is to kiwis (>50%).

You may want to have some mashed DNA in lysis buffer incubating, and use that rather than the one the group with you has prepared as it takes a while for the cells to lyse. Preparing a couple before you begin demonstrating also means you can check the lysis buffer is ok.

Do you know what this is? It's a kiwi fruit. And what's a kiwi fruit made out of? (you'll probably get seeds, flesh, skin types suggestions)

What are all living things made out of? If I scratch my nail across this what do I have under my finger nail? Cells. *Just as a house is made out of bricks every living thing is made out of cells but they're very small*. There are different cells in the flesh to what there are in the seeds or in the skin and in you their are hundreds of types of cell. Different types of cells in your eyes, blood, brain and skin too.

First what I want you to do for me is mash up some kiwi fruit.

Add a lump of Kiwi to a plastic cup and get them to mash it with the rolling pin (gently!). You can explain that what they're doing is like demolishing a house, all you've got left is a pile of bricks.

Now what I'm going to add is some washing up liquid.

Add lysis buffer to the cup containing the kiwi to a depth of about 1cm and put the cup in the water bath. You can ask: what does washing up liquid do? (You'll probably get "it makes bubbles" at this stage!) What do you use it for? Cleaning plates. Well what does it take off the plates? The grease and fat. It does this by dissolving the fat: this is like what happens when sugar or salt disappears into water. A cell is basically a bag full of water and other important things like DNA, and the bag is made from fat so the washing up liquid dissolves and breaks up the material the bag is made from (the cell membrane). This releases everything that is inside.

What do you know about DNA? Discuss! DNA is like the plans for building us. Just like you need plans for building a hospital. But if you build a hospital it's useless unless you know how to build the doctors, nurses and beds inside them and the doctors and nurses know what to do. So it's not just the plans for building you it's also the instructions for how you should be run. Alternatively, DNA could be like an instruction manual for how to build a person (or kiwi), and there is some inside almost every cell in our body and every cell in the kiwi. What we're going to do is we're going to take the DNA from the kiwi fruit.

Take the kiwi mush/lysis buffer mix out of the water bath. So this liquid here is full of DNA.

Pour the liquid from the cup into a plastic flute through a sieve to remove the lumps. We need to separate the DNA from everything else in the mixture.

Get out the alcohol and pass it around the noses present, taking care to keep control of it. What does that smell like? (kids often recognise it as hand gel) It's not water, it's pure alcohol. I emphasize this as children commonly think anything that is liquid has water in it.

Using a pipette, put about two pipettes-full of isopropanol into the glass by pouring it down the sides of the glass so it doesn't mix too much with the rest of the mixture and forms a layer on the top. Show the glass around. What you can see here are two layers, the green layer is the water with the DNA in and the clear layer is the alcohol layer.**Now do alcohol and water mix? Sure they do. Because if you look at a bottle of whiskey or beer there's only one layer there. So what's happening is the water is moving up into the alcohol layer and the alcohol is moving down into the water layer *wibble your fingers about* and the two are mixing.

The DNA is the stringy white stuff that collects between the two layers. Can you see anything appearing between the two layers? Some stringy white stuff forming? That's the DNA. It takes a while to see this sometimes, so you can either show them a previous group's glass or pick up some of the bottom layer with a pipette and slowly release it through the top layer. It's helpful to have a few really good examples lying around to show "one that we made earlier", to make sure that they see the DNA even if the experiment didn't work for them.

Possible discussion points:

Now what I'm going to do is try and pick up a single molecule of DNA. (showman mode, on the end of a spoon I fish a little bit out.) What's the largest number you can think of? Because what i have here on the end of this spoon is billions molecules of DNA. Just as the Kiwi is made up of the bricks we call cells the cells are made up of molecules.

So how big do you think one of these molecules is? It's about a millionth of a millimetre across. But because DNA is an especially long molecule it's a metre long. Now what I want you to do is use your imagination and I'm going to pick up one molecule of DNA *pretend to pick up a very thin strand and pass it to a child to hold and stretch it out to about a metre*

Now this is a molecule of kiwi DNA and if we use your imagination again I can pick up a molecule of your DNA and that's about a metre long too. Now in your right hand we've got a molecule of kiwi DNA, this is the instructions on how to build and run a kiwi and in your left hand we have your DNA which is the instructions on how to build and run you. Now how similar do you think these two are.

How much is the same? (Sweepstake the entire audience) About 85cm is the same (alternatively 85% the same), that's this much. (Mark out 85 cm and you've got around percentages!)

That's because both you and the kiwi are made up of cells and the cells in the kiwi do the same sort of thing as the cells inside of you. They make more cells, they use sugar and oxygen to make energy and use protein and fat. So who do you think is the most similar person in the worl to you? It's your brother or sister, not your mum or your dad. Which is why you've got to look after you're little brother as they're the most similar person in the world to you. You're all but a tenth of milimeter the same as you're brother or sister and you're all but about millimetre the same as anyone else in this room. You're all but 2 cm different from a chimpanzee. Which is why I think we should look after everything in this world as we're really not very different from anything else.**

Risk Assessment

Hazard: Ethanol/isopropanol

Description: Irritant, flammable, and very toxic if ingested

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Only have a small amount of ethanol/isopropanol out, away from naked flames AND THE PUBLIC. Avoid contact with skin and eyes. Do not ingest. Only allow parents and children to mash kiwi on its own - not once mixed with detergent or ethanol/isopropanol. Ensure eyewash is nearby and that you know the location of it. In case of contact, wash off skin. Use eyewash to wash out of eyes if trained and confident to do so, and call first aider. If ingested call first aider immediately.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Water bath

Description: Hot water can scald; electric shocks possible if broken.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Maintain the water bath at 60°C out of reach of children. In case of burns, run tepid water over affected area for at least 10 mins. Call first aider. Ensure has passed PAT test in last 2 years. Ensure cables are taped to the ground/table to reduce risk of person tripping on/pulling the cables. Refer also to the Electrical Parts RA.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Glassware and plastic containers

Description: If broken can cause cuts.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Dispose safely of any broken glassware immediately. Keep spares out of reach. Check plastic container and ethanol/isopropanol are compatible. First aider to be summoned in the event of an accident.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Kiwi/detergent solution

Description: Solution is harmful, especially if splashed into the eyes.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Do not allow children to mash the kiwi once it has been mixed with detergent or ethanol/isopropanol. Keep all mixtures within demonstrator's reach. Avoid contact with eyes or the mouth. Try to work on a surface which is not at eye level. Demonstrator can show children how to mash the kiwi without splashing kiwi everywhere. If any does splash out of the container, clean up immediately. Know the location of the nearest eyewash. In case of contact with eyes, use eyewash to wash out of eyes if trained and confident to do so and call first aider. If ingested call first aider immediately.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Sharp knife

Description: Possible cuts/other injuries.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Supervised use only. Keep sharp knives away from children. It's impractical to cut all the kiwi beforehand, but after cutting fresh kiwi, keep the knife in the pencil case provided and keep this in a drawer/out of sight. First aider to be summoned in the event of an accident.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Wet surfaces

Description: Slip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Wipe up any spills. Use wet floor sign if necessary. Keep experiments away from electrics. First aider to be summoned in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Kiwi fruit

Description: Small risk of allergic reaction to kiwi fruit in a small minority of people, and potential consequent anaphylactic shock.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Demonstrator to check that visitors are not allergic to kiwi fruit before commencing the experiment. In case of contact, call first aider. Rinse skin with clean water.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Small parts

Description: Small pieces in model may present choking hazard.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep model completely assembled and prevent children taking it apart. Keep the black stopper on top of the stand as this prevents the rest being disassembled. If child ingests small part of model, call first aider immediately.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2012-01-17 - Michael Darling (md510@cam.ac.uk), **Check 2**: 2012-01-24 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2012-12-24 - Beatrice Tyrrell (bet23@cam.ac.uk), **Check 2**: 2012-12-30 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2013-12-25 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk), **Check 2**: 2014-01-01 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2015-01-06 - Kym Neil (kym.e.neil@gmail.com), **Check 2**: 2015-01-11 - Arporn Wangwiwatsin (Koi) (aw584@cantab.net)

Check 1: 2015-12-28 - Natalie Cree (nc434@cam.ac.uk), **Check 2**: 2016-02-02 - Jiali Gao (jg732@cam.ac.uk)

Check 1: 2017-02-08 - Alfred Chia (ac939@cam.ac.uk), **Check 2**: 2017-02-09 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2018-02-02 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk), **Check 2**: 2018-02-07 - Sarah Wiseman (sw628@cam.ac.uk)

Check 1: 2019-01-12 - Amanda Buckingham (abb53@cam.ac.uk), **Check 2**: 2019-01-14 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2020-01-23 - Holly Smith (hs606@cam.ac.uk), **Check 2**: 2020-01-25 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-22 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2022-02-26 - Hayoung Choi (hc585@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-02-10 - Amy Migunda (aom36@cam.ac.uk), **Check 2**: 2023-02-11 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-02-04 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Isobel Gilham (ig419@cam.ac.uk)

Lenz’s Law

What happens when we drop a magnet through a pipe? - What happens when we drop a magnet through a pipe? Experiment with dropping them through perspex and metal pipes and see if there’s any differences.

Last initially checked on 2024-02-15 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Lauren Mason (llm34@cam.ac.uk)

Tags

Busking

Floating

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

Note that the equipment for this experiment is stored in the Electromagnetism box

- Perspex Pipe
- Copper Pipe
- (We don’t have but an aluminium pipe would also be useful)
- Some small magnets
- Green Iron Filling Paper

Experiment Explanation

Lives in Electromagnetism Box.

Get a volunteer to hold the pipe and challenge them to put the magnet in it and catch it as it comes out. If you’ve got a group ask them if they’d like the copper or perspex pipe, the copper pipe is the much better choice as it means you’ll have more time.

This is because the moving magnet is inducing an electrical current in the metal. There are two ways to explain why this causes it to slow down:

Easier - Some energy is needed to make the electrical current (like turning the handle before). This time the energy comes from the falling magnet, and when it loses kinetic energy it slows down.

Harder - Eddy currents of electricity are formed, and these create an electromagnetic effect opposing the motion of the magnet, hence it slows down.

There is also green ‘iron filing’ paper, which shows up the movement of a magnet through it. You can use this to ‘see’ the movement of the magnet inside the copper pipe.

People may say it’s to do with the metal being magnetic, but it’s really not. Copper is not magnetic, try sticking the magnet to the outside of the tube and it won’t.

Risk Assessment

Hazard: Magnets

Description: Magnets shattering, possibly causing cuts/splinters.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Warn visitors if you give them a magnet. Use the minimum number of free magnets. Keep the magnets under control. Cover with tape to reduce impact, and contain any shards. Pad edges of magnet to reduce finger trap.

Call first aider in case of injury

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Magnets

Description: Magnets that are not caught may be a trip hazard or encourage children to dive after them

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Recover magnets quickly but sensibly.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Small Magnets

Description: Magnets are small and may be a choking hazard for young children.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: Magnet is wrapped up to make it larger. Do not let young children handle magnets. Keep hold of magnets and pick them up quickly.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Pipes

Description: Any pipe hitting people in face/eye.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Demonstrator should hold pipe for younger children and monitor use for others.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2018-12-12 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-30 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-30 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-31 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2021-01-03 - Holly Smith (hs606@cam.ac.uk)

Check 1: 2022-02-05 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-13 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-02-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Lauren Mason (llm34@cam.ac.uk)

Life Cycles

Perpex blocks with specimens of frogs and bees from different lifecycle stages. - Ever wondered what happened to a creature between it being an egg and an adult? Look at our life cycles collection for Bees and Frogs and see for yourself!

Last initially checked on 2024-02-15 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Sets of preserved life cycles of frogs and bees.
- Honeybee - egg, larvae, and pupa; worker bee, drone, and queen bee; pollen, honey, and royal jelly; foundation honeycomb, drone cells, and queen cell; worker bees collecting nectar
- Frog - eggs, tadpole, various stages from tadpole to frog, adult, magnifying glass
- Beeswax candle set

Experiment Explanation

*** OVERVIEW/THINGS YOU MIGHT LIKE TO TALK ABOUT ***

- The life cycles of frogs and bees. Can use butterfly life cycles as an introduction for younger kids as they should know about this.
- Social structure of bee colonies and communication amongst bees.
- Using stages of insect development to "date" a decomposing corpse.

*** BASIC PROCEDURE AND EXPLANATION ***

1. Let them pick which life cycle they want to look at first. Ask if they know what animal it is.

2. Tell them the blocks show the lifecyle of the animal. Explain the concept of lifecycles i.e. that animals change throughout their lives and then the adult can reproduce to start the cycle again.

3. Ask the child to put the blocks in the correct order. Talk them through it when they're done. The blocks were numbered so stickers have been put over these to stop the kids using this. The frog order goes red, yellow, blue, orange, blue, yellow, green. The bee box should have a sheet explaining what is in each block.

4. Start by describing the egg. This is one cell (a tiny ball of nutrient and information (DNA)) which divides lots and lots of times to produce larvae.

5. Next discuss the larvae/tadpole. Emphasize how the larvae spends all its time eating and eating and eating so it can grow really fast and store energy for metamorphosis!

6. Explain the pupae stage for the bee - at this point the larvae undergoes metamorphosis and becomes an adult! What is

metamorphosis? It refers to something changing from one form to another completely new form. Isn't it amazing that the larval form can change into the adult form in just about two weeks?!

7. After you've finished explaining the life cycle of the animal, you might ask the child if humans go through metamorphosis. Explain that while humans don't go through metamorphosis, we do change a lot in our mummy's tummy! We also go from an egg (one tiny cell smaller than the full stop at the end of this sentence) which divides lots of times to create a baby!

*** EXTRA INFO ***

BEES

Larvae -> Pupae -> Worker/Queen 1) Social Structure of Bees (http://www.indianchild.com/honey_bee.htm) - Each bee colony has a very organized social structure. - Bees tell each other where food is through different dances - call these waggle dances Males/drones: - Develop from unfertilized eggs (parthenogenesis) - means females can produce as many males as they want to (as don't have to mate with male first) - Mate with queen to produce new bees Worker bees; - Develops from fertilized eggs - Jobs like clean/ incubate eggs/feed drones and larvae/guard hive/find food Female bee: Queen - Develops from fertilized eggs - Lays eggs, mother to all bees in the colony. ~2000 eggs/day - Produces pheromones which controls the behavior of her workers - Fed lots of food! Fed royal jelly from larvae rather than normal honey which has epigenetic factors which cause it to develop into a Queen rather than a worker.

2. Communication Among Bees (http://www.indianchild.com/honey_bee.htm)

- Bees communicate by pheromones (chemicals produced by the queen that the other bees "smell") and dances.
- This communication is very important to maintain the organization/social structure within the colony so that all of the bees can survive (the queen, workers, and drones cannot live alone - they depend on each member of the colony).
- Dancing - round dance, go in a circle and waggle in the direction of food is in (long distance). Waggle dance, food is nearby direction of run indicates direction and length of waggle shows how far.
- Stingers - die after they've stung as pulls organs with it. (different in wasps)

Honey. Why do they make it? What from? Uses nectar to feed larvae. Honeycomb, useful to farmers as pollinators.

FROGS 1) Egg -> Frogspawn -> Tadpoles -> Frogs

2. Frogspawn is like jelly, provides a food source for the growing embryo (the black spot)

3. Tadpoles - sometimes eat each other (cannibalism). They start with no legs, then develop hind legs, then front. Then become froglets.

4. Tree frogs; where do they lay their eggs? - in the water collected at the bases of leaves. Are often brightly coloured and very poisonous (used to make poison arrows). The Golden Tree Frog is toxic enough to kill 20 people or two elephants, chickens and dogs have died from touching paper that has been touched by a frog! Poison stops nerve impulses leading to muscle contraction.

Amphibian, need to stay damp as they breathe through their skin. They're vertebrates and have a backbone.

BUTTERFLIES Ova -> Larvae -> Pupae -> Adult 1) Patterns/colouration - eye spots deflect attack from the butterfly's body, camouflage is another way of increasing the likelihood of survival allowing it to rest undetected

3. Forensic Entomology: (http://www.forensicentomology.com/appear.htm)

- Forensic Entomology examines the stages of development of insects in a decaying corpse to determine when the body died!
- For example, many insects will lay eggs on a corpse. These eggs will hatch and become larvae, which feed on the decaying corpse. By examining the size/weight of the larvae, these scientists can determine how old the corpse is!

Caterpillars can be poisonous and brightly coloured to warn predators. Some butterflies only live a couple of weeks. Monarch butterflies migrate from Canada to Mexico (3000 miles) using landscape (mountains/sun) to navigate. Some moths use earth's magnetic field. Some eat plants like milkweed which make them poisonous to other animals.

*** SCIENCE BACKGROUND FOR DEMONSTRATORS ***

More information on Forensic Entomology (http://www.forensicentomology.com/appear.htm) "What information can a forensic entomologist provide at the death scene?"

Forensic entomologists are most commonly called upon to determine the postmortem interval or "time since death" in homicide investigations. The forensic entomologist can use a number of different techniques including species succession, larval weight, larval length, and a more technical method known as the accumulated degree hour technique which can be very precise if the necessary data is available. A qualified forensic entomologist can also make inferences as to possible postmortem movement of a corpse. Some flies prefer specific habitats such as a distinct preference for laying their eggs in an outdoor or indoor environment. Flies can also exhibit preferences for carcasses in shade or sunlit conditions of the outdoor environment. Therefore, a corpse that is recovered indoors with the eggs or larvae of flies that typically inhabit sunny outdoor locations would indicate that someone returned to the scene of the crime to move and attempt to conceal the body.

Similarly, freezing or wrapping of the body may be indicated by an altered species succession of insects on the body. Anything that may have prevented the insects from laying eggs in their normal time frame will alter both the sequence of species and their typical colonization time. This alteration of the normal insect succession and fauna should be noticeable to the forensic entomologists if they are familiar with what would normally be recovered from a body in a particular environmental habitat or geographical location. The complete absence of insects would suggest clues as to the sequence of postmortem events as the body was probably either frozen, sealed in a tightly closed container, or buried very deeply.

Entomological evidence can also help determine the circumstances of abuse and rape. Victims that are incapacitated (bound, drugged, or otherwise helpless) often have associated fecal and urine soaked clothes or bed dressings. Such material will attract certain species of flies that otherwise would not be recovered. Their presence can yield many clues to both antemortem and postmortem circumstances of the crime. Currently, it is now possible to use DNA technology not only to help determine insect species, but to recover and identify the blood meals taken by blood feeding insects. The DNA of human blood can be recovered from the digestive tract of an insect that has fed on an individual. The presence of their DNA within the insect can place suspects at a known location within a definable period of time and recovery of the victims' blood can also create a link between perpetrator and suspect.

The insects recovered from decomposing human remains can be a valuable tool for toxicological analysis. The voracious appetite of the insects on corpses can quickly strip the remains down to the bones. In a short period of time the fluids (blood and urine) and soft tissues needed for toxicological analysis disappear. However, it is possible to recover the insect larvae and run standard toxicological analyses on them as you would human tissue. Toxicological analysis can be successful on insect larvae because their tissues assimilate drugs and toxins that accumulated in human tissue prior to death."

Risk Assessment

Hazard: Breaking the blocks/jar/magnifying glass

Description: Smashing a specimen block/jar or magnifying glass could cause cuts.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: It is very unlikely that the perspex blocks would break, even with a significant amount of force. However, demonstrators should keep a careful eye on the blocks and jars and magnifying glass, account for all specimen tubes every time a demonstration is completed. Call first aider in case of injury (cut). Clear up perspex (using the dustpan and brush from Set Up and Clear Up), wrapping up in paper or similar so that it won't rip through the bin bag. Place in broken glass box if available at a school. In case of injury, call first aider.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Tripping over blocks

Description: Blocks are quite small and their transparency means that it might be difficult to see them, creating a potential tripping hazard.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Demonstrators should make sure that blocks are not played with by young children without supervision. If a block is dropped, it should be picked back up as soon as the area is safe to do so. In case of a child (or adult) tripping over, call first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Perspex blocks

Description: Kids may throw them or drop them on feet

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Take away from kids if they are being silly with them.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Magnifying Glass

Description: Kids (or demonstrators!) may set fire to paper or dry grass if very sunny day.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Take away from kids (and scold demonstrators) if they are deliberately trying to set fire to things

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-17 - Michael Darling (md510@cam.ac.uk), **Check 2**: 2012-01-24 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2012-12-28 - Beatrice Tyrrell (bet23@cam.ac.uk), **Check 2**: 2012-12-30 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2013-12-25 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk), **Check 2**: 2014-02-02 - Raghd Rostom (rr415@cam.ac.uk)

Check 1: 2015-01-05 - Arporn Wangwiwatsin (Koi) (aw584@cantab.net), **Check 2**: 2015-01-23 - Zephyr Penoyre (jp576@cam.ac.uk)

Check 1: 2016-01-07 - Natalie Cree (nc434@cam.ac.uk), **Check 2**: 2016-01-24 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2017-01-13 - Alfred Chia (ac939@cam.ac.uk), **Check 2**: 2017-02-09 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2018-01-08 - Gemma Shaw (gcs33@cam.ac.uk), **Check 2**: 2018-02-02 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2019-01-13 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-01-13 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-25 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-22 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-02-01 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-02-05 - Chiara Delpiano Cordeiro (cd796@cam.ac.uk), **Check 2**: 2023-02-06 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2024-02-15 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Mechanical Advantage

Using pulleys and levers to explore mechanical advantage - Check out this huge tripod with weights and pulleys, then try using pulleys and levers to explore the idea of "mechanical advantage"

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-30-01 by Lucy Bland (lb831@cam.ac.uk).

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Engineering

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **This experiment can take place outdoors**
- Tripod
- Various pulleys
- Water weights in bag

Experiment Explanation

Here is a hopefully not too ropey write-up of what is an awesome experiment (I hope you won't string me up with all these puns)! You start with the contraption up and the bag containing 4 filled 2 litre water bottles out loose

(NB: At the moment there are currently only 3 bottles)

The bag

First, get the kids try and lift the bag, and then like a Christmas turkey get them to guess the weight. Wild guesses will ensue. Tell them there are 4x2L bottles in the bag. Ask them how heavy 1L of water is. (Wild guesses). Tell them that 1kg = 1L of water. Then get them to tell you how heavy the bag is (4x2=8 is surprisingly difficult). 8kg of weight is how heavy the bag is (or 80N downwards), so how much force do you need to apply to lift it slowly? Just over 8kg worth of weight (or 80N). I think we have bagged that idea, let's move on. Maybe say that as far as you pull down, the bag lifts up, as it maybe is useful to say that at this point so they are thinking of it...

First Pulley

Put it on to the pulley that looks like the first picture in figure 1 (I know the diagram isn't great, but I am not artistic and was using paint). Ask them how much weight is pulling down (8kg/80N), then ask how much force you need to lift it up (just over 8kg/80N), then ask how much one rope must pull up to lift it (just over **8kg/80N**). Get all people to lift weight (try and get everyone to do it, so they appreciate the change in other pulley system). *Make sure you are holding on to the leg opposite pulley one, or else it will shift across the floor*.

Second Pulley

Move the bag on to pulley two. Before you get them to lift it ask how many ropes are there *(ensure the one you pull it with is pulled out to the side so they don't mistakenly count it – there should be two of them)*. Then ask them how much weight is pulling down (8kg/80N), then ask how much force you need to lift it up (just over 8kg/80N), then ask how much one rope must pull up to lift it (just over **4kg/40N**). Get all people to lift weight (try and get everyone to do it, so they appreciate it is easier to lift). Some may spot that you have to pull it twice the length to get it to lift the same amount of distance (don't worry if they don't yet).

Third Pulley

Move the bag on to pulley three. Before you get them to lift it ask how many ropes are there *(ensure the one you pull it with is pulled out to the side so they don't mistakenly count it)*. They will say 3 or 4 usually, so then say no and ask them to actually count. It is 5 taking the weight. Then ask them how much weight is pulling down (8kg/80N), then ask how much force you need to lift it up (just over 8kg/80N), then ask how much one rope must pull up to lift it (this is a bit trickier - just over **1.6kg/16N**). With the first person, ask them to hold the rope, and walk backwards, and keep on going, keep on going, keep on going. They realise now how much more rope you have to pull. Thus you can now discuss how to lift it the same distance, you must do the same work, so in total put in the same amount of force. Thus as the force is less, you have to go further (5x the distance). Get all people to lift weight (try and get everyone to do it, so they appreciate it is much easier to lift).

Closing Comments

Whilst everyone else is having a go at the Third Pulley, ask them if you had a very heavy weight, which system is better (some will say first here as you have less far to pull – this is incorrect as very heavy things you couldn't pull). The answer is three – easiest to do work. Therefore you use two and three to help you lift heavy weights. So what is the point of 1 then? Get lots of answers about how it is easier to carry, and you then point out to them that it doesn't change the weight they are carrying. What it does is that it changes the direction in which you are pulling, so you are pulling downwards. You can also ask them which system did they use the most energy while lifting. The answer is that it doesn't matter which one you use, you will expend the same amount of energy. This is because the height you lifted the weight through was the same for all three systems; it doesn't matter whether you pulled with a large force and moved the rope a small distance (first pulley), or whether you pulled with a small force but moved the rope a large distance (third pulley).

Appendix

You want more? You must be pulleying my leg. For advanced people, you can talk about why a pulley system with an odd number of pulleys may be beneficial (as in fig. 3) as it allows the user to pull down, using their weight to their advantage. With an even number (fig. 2) you'd have to pull up, which is harder. You may also want to explain uses of pulleys getting cargo out of ships etc… how would you use them to move a heavy weight horizontally, whilst keeping it off the floor (or out of the sea!)… you could talk about components here and forces pulling against each other etc.

Figure 1:

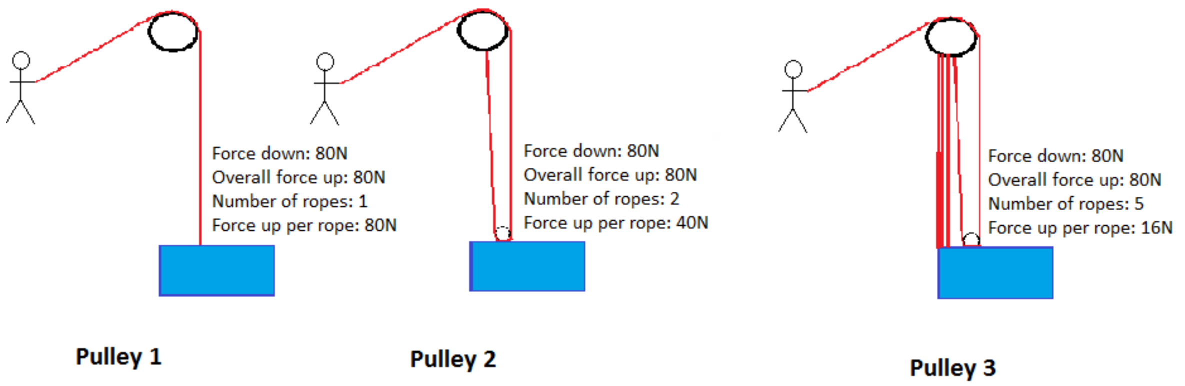


Figure 2:

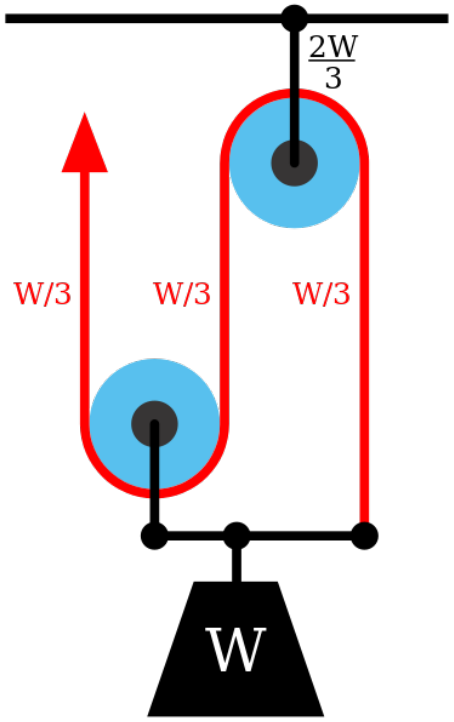
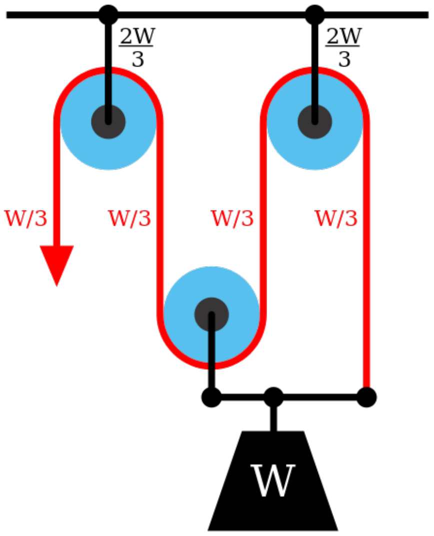


Figure 3:



Risk Assessment

Hazard: Pulleys

Description: Finger trap in pulley blocks / entanglement of ropes.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Ask children to hold on to the ends of ropes when pulling. Their hands should not come close to the pulleys. Demonstrator to maintain control of experiment. If the experiment must be left unattended in a public area the pulley blocks should be detached and stored safely, and the frame folded down. Verbal warning initially will draw attention to risk and so be preventative.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Frame

Description: Impact injury due to frame collapsing or sliding.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Frame is designed to be stable and far stronger than it needs to be, and should not collapse if correctly put up. It would, however, be possible for it to be pulled over by kids pulling hard on the ropes after raising the weight to its maximum height and pulling sideways, demonstrator should familiarise themselves with the stability of the frame so that they know what directions and forces might present a risk.

Demonstrator can lean/pull on the frame to counter these forces and prevent frame from sliding. Demonstrator to secure opposite leg to pulley in use. Ensure bolt at top is secure. Experiment should always be closely supervised when in use.

Ask a committee member to check that the frame is set up correctly every time after assembly.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Weights

Description: Injury due to weight dropping suddenly and hitting someone.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Water weights are used - intrinsically soft with no sharp edges. Demonstrator to inspect the ropes prior to use for signs of wear and replace as necessary. The ropes have soft stoppers on them (knots which get stuck at the pulley) so that the weight can't hit the ground. Also make sure small humans don't suddenly let go of the rope. Ensure people don't walk underneath frame.

Call a first aider in the event of an accident.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Weights

Description: Injury from people trying to pick up the heavy bag with a bent back.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: The weight isn't that much (6kg or so) in the first place. To mitigate, do not let small humans pick up the bag themselves. Hand it to them slowly. If you see them start to bend over (either pulled by the weight or otherwise), take the bag off them.

When picking it up, bend at the knees. Or if you must bend at the hips, make sure to keep your back straight.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Rope

Description: Rope burns if rope is allowed to slide through hands.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Ropes are relatively short, making it difficult for sufficient heating to cause burn to occur. Demonstrator to discourage audience members from running rope through hands. Demonstrator ready to hold onto rope or bag if necessary.

Call first aider if required.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Water in weights

Description: Water spillage from weights presents slip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Water weights should be double wrapped with translucent/transparent plastic, or bottle caps gaffered in place. Cloth/mop should be available to mop up spills. Situate experiment away from mains electricals where possible. If any electrical equipment may be affected make sure it is turned off.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Rope

Description: Rope lying across floor may be trip hazard.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Ensure rope does not lay across anywhere the public may walk.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk), **Check 2**: 2012-01-21 - Rosy Ansell (rosemary.a.r.hunt@gmail.com)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-18 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk)

Check 1: 2015-02-01 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2015-02-12 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2016-01-02 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-02-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2017-12-09 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-20 - Yaron Bernstein (yb258@cam.ac.uk), **Check 2**: 2019-01-30 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2019-12-29 - Käthe-Marie White (kmw54@cam.ac.uk), **Check 2**: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-06 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-01-14 - Johan Kidger (jpk51@cam.ac.uk), **Check 2**: 2023-01-15 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2023-03-22 - Timothy Wong (chw55@cam.ac.uk), **Check 2**:

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk), ** Check 2**: 2024-01-30 - Lucy Bland (lb831@cam.ac.uk)

Microbes: bacteria, viruses and parasites

Cuddly microbes to explain microbiology - Learn about the fascinating world of microbes with our fun cuddly toy bacteria, viruses and parasites, plus awesome slides and pictures. Now with added Covid-19! Use our cuddly poliovirus to learn how we can prevent and eradicate diseases!

Last initially checked on 2024-02-04 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Isobel Gilham (ig419@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- One large black box containing all types of microbes.

Experiment Explanation

Overview

We've put together three boxes to talk about microbes. This can be combined into one big experiment, or split into three separate ones. Please try to keep each type of microbe in its rightful box.

Bacteria box

In the box: - 9 x cuddly bacteria - 1 x cuddly penicillin bug (to talk about antibiotics) - 1 x cuddly yeast (to say that not all microbes are bacteria) - 1 x plate of plastic bacteria (E.coli) - 2 x bacteria viewers (look a bit like small microscopes) - 3 x slides sets for bacteria viewers - 1 x flask for growing bacteria - Packets of tools for growing bacteria - Laminated fact sheets for cuddly bacteria - Laminated instructions sheets for hand washing activity - UV hand wash cream (this is £15 per bottle, so use only minimum amount per group) - UV light for hand wash activity

If you want to do the hand wash activity you'll need a soap, warm water and bowl and some paper towels to dry hands on.

There are several things to do: lots of cuddly bacteria to talk about (everyone loves these), UV hand-washing experiment (good for younger kids) and bacteria viewers and lab props (better for older kids).

Stories you could tell: - How some bacteria are really good for us and others are bad (with the cuddly bacteria) - How you can pass on bacteria (good and bad) on your skin- see hand wash activity notes (good for younger kids) - How to grow bacteria in the lab (with lab props and slide viewers)

Element One: Cuddly Microbes

The following explanations are also found on laminated sheets in the box, and there is some additional information on labels attached to the cuddly bacteria:

1. ***E. coli (Escherichia coli)*: Gram negative, rod shaped** *SLIDE in microscope box* Found in the intestines of most mammals- it's there inside you only hours after you're born! There are lots of bacteria in our digestive system that are harmless to us – in fact they stop harmful bacteria from living and growing there instead. Sometimes E.coli can make us ill; some unusual strains produce toxins which can give us food poisoning. Biologists like *E. coli*: It's very easy to grow in the lab and can make lots of proteins and DNA very quickly.

2. ***Salmonella (Salmonella enterica)*: Gram negative, rod shaped** *SLIDE in microscope box* Can infect humans and animals, so sometimes infects people of food isn't cooked properly (particularly chicken or eggs). Causes gastroenteritis (diarrhoea and vomiting…) The bacterium itself can actually live inside certain types of white blood cell, which is a very effective way of hiding from the cells of the immune system that circulate in the blood.

3. **Typhoid Fever *(Salmonella typhimurium)*: Gram negative, rod shaped** Very closely related to the Salmonella bacteria that cause food poisoning. Typhoid fever is a lot worse than food poisoning however: its symptoms include a high fever, abdominal pain, a skin rash and headaches. Some people can be infected without having symptoms, but can still pass it to other people making them carriers of the disease. 'Typhoid Mary' (Mary Mallon) was the first recognised asymptomatic carrier and spread typhoid around New York in the early 1900s in her work as a cook, over 50 have fatalities have been linked to her. It is spread by drinking water or eating food contaminated with the bacterium. Typhoid fever is most common in India and its spread can be prevented by good hygiene.

4. **Diarrhoea (*Campylobacter jejuni*): Gram negative, spiral shaped** Most common cause of food poisoning in the UK, linked to handling raw chicken. It produces a toxin that kills certain human cells, which helps the bacteria to survive, without being attacked by the immune system.

5. **TB (*Mycobacterium tuberculosis*): 'Acid fast' will not gram stain** Infects the lungs when the bacterium is breathed in. Here it gets contained by the immune system in a tough shell. Only about 1 in 10 people who have the bacterium get ill: this usually happens when the immune system is weak and cannot contain the bacterium. The disease can cause damage to the lungs and in really bad cases it can spread to other parts of the body.

6. **Cholera (*Vibrio cholerae*): Gram negative, comma shaped** Usually spread when water is contaminated by the bacterium. Produces a toxin that stops you absorbing water through your intestines. This causes really bad diarrhoea, which can be fatal as you lose too much water and salt from your body.

7. **Listeria (*Listeria monocytogenes*): Gram positive, rod shaped** Causes fever and muscle pains. If the bacterium can get to the brain this can cause meningitis. Pregnant women are the most commonly infected – the mother usually gets a mild fever but the baby might be badly affected or born early. The source of the infection is often food – pasteurising dairy foods helps kill the bacteria and reduce the numbers of infections.

8. **Stomach Ache (*Shigella*): Gram negative, rod shaped** Very closely related to E. coli. When the bacterium is ingested it can get inside the cells of your intestine. It produces some toxins that can also make you ill.

9. **Yogurt (*Lactobacillus bulgaricus*): Gram positive, rod shaped** One of a number of species of bacteria that can be used to make yoghurt. What Wikipedia has to say about the use of *L. bulgaricus* in the manufacture of yoghurt: "Lactobacillus delbrueckii subsp. bulgaricus is commonly used alongside Streptococcus thermophilus as a starter for making yoghurt. The two species work in synergy, with L. bulgaricus producing amino acids from milk proteins, which are then used by S. thermophilus. Both species produce lactic acid, which gives yoghurt its tart flavour and acts as a preservative. The resulting decrease in pH also partially coagulates the milk proteins, such as casein, resulting in yoghurt's thickness. While fermenting milk, L. bulgaricus produces acetaldehyde, one of the main yoghurt aroma components. Some strains of bulgaricus also produce bacteriocins which kill undesired bacteria. It is often helpful to sufferers of lactose intolerance, whose digestive systems lack the enzymes to break down lactose to simpler sugars."

10. gonorea, syphilis, chalmydia

YEAST/FUNGUS (Yes, we know that they're not bacteria, but we'd found that people ask about antibiotics, so we think that they're a nice bonus to have in the box)

Penicillin (*Penicillium chrysogenum*)

This is a fungus that makes penicillin, an antibiotic that kills some types of bacteria. It does this to kill off the bacteria that are competing for the food it needs for growth, but we have used penicillin from this fungus to treat bacterial infections in humans.

Yeast for bread and beer

Also a kind of fungus. It's one cell, just like the bacteria, though the cell is much bigger. In bread the yeast can use the sugars in the dough for its growth; it breaks them down in a reaction that produces the gas carbon dioxide, which make the bread rise. In beer the yeast converts the sugars to alcohols.

Element Two: Growing Bacteria in the Lab

The kit: - 1 x plate of plastic bacteria (*E. coli*) - 1 x flask for growing bacteria - Packets of tools for growing bacteria

NB. The kit we have has not been used in a lab and the 'bacteria' on the plate are not real!

Under sterile (no other bacteria) conditions: 1) You can grow some types of bacteria in the lab. *E. coli* is happy to grow on agar plates, as long as it has all the nutrients it might need. The L-shaped spreader is used when you put the cells on the new plate, to make sure that the bacteria aren't too close together. 2) If you want more cells than this, get some bugs you're interested in with the green tool. 3) The plastic flask can be used to grow bacteria in a growth medium/ broth. (Extra detail: For *E. coli* you'd usually use Luria-Bertani medium (LB) at 37 degrees C to provide the necessary nutrients. This contains 10g Tryptone (enzymatically digested milk protein casein - supplies amino acids), 5g of Yeast Extract (supplies lots of nutrients), 1g glucose, 10g NaCl pH ~7.2, deionized, distilled water to 1 litre.)

Element three: bacteria viewers

The kit: - 2 x bacteria viewers (look a bit like small microscopes) - 3 x slides sets for bacteria viewers

These are essentially a more durable version of a set of slides and a microscope. In the set of slides (which come with a booklet for information) you can see various different shapes of bacteria - just like in the cuddly bugs: 1) Round (1= "coccus", 2+ = "cocci") 2) Rod (1= "baccilus", 2+ = "baccili") 3) Spiral

These shapes are determined by the cell wall (the tough outer layer) and the cytoskeleton (internal "scaffolding"). They matter because they affect how the cells can absorb nutrients from its environment, how they can attach to surfaces and how they're able to move.

Element four: Handwashing Activity

Why should we bother washing our hands? This activity uses glow in the dark stuff to show how easy it is to miss the bits of your hands where bacteria are…

The kit: - Laminated instructions sheets for hand washing activity - UV hand wash cream (this is £15 per bottle, so use only minimum amount per group) - UV light for hand wash activity *Also needs a bowl and paper towels that are not supplied in the box*

There is a set of laminated instructor notes in the box, taken from the Wellcome Trust. A full version can be viewed online here: http://www.yourgenome.org/downloads/pdf/teachers/handshake/handshake_tnotes.pdf

Essentially: - No hand washing: Form a 'line' around your group of children. Squirt UV cream on the first child's hand and get them to rub their hands together, then shake the hand of the next person in the group, then they shake the next person's hand… Shine the UV torch onto each of the kids' hands to show up the 'bacteria'. All should now wash their hands thoroughly. - Compare the results with hand washing: Repeat the procedure but get each person to wash their hands in the bowl after the UV cream has been rubbed in but before they shake the hand of the next person. - If the group activity isn't suitable, you could always compare before and after hand washing on the same child. - This should show that washing hands helps to remove microbes – and washing with soap does this better than with just water as the soap breaks down some of the natural oils on your hands that help the bacteria to stick. Look at where the bacteria were found – it's easier for bacteria to stay between our fingers and under our nails – and that's why it's important to wash your hands properly!

Viruses box

In this box: - 12 x cuddly viruses - 1 x plastic model HIV virus (in box) - microbiology text book

VIRUSES: Can be as simple as DNA or RNA in a protein coat. They use the cells of their host to make lots of new viruses. Often these new viruses get released by causing the cell to burst. Viruses can't survive for very long outside of cells so new viruses quickly find a new cell to infect.

HIV (Human Immunodeficiency Virus): Retrovirus (RNA genome copies itself into DNA, using viral reverse transcriptase. The DNA integrates into the host chromosome and new viral genomes are produced by host transcription/translation machinery)

Can be spread via some bodily fluids and blood. Lives in white blood cells (CD4+ helper T cells) and eventually kills them, which means the immune system cannot function properly. People where HIV has killed too many white blood cells have AIDS (acquired immune deficiency syndrome), and this means that they can become very ill or even die from diseases that would not harm a healthy person (opportunistic infections – a big killer is tuberculosis caused by *Mycobacterium tuberculosis* – cuddly bug in the bacteria box).

Common Cold (Rhinovirus): positive sense RNA

Spreads easily from infected people when they sneeze or contaminate surfaces. The virus is very happy at the temperature and conditions in the human nose which is where they initially infect. There are lots of different types of rhinovirus whose protein coats all look different to the immune system, which is why we don't get become immune to the common cold.

Measles (Morbillivirus): negative sense RNA virus

Usually spread by breathing in virus from droplets in the atmosphere. Causes a fever, rash and red eyes. Most people will have been vaccinated against this with the MMR jab, which mostly eradicated measles from the UK. However since the scare about the MMR jab (spuriously linked to autism), the disease has been cropping up in affluent areas of London! (Vaccine scares can destroy herd immunity, the protection the population has when enough people are vaccinated and the virus cannot find enough hosts to spread to.)

Kissing Disease (Epstein-Barr Virus): DNA virus

Most of you will have this virus right now. It is usually spread via saliva, causing a mild fever in the majority of the population in early childhood. (Lots of people have asked me why this is and the answer is we don't really know – scientists think it might be something to do with how the immune response develops over childhood.) However some people who don't get the virus in early life might get it when they come into contact with other people's saliva in their teenage years - they then get Glandular Fever. An interesting thing about the virus is that you never really get rid of it; some of its DNA forms little circles in the nucleus of the white blood cells it infects, and it can remain dormant (latent infection) for a long time (occasionally getting out into saliva but not making you ill). The virus that causes chicken pox can do this in nerve cells.

Influenza: Negative sense RNA virus

Infects almost all mammals (eg. swine flu, bird flu), aquatic birds are primary host. Common problem in humans - see most in winter when low air humidity allows the visus to spread more effectively. Spread by breathing in virus particles (Respiratory tract). Causes symptoms including fever, headache, cough, muscle aches and less commonly vomiting and diarrhoea. It can be vaccinated against, however it is able to change its structure (by mutating its genome which is a random process) so it can evade the immune system. This means flu vaccines keep having to be updated to protect people against the new variations of the virus. This, and the fact that influenza virus also infects birds, is the reason why it would not be possible to eradicate influenza. Could compare this to viruses like smallpox and polio which have or have nearly been eradicated because they have more stable genomes and no animal reservoir.

Rabies: Negative sense RNA virus

Enters via skin and exits via saliva - spread through being bitten by an infected animal (usually dog). Results in death by killing brain cells in the cerebellum. The virus travels to the brain from the bite site up the nerves and it progresses slowly, so it is possible to stop the progression of the disease by vaccinating after being bitten.

Ebola: Negative sense RNA virus

Spreads by direct contact. This virus has a high fatality rate of up to 90% (but closer to 40% in the most recent outbreak). It causes symptoms including fever, muscle aches, skin rash, vomiting + diarrhoea, weakness, bleeding from nose, mouth etc. The virus can infect many cell types and it spreads within the body through the circulatory system. It causes such severe disease because it causes clotting within the blood vessels, bleeding inside the body (haemorrhage) leading to a drop in blood pressure and multi-organ failure. It is also so severe because it originated in a different animal to humans - the fruit bat - and transmitted to humans relatively recently. This is in contrast to viruses such as the common cold which have been in human populations for a long period of our evolution meaning we have adapted to survive it.

Winter Vomiting Disease (Norovirus): Positive sense RNA virus

Very common in the UK and very contagious. Causes vomiting and diarrhoea. Spread can be prevented by washing hands regularly.

Polio: Positive sense RNA virus

See "Polio, vaccination and disease eradication" experiment

Chicken Pox: Double stranded DNA virus

Otherwise known as Varicella-Zoster virus, a member of the herpesvirus family. Highly contagious; Spread through direct contact, coughing and sneezing, and causes red spots on the skin all over the body. Causes mild symptoms if caught when young, but causes Shingles in adults which is more serious. After initial infection, the virus goes dormant (latent) in the nervous system, and later in life it might reactivate to cause shingles.

T4 (T4-Bacteriophage):

Bacteriophage are viruses but they do not infect humans – they infect bacteria. One day this might be useful to us for treating bacterial infections ('phage therapy') where you can infect specific bacterial cells with genes that kill them/stop them reproducing.

HPV, here's, cancer (not virus)

Parasites Box

- 6 x cuddly parasites (4x protozoa, 2x insects)
- 2 x cuddly mosquitos (parasite "vectors")
- laminated fact sheets
- laminated parasite matching game
- microbiology text book

What is a parasite?

- Being a parasite is essentially free-loading off the host that it feeds on.
- Some parasites live on the surface of their hosts, these are ectoparasites (e.g. some mites/lice, ticks).
- Some types parasites live inside their "prey", these are endoparasites. Some of these live in gaps between the host tissues (eg trypansomes, tapeworms) while others live inside the host cells (eg malaria parasites)
- Most parasites live in more than one species at some point in their lifecycle (see individual descriptions).
- The parasites that you're most likely to hear about are single-celled Protozoa (including the parasites that cause malaria and trypanosomiasis), and parasitic worms (such as tapeworms).
- There is constant conflict between parasite and host: the host's immune system is trying to kill the parasite, and the parasite is trying to hide from the immune system. Co-evolution of the parasite with the host has led to them becoming well adapted to each other – a good parasite is one that manipulates the host so it can reproduce maximally but doesn't kill the host because it needs somewhere to live!
- Parasitic diseases are a massive problem for global health. Malaria kills nearly 1 million people per year, most African children under 5 years old. Parasitic worms might reduce your quality of life so much that you can't care for your family, leading to a wider impact (eg elephantiasis). In many regions where parasitic diseases are a problem there is very basic healthcare, making treatment more difficult to access.
- Also a big problem in animals - cost to pet owners of preventative treatment (to avoid illness), most farm animals have a significant parasite burden (gives economic costs of reduced production, greater food intake required, medications etc.

Some examples of parasites:

PROTOZOA: Single-celled eukaryotes

1) Malaria (*Plasmodium falciparum*): 4 parasites cause malaria: *Plasmodium falciparum* (the most common and most deadly), *Plasmodium vivax*, *Plasmodium malariae*, *Plasmodium ovale*. These are carried by *Anopheles* mosquitoes, the vector, which are active and hence bite people at night. When they bite an infected person they take up the parasite into their digestive system (parasite stage = sporozoite), and then secrete it into the next person they bite in saliva (used to inject anticoagulants to keep the person bleeding so the mosquito can get its blood meal). The parasite then travels in the bloodstream to the liver where cells are infected (parasite stage = merozoite). Parasites are released and enter red blood cells in the circulation, where they multiply and burst the red blood cell, causing the symptoms of malaria. Inside some red blood cells the parasites become gametocytes which are taken up by another mosquito if it bites the person.

Symptoms at first include fever, chills, headache and vomiting. In some cases this can rapidly progress to severe anaemia, respiratory distress or cerebral malaria - and can be fatal. However if you live in a malarial area (and get infected often) you may develop partial resistance to malaria and be infected without symptoms (asymptomatic infection). When you travel to a malarial area (Asia, South America, Africa - but the range is spreading) you use chemoprophylaxis (drugs to stop an infection becoming established), in combination with avoiding being bitten (mosquito nets, DEET mosquito repellent) - and there are also drugs available to treat malarial infections.

2) African Sleeping Sickness (*Trypanosoma brucei*): Parasites are injected into you by the bite of a tsetse fly in Africa (tsetse fly = the vector), or they can cross the placenta to infect a fetus. Trypanosomes don't live inside cells like malaria but they live in the blood stream – this means they have to do clever things to hide from the immune system, such as constantly changing their protein coat so that the immune system can't recognise them as a parasite. 2 different trypanosome subspecies cause sleeping sickness: *T. brucei rhodesiense* gives a rapidly-progressing disease (death in weeks to months) whereas causes a slowly-progressing disease (you might not have any symptoms for years!). Sleeping sickness occurs when the trypanosomes enter the brain and start to destroy the areas that control sleep and wakefulness, leading to blurred sleep/wake transitions and falling asleep at inappropriate times, progressing to coma and death! Trypanosomiasis (disease caused by trypanosomes) is treatable - but it's much easier at the early stage (drugs: pentamidine/suramine) than once the parasites enter the brain (drugs: melarsoprol - which comes from arsenic and has nasty side effects that can be fatal themselves!).

African trypanosomes also infect cattle, making agriculture in areas with tsetse flies really unproductive - cattle become really thin and so can't work (pulling ploughs etc) and aren't useful as food for people either!

3) Chagas disease/ American trypanosomiasis (*Trypanosoma cruzi*) Chagas disease, also known as American trypanosomiasis, is caused by the protozoan parasite *Trypanosoma cruzi (T. cruzi)*. 10 million people in the world are infected, mainly in South America. The vector transmitting the trypanosomes to humans is the triatomine bug ('kissing bugs'). These live on the walls of houses and are nocturnal, biting people on their exposed faces when they are asleep at night. Unlike the African trypanosomes, South American trypanosomes aren't injected with the bug's saliva but the bug defecates next to the bite and it's the faeces that contain the parasites. They get into the person's bloodstream when they rub their face and smear the faeces into the bite!

The first sign of infection is often a large swelling of the eyelid on the side of the face that was bitten. Parasites can then enter the heart (30% cases) causing problems with the heartbeat, and maybe sudden death. Digestive problems can also occur (10% cases) when there is enlargement of the oesophagus as food can't enter the stomach - the food that gets trapped can start rotting which is pretty disgusting! Chagas disease is highly treatable though, with nearly 100% of people cured if treated early (benznidazole or nifurtimox).

4) Toxoplasmosis (*Toxoplasma gondii*) *Toxoplasma gondii* is a species of parasitic protozoa.The definitive host (where the sexual stage of the life cycle occurs) is the cat - gametes are formed in the digestive tract and exit in the faeces. Then they enter another host (intermediate host) when they eat or drink contaminated food or water. So far every warm-blooded animal tested can act as a host - including humans. Here the parasite can enter any nucleated cell and replicates to form a tissue cyst. This can be passed on to another intermediate host or a cat by carnivory.

Usually toxoplasmosis has very mild symptoms (there might be some fever) and in France up to 90% of adults are infected (due to the French love of rare meat)! However serious disease can be caused in immunocompromised people (AIDS sufferers or post-transplant patients on immunosuppressive drugs) and pregnant women (increasing the risk of spontaneous abortion and birth defects). This is why pregnant women are advised not to touch cat litter! (also explains why pregnant women are advised to clean fruit/veg thoroughly as gametes can contaminate them, and women become infected this way)

T.gondii infection of the brain can lead to changes in behaviour by changing the amounts of chemicals in the brain (dopamine). Rats and mice lose their fear response to the scent of cats (tested using cat urine) and are more curious - very important effect, as means rats are more likely to be caught and eaten by cats giving greater rate of infection of cats (completing the parasites life cycle). Studies in humans have linked toxoplasmosis to schizophrenia (including hallucinations and reckless behaviour), slower reaction times and greater chance of causing traffic accidents.

PARASITIC WORMS:

(There's some slides for these in "Microscopes & Cells" which can be borrowed. Please sign the respective risk assessments before using items from them).

Flukes (Trematodes): Adult flukes are leaf-shaped flatworms. Prominent suckers at the mouth and on the stomach help maintain position. Flukes are hermaphroditic (both male and female) except for blood flukes (schistosomes), which are bisexual. The life-cycle includes a snail intermediate host.

Tapeworms (Cestodes): Adult tapeworms are elongated, segmented, hermaphroditic flatworms that inhabit the intestinal lumen. You can eat the cysts in undercooked animal tissues (pork is probably the greatest risk if undercooked), and then they develop in your intestines. They eat your food from your intestine – instead of you getting the nutrients. They attach to the intestinal wall using suckers in the head. Problematic in the developing world where there is already malnutrition. People used to use tapeworms as a slimming aid… They can grow up to 15 metres long and live for 20 years! Larval forms live in extraintestinal tissues.

Roundworms (Nematodes): Adult and larval roundworms are bisexual, cylindrical worms. They inhabit intestinal and extraintestinal sites.

1. **Schistosomiasis** (caused by a fluke/ trematode)
    - Schistosomiasis is a chronic, parasitic disease caused by blood flukes (schistosomes)
    - At least 230 million people require treatment every year – praziquantel
    - Infection from larval forms released from freshwater snails in contaminated water
    - Penetrate the skin and live in circulation where females release eggs
    - Cause damage because of the host immune response to the parasites

2. **Liver fluke** (*Fasciola hepatica*) (caused by a fluke)
    - Freshwater snail intermediate host, where reproduction occurs, then they are released as cercariae and swim through water to be ingested by ruminants normally, or sometimes humans eating uncooked foods like watercress
    - Adult lives in the liver where they feed on the lining of bile ducts – makes cheese-like holes in the liver
    - Produce eggs – up to 25000 a day per female
3. **Dracunculiasis** (guinea-worm disease, caused by a nematode)
    - Dracunculiasis (caused by Dracunculus medinensis, a long thread-like worm) is a parasitic disease on the verge of eradication
    - Exclusively transmitted by drinking water contaminated with parasite-infected fleas such as rural isolated ponds
    - Takes 10-14 months for worm to mature in the body
4. **Hookworm** (*Ancylostoma duodenale* and *Necator americanus*, kinds of nematodes)
    - Soil-transmitted helminths (parasitic worms)
    - Major burden of disease worldwide - estimated 576-740 million people infected with hookworm
    - Hookworms live in the small intestine, eggs are passed in faeces of infected person – this is a problem in the developing world where people may defecate outside (near bushes, in a garden, or field) of if the faeces of an infected person are used as fertilizer, eggs are deposited on soil.
    - Eggs then mature and hatch, releasing larvae (immature worms).
    - The larvae mature into a form that can penetrate the skin of humans, and infection is mainly acquired by walking barefoot on contaminated
    - Most people infected with hookworms have no symptoms. Some have gastrointestinal symptoms, especially persons who are infected for the first time. The most serious effects of hookworm infection are blood loss leading to anemia, in addition to protein loss.
    - Infection is treatable – anthelminthic medications eg. albenadazole

PARASITE VECTORS:

(There are two cuddly toys for this, so you can show a second uninfected mosquito feeding off a human host)

Mosquito (*Culex pipiens*): - Most mosquitoes are harmless but some can transmit disease - Viral diseases, such as yellow fever, dengue fever and Chikungunya, transmitted mostly by Aedes aegypti - Parasitic disease malaria, carried by mosquitoes of the genus Anopheles - Lymphatic filariasis (the main cause of elephantiasis – worms block lymphatics impairing lymph drainage causing swelling of the limbs) - We have cuddly toys of mosquitoes – in the parasites box

ECTOPARASITES:

(There's some cuddly toys and slides for these, and hopefully some preserved samples borrowed from the "Horrible Housemates" experiment) 1) **Head louse** (*Pediculus humanus capitis*) - Lice are wingless biting or sucking insects. Lice infestation of any part of the body is called pediculosis! - Live on your head (an ectoparasite) - has a single strong claw on each leg that can grab onto 6 hairs so they can move rapidly (may be on several heads in one day). But their short stumpy legs mean they can't jump or walk well on flat surfaces. - Your head provides a source of food - blood - Eggs are called nits and the female attaches the eggs close to the scalp with a transparent quick-setting glue - The time taken to hatch depends upon temperature - Head lice have no lungs! They take in air by muscle contraction of the abdomen (via spiracles) - Head lice have been recovered from prehistoric mummies!

2. **Bed bug** (*Cimex lectularius*)
    - Ectoparasites that feed on human blood (haematophagous)
    - Live in houses and especially beds – most active at night so they can feed on the host without being noticed
    - Adults can survive more than a year without feeding
    - They don't usually spread disease but they can cause allergic skin reactions
    - Light brown flattened oval-shaped body, vestigial front wings, microscopic hairs on abdomen that give a banded appearance

Polio, vaccines, and disease eradication

There are a few key concepts you can talk about with polio, depending on how keen the children are and their level of understanding: - The virology of poliovirus; how it replicates etc. - How poliovirus causes disease - Vaccination - Disease eradication

The Virology

This is quite hard to explain without getting bogged down in detail. For most children, I'd restrict it to explaining that polio is a virus, so it needs to hijack our cells to make more of itself. Polio is a virus which can cause a disease called poliomyelitis. Viruses are incredibly small particles (virions) containing the genetic instructions needed to make more virions. To infect a cell, the virus sticks to the cell surface then injects its RNA (the genetic instructions) into the cell (if we're being precise, the whole virion is internalised by receptor-mediated endocytosis before the genome enters the cytoplasm, but we can probably skip this).

The host cell is then 'tricked' into producing thousands of new virions; the RNA has the instructions to make the viral proteins and also acts as a template to produce more genomes. Eventually, the cell bursts, releasing up to 10,000 new virions into its environment, ready to infect more cells.

How polio causes disease

Polio spreads by the faeco-oral route; ie poo contaminating drinking water. That's why it's often seen in areas with poor sanitation (eg. poor sewage disposal, no water treatment). It's also the reason that young children are more likely to get infected, since they tend to have lower standards of hygiene!

The vast majority of people infected get a fairly harmless infection in the gut or get vague 'flu-like' symptoms.

Polio becomes a problem if it infects cells called motor neurones in our spinal cord. We need these cells to control our muscles, so if lots of them are killed then the muscles become paralysed (because information can't get from the brain to muscles to tell them what to do). The resulting disease is paralytic poliomyelitis, which is what most people think of when you mention polio. Interestingly, infecting the cells in the central nervous system does not help the virus transmit to other hosts (it is 'accidental' infection - the virus would benefit more from infecting cells which can allow replication and transmission to new cells, so infection of these motor neurons is a waste of its resources).

What effects can paralysis have? It depends on where is affected. Obviously, if the legs are affected the patient won't be able to walk. Even worse is bulbar poliomyelitis, where the muscles we use to breath can become paralysed. There isn't a cure for polio. All we can do is support the patient to keep them alive. If their breathing muscles become paralysed then they need mechanical ventilation, meaning that a machine is used to do the work for them. Famously, in the 1950s this took the form of negative pressure ventilation, aka the iron lung.

Vaccination

Polio affected thousands of people in the Western world in the 1950s. But ask the children how many people they've met who've had polio. The answer should (hopefully!) be none. Why? Because there's a vaccine to prevent it! Normally our bodies fight infections using our immune systems. Our immune system 'learns' how to fight an infection when it's exposed to the pathogen, so it fights it more effectively the second time around. That's why we normally only get chickenpox once, even though it's a really infectious disease. Vaccines are a way to teach our immune system to fight a disease. Different vaccines work in different ways; some use a dead pathogen or part of a pathogen, while others use a live one that's been deliberately weakened so that it's no longer able to cause disease, but still similar enough to the dangerous one that our immune system learns to fight that one too. In the case of polio, there are actually vaccines that work both ways; the live vaccine is more 'realistic' so it produces more effective immunity, but there's a risk that the 'safe' strain can mutate back into a 'dangerous' one. In the UK we use the dead vaccine, since you're highly unlikely to be exposed to polio anyway, but in areas where polio is still common we use the live one, since the benefit outweighs the risk. In the (hopefully unlikely) event you end up talking to an anti-vaxxer about this, feel free to try and explain the science behind why vaccines do indeed work and are safe, but keep it a calm and cordial discussion and don't spend too long on this - you're meant to be entertaining the children more than educating the parents!

Disease eradication

The polio vaccine is important because it might be possible one day to use it to eradicate polio completely. In fact, we're tantalisingly close to doing so! Have they heard of any other diseases that have been completely eradicated? There's only one human disease: smallpox. For the vets, there's also rinderpest - infected cows, buffalo, deer, giraffes etc. Polio has certain special features which are needed for a disease to be eradicated: - It doesn't change so much over time that the vaccine stops working. Contrast with flu, where we need a new vaccine very year, and even that isn't guaranteed to work! - It doesn't infect animals. Animal viruses which also infect humans are basically impossible to eradicate, since it just needs one person to be infected by an animal and we're back to square one. Sadly, this applies in the case of Ebola. We've come incredibly close to eradicating polio in recent years, and it's now largely confined to Nigeria, tribal regions of Pakistan and Afghanistan. However, these areas are all highly politically unstable and health workers have been targeted by violence, so it remains to be seen whether the final push will be successful.

Risk Assessment

Hazard: Microbe toys and accessories

Description: Trip hazard if dropped on the floor.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Keep all props in contained area and pick up any fallen toys as soon as is safe. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Microbe toys and accessories

Description: Germ transmission if put in mouth or chewed, which may be more likely since these do resemble toys.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Wash between events if possible. Encourage children not to put near face/mouth.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: UV cream

Description: UV cream in eyes.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: When giving UV cream to children, tell them not to put their fingers near their eyes and ensure they rinse it off. Call first aider in case of injury. If washing up liquid gets into an eye, demonstrator must call a first aider and may perform an eye wash if trained and confident to do so.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: UV cream

Description: Slip hazard if spilled.

Affected People: All

Before Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Mitigation: All spills should be cleared up immediately. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 1, Overall: 1

Hazard: UV cream

Description: Possible allergic skin reaction to cream.

Affected People: All

Before Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Mitigation: Suggest that volunteer from group isn't one who is known to have sensitive skin. If it starts to itch/hurt, wash off immediately and call first aider. Seek further medical advice where appropriate.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Sensitive Topics

Description: We have a cancer cell and some things here which can cause cancer which affects lots of people. There are also several other potentially fatal diseases, in particular SARS-CoV-2 which is responsible for the ongoing pandemic and could lead to distress.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Deal with topic respectfully, move on if it seems distressing. Move to different experiment if required.

After Mitigation: Likelihood: 4, Severity: 1, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-17 - Michael Darling (md510@cam.ac.uk), **Check 2**: 2012-01-24 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2012-12-28 - Beatrice Tyrrell (bet23@cam.ac.uk), **Check 2**: 2012-12-30 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2019-01-20 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-01-23 - Amanda Buckingham (abb53@cam.ac.uk)

Check 1: 2020-01-24 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-25 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-12 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk), **Check 2**: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-01 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-02-09 - Sian Boughton (seb216@cam.ac.uk)

Check 1: 2023-01-22 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2023-02-10 - Amy Migunda (aom36@cam.ac.uk)

Check 1: 2023-02-04 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Isobel Gilham (ig419@cam.ac.uk)

Mini Explosions

Exploding film canisters with lemon juice and bicarb. - Make an impressive explosion with kitchen ingredients and find out more about what makes things go with a bang.

Last initially checked on 2023-12-27 by Andrew Marriott (asm206@cam.ac.uk) and double-checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Chemistry

Equipment Needed

- Lemon Juice (or vinegar, but this reacts faster and smells bad!)
- Bicarbonate of soda
- A couple of washing up bowls
- Teaspoon or similar for scooping bicarb
- Clear plastic box with the hinged lid
- (All of this lives in a large blue box with white lid – note that this is shared with Fire Extinguishers)
- Green or black tray to catch any leakage from clear plastic box (doesn't live in blue box)
- Gaffer Tape (lives in gaffer tape box) to seal the hinge of the clear plastic box

Experiment Explanation

In a nutshell.....

Acid + Carbonate → Salt + Water + Carbon Dioxide

Production of carbon dioxide in a sealed container to produce explosions.

How to set up the experiment

Set up the clear plastic box in a large tray, with the lid opening towards you.

Important: Stick some gaffer tape along the hinge line facing the audience to prevent lemon juice escaping through the crack. Fill one of the smaller Tupperware containers with water to use for washing out film canisters.

Demonstrating the experiment

Initially, mix lemon juice (about 1/8 fill the canister) and bicarb (1/4 of a teaspoon) in the film canister with the lid off, so that the kids can see it frothing up. If the kids seem responsible, you can add the bicarb and let a volunteer add a squirt of lemon juice. Ask them where they think the bubbles are coming from/what's in the bubbles (space for a bit of a discussion of different gases here, many of them will have heard of CO_2).

Get them to think about what lemon juice is like (sour therefore an acid), and what else is sour (vinegar, other citrus juice...) and discuss that any acid can let out the gas that's "trapped" in the powder. Possibly also discuss use of bicarb in baking - heating it up releases gas, which puts bubbles in your cakes.

The bubbles should froth well over the top of the canister. Ask them to predict what will happen if you put a lid on (does the gas have anywhere else to go?)

Now try it and see if they're right! With older kids you can discuss how molecules create pressure, ask them to push their hands against each other a bit to demonstrate reaction forces.

Some children ask why there is no 'fire' if it is an explosion. It can be worth explaining that an explosion is simply a rapid expansion of gases and release of stored energy, often with heat being produced, though this is not a necessary condition. Sealing the canister causes the pressure to build up, which stores energy, until the lid can no longer resist the force of the trapped gases. The stored energy is then released rapidly when the lid pops off and gases expand, causing the explosion.

There are 2 slightly different approaches:

Method 1 (easier and effective)

Fill the canister about 1/6 of the way with lemon juice (or let a responsible volunteer do it), press bicarb into the well in the centre of the lid. Invert the lid and make sure the bicarb stays stuck in there. Inside the plastic box, with the lid partly shut, gently put the lid on the canister; the bicarb is now held at the top of the canister away from the lemon juice.

Invert the canister, place it on the bottom of the box, and shut the lid fully (it's often a good idea to have the lid partially shut before you invert the canister to reduce the risk of it getting on you). The bicarb and lemon juice will mix, pressure builds, and the pot will explode upwards. The less lemon juice there is, the more time you have before the explosion but the explosion is no less vigorous (assuming the seal is good), since the film canister will always pop at the same pressure and a slower reaction will build up pressure more slowly. You could ask older children to work this fact out for themselves.

Method 2

Put some lemon juice in the canister, put a piece of tissue paper over the top of the canister with bicarb on top of that, push the lid on so it hold the tissue paper. The bicarb is now held at the top of the pot away from the lemon juice. Put the canister upside down in the clear plastic tank and shut the lid (it's often a good idea to have the lid partially shut before you invert the canister to reduce the risk of it getting off you). The bicarb and lemon juice will mix and the pot will explode upwards.

It's usually a good idea to try both methods before the kids arrive and see which one works better for you and the type of film canister you happen to have.

Some film canisters explode better than others, so it is worth trying different ones to make sure you are using the right lid. The translucent white plastic ones work really well. Ask a committee member or experienced demonstrator.

Other things to think about

Vinegar (acetic acid) is a stronger acid than lemon juice (citric acid); if using vinegar expect this reaction to be quite quick… (can talk about why stronger acids cause a faster reaction). You could also link the experiment to a rocket launch – the canister shoots upwards because the gas pressure pushes the CO_2 and liquid out of the bottom, generating an upwards reaction force. Rockets work in the same way by forcing gas out of the back at great speed (though this is normally powered by combustion rather than an acid-base reaction).

Packing away

Give everything a wash, ideally with hot, soapy water. Dry the box (by leaving it out or using paper towels). Put everything (except the big tray) back in the big blue box – to make everything fit you will probably need to put smaller components (e.g. the tub of film canisters) inside the clear plastic box.

Risk Assessment

Hazard: Liquids

Description: Spillages pose a slip hazard.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Clear up spills as soon as possible if on a slippery floor. Do experiment outside if possible. Do experiment in tray to avoid spilled liquid going on floor. Put wet floor sign down if needed.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Explosions

Description: Explosions could get out of box, (or occur before the canister has been put in the box) and get into eyes, or box could jolt and hit children if they are too close.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Do experiment in a clear lidded fish tank so kids are not peering over the top to see what is happening and tell them to stay a good distance back, keep lid opening faced towards demonstrator. It is important to keep the kids under control. Try to keep control over at least one of the reagents, so the kids can't just do it themselves.

Ensure the top of the tank is not at eye level (it is possible for a small volume of the reagents to be propelled through the crack between the top of the tank and the lid). Run a length of plastic tape along the hinged side (which should be closest to your audience) to prevent splattering.

Only assemble the cannisters when in the box and the lid is partially closed. Tissue paper may be used as a "fuse" to increase the time taken for the reactants to come into contact with each other - this gives more time to get the canister into the tank. Lemon juice is usually better than vinegar, as it reacts more slowly, so again, there is more time to get the canister into the tank. In addition, eye protection should be provided for demonstrators to minimise possible risk of solution splashing into demonstrator's eyes.

Eyewash should be kept in Mini Explosions box. If solution or reactants have entered eyes, call first aider, who will use eyewash to wash out of eyes if trained and confident to do so.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Reactants

Description: The reaction mixture could be eaten by a child and cause a stomach upset.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Do not let the kids do the reactions themselves or leave them alone with the experiment.

It is important to keep the kids under control. Try to keep control over both reagents. Warn children not to eat/put hands in mouth.

In the event of eating, advise them that the reactants are all edible but to seek medical attention if they start to feel very bad as experiment has been in cupboard for unknown amount of time.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-20 - Catherine Collett (chc47@cam.ac.uk)

Check 1: 2012-12-12 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2012-12-16 - Rachel Chapman (rc506@cam.ac.uk)

Check 1: 2013-12-15 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-01-23 - Vamsee Bheemireddy (vrb23@cam.ac.uk)

Check 1: 2014-12-27 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-02 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-01-20 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-18 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2016-01-09 - Haydn James Lloyd (hjl43@cam.ac.uk), **Check 2**: 2016-01-09 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-02-06 - James Nicholas (james.nicholas@cantab.net), **Check 2**: 2017-02-06 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-01 - Georgia Harris (grh37@cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-01-10 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-08 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-16 - Holly Smith (hs606@cam.ac.uk)

Check 1: 2020-12-27 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2021-01-17 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-23 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-01-29 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2023-01-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2023-01-15 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2023-12-27 - Andrew Marriott (asm206@cam.ac.uk), **Check 2**: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk)

Monty Hall's Perplexing Goat

A wonderful experiment of probability involving a cuddly goat called Bertrand, a couple of coins, three doors, and three boxes. - A wonderful experiment of probability involving a cuddly goat called Bertrand, a couple of coins, three doors, and three boxes.

Last initially checked on 2024-02-15 by John Leung (cfl35@cam.ac.uk) and double-checked on 2024-02-15 by Lauren Mason (llm34@cam.ac.uk)

Tags

Probability

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- [Cuddly] Laminated goat called Bertrand
- Fair coin
- Coin with two Head's (also known as Bertrand's Coin)
- Three mini-suitcases of Bertrand (also known as boxes)
- Six coins, 3 gold, 3 silver (2 to go into each mini-suitcase)
- New contraption with 3 doors behind which Bertrand can hide (aka Bertrand's home)
- Marbles, in case committee have lost any (optional)

Experiment Explanation

WARNING: "This is written by an entirely mad CHaOS committee member a bit to close to Christmas. Please do the experiment however you want, and don't feel you need to imitate a goat or the style this is written in. This summary will give you some idea what is going on… A wonderful experiment of probability involving a cuddly goat called Bertrand, a couple of coins, three doors, and three boxes. It involves tossing a fair coin, and seeing how many heads you get in a row before getting a tail (and the probability distribution you get from that). It explains the Monty Hall Problem, and the importance of prior probabilities (three doors, with the prize behind one door). There are then more complex problems, involving three boxes, each with two coins inside them!"

Monty Hall's Goat (Bertrand)

Hello boys and girls. I said HELLO boys and girls

Hello Bertrand

That wasn't very loud now was it – you can do better than that. HELLO BOYS AND GIRLS

Hello Bertrand

Deary me, you still seem to be hung over from the new year. I said **HELLO BOYS AND GIRLS** *HELLO BERTRAND*

Oh dear, oh dear, no need to shout. Honestly what are the young like these days. I think I should tell you a little bit about me before I got here. I used to have a job as a pantomime horse, but quit while I was a head.

So what is probability? Well it is the chance of something happening to you. What is the probability that I am going to give you £50000? Given that I am a goat with no worldly possessions, 0. What is the probability that I am going to be sitting on this table in 2 seconds time – 100%. We can measure probability from a scale of 0-1, or multiply it by 100 to get

Right, now where did I put down my coin

It's behind you

Oh no it isn't

Oh yes it is

Oh NO IT ISN'T

Oh yes it is!

Oh yes, so it is. I thought you were just telling me my career was behind me… Anyway, who wants a fun game where I make up the rule. How many times do I have to toss this coin before it I get a tail? Hands up for once. Hands up for twice. Anyone thinking I am going to get three heads in a row before getting a tail? Anyone more than that? What is the best one to go for? Well if you think about it, you have a 50% chance that it is going to be the first one. Then a 25% chance that I will get precisely one head followed by one tail, and then 12.5% two heads and then a tail. Three heads 6.25%, four heads 3.125% etc… We can draw this in a tree diagram, and get some stick for this… Perhaps we ought to turn a new leaf… OK, are you ready for this… Drumroll please – no no no – I mean hit the drum with a stick in a rapid way, not roll the drums down the hill and of a cliff into water (bom bom tish). Right ready for this, here we go….

[Bertrand's coin has two heads]

We have a head. Bad luck to those who said that you would get zero heads. Now let us see if the one headed people were correct

[Second toss]

No head again. What about two heads?

[Third toss]

Still a no… Hmm that is unfortunate. Is Three a magic number?

[Fourth Toss]

No. Hmmm, let's keep going

[Fifth, Sixth, Seventh Toss, till]

You are cheating – there is no tails on this coin

Oh No I am not

Oh Yes you are

Oh no I am not

Oh yes you are

Oh no I am not

Oh Yes you are

Oh well maybe you are right. Fine fine, spoil all my fun. Let's use an actual coin – here you can check it does have a head and tail. Let's note down on a piece of paper what it will look like – remember it is the number of heads we get before getting a tail…

[Paper should look like 0 – iiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiii 1 – iiiiiiiiiiiiiiiiiiiiiii 2 – iiiiiiiiiiii 3 – iiiiii 4 – iiiii 5 – ii 6 – i 7 – 8 – i 9 –]

Right, well you kids (in America) have had the time of your life tossing all those coins – let us see if we can take tree diagrams just that little bit further… This is now a Mony Hall Problem. Here is my house, which has three doors. I am going to hide behind one of them… So which one am I behind?

[Kid picks one]

Ah wrong one. But how much chance did you have? Draw out a tree digram – 1 in 3 chance, right? How much chance do you have of getting it right both times? Less right? Compared to not getting it right either time, a lot less, right? So then, let us place a variation, where this time I use my beautiful assistant

[Looks at demonstrator]

ARGH! You were not my beautiful assistant from last week. Where has he gone? What I am stuck with you? But you don't even have a beard… Oh well, needs must I suppose, but do try and grow a beard for next time.

Right, so like last time, I am hiding behind one of the doors of my house [the one with three doors where they have no idea which one you put Bertrand (the goat behind)]. Pick one, but this time you don't get to open it yet. Beautiful assistant, open one of the doors I am not behind. Right here is the tricky question – you now have a chance to swap doors from your original choice – should you swap or not? Does it make a difference?

OOoooooohhhhhhhh – that's more like it – audience participation and all that jazz. Take your time, think carefully. Does it matter??? Drum roll please NNNNOOOOOOOOO not another one down a hill and off a cliff (bom bom tish). Look, that is getting expensive. Anyway, so what is the answer. Surely it doesn't matter?

Firstly, my name is not Shirley, it is Bertrand. Secondly, it does matter. You should always swap. Don't believe me? Let's do it a few times, and see which action would have won you me (because heck, I am better to win than the demonstrator standing next door to me).

Swap - iiiiiiiiiiii

Don't Swap - iiiiii

So why do you win it about double if you swap than if you don't swap? Simples – You have a two thirds chance of getting the goat rather than a one third chance. And no, I haven't suddenly become a well dressed meerkat. By the not-that-beautiful-but-still-helpful assistant (you can grow a beard one day, I have faith in you) removing the wrong choice out of those two, you get two choices for the price of one.

Right, my still-not-attractive assistant has got annoyed with me now, and has put on a pair of horns [put on devil horns]. In this one, I am hiding behind one of the three. You get to pick one door. Out of the other two doors, he will open one of the doors and take away whatever is behind it. He will always take away me if he can, else he picks randomly from the two doors. Should you swap, or not swap?

Swap - Don't sway - iiiiiiiiiiiiiiiiiiii

You now only have a one third chance of getting me, and that is only if you picked me at first. If you didn't pick me, then you cannot get me. If you did pick me, then I am protected. Thus you should never swap

Right, remove those horns, and put on a halo instead. This time my wonderful-yet-not-bearded assistant allows you to choose one of the three doors. He then looks at the other two doors, and opens a door where myself (Bertard the goat) is not standing. He then ONLY offers you the chance to switch from your current door if it is beneficial i.e. if I am standing behind the door that you haven't currently selected. It is therefore always beneficial to switch

Right, remove that halo, and put on the Dunce's cap instead. This time, my brilliant-yet-lacking-facial-hair-clearly-showing-lack-of-intelligence instead randomly picks one of the other two doors without looking. There are therefore the following outcomes

Dunce picks the goat – iiiiiiiiiii Don't swap to win – iiiiiiiiiii Do swap to win – iiiiiiiiiiii

Equal chance of all 3.

Thank you, thank you for the applause, (hint hint), but there is more, as I know you were all shouting for an Encore. Just before we do, do any of the rest of you want to grow facial hair? I always think a goatie is the pinnacle of fashion, being a goat myself…

There is more!!! I now have three boxes sitting on the table, or mini-suitcases of mine, in case I want to go on holiday somewhere. Now in one of them, box GG, there are 2 gold coins, in another, box SS, 2 silver coins, and in a third, box GS, one gold and one silver coin. I can thankfully tell the difference through feel – my optician recently told me I was colour blind. It was a real shot out of the orange. Hoorah! Hope you are not feeling all boxed in!!!

I want you to pick one random box – good that one. Which box is it – you have a 1 in 3 chance of guessing.

OK – to make it easier I will pick out one coin at random and tell you there is one gold coin – what is the chance of getting each box. OK – you are predicting 50:50 between box GG and box GS. That is incorrect. Let us see what actually happens

Pick G out first Box GG – iiiiiiiiiiiiiiiiiiiiiii Box GS – iiiiiiiiiii Box SS –

Pick S out first Box GG – Box GS – iiiiiiiiiii Box SS – iiiiiiiiiiiiiiiiiiiiiii

As you can see, if we combine both scenarios together, there is an even chance of getting any of the three boxes. But as if I pick out a gold coin it is twice as likely to be box GG rather than box GS, as box GG has two gold coins in it…

What, you want another encore? OK, here is the scenario, but before I do, did you know I have been married sixteen times! four richer, four poorer, four better, four worse. After the loss of each partner, I was down in the dumps and got a new hat. No wonder my hats always looked terrible.

Three CHaOS demonstrators, Alice, Bob and Charlie are sitting out the back. However, I want my house cleaned, and I need two demonstrators to do this. I have decided which two will need to do this, but haven't told any of them yet. Alice comes to me, and begs me to tell her one person who is definitely cleaning my house. I tell her Bob is definitely cleaning my house. She then goes and tells Charlie, believing that she now has odds of 0.5 of getting off cleaning my house. But Charlie believes that he now has odds of 0.6666 of not doing cleaning – who is correct?

The answer is Charlie. Alice was guaranteed to be told someone who has to do cleaning, and so it hasn't affect her chances of having to do the cleaning. However, Charlie didn't, and so his chance of not doing the cleaning has gone up. Confused? Me too. Let's put this into a table

Not cleaning	**Me: "B cleaning"**	**warden: "C cleaning"**	**sum**
Alice	1/6	1/6	1/3
Bob	0	1/3	1/3
Charlie	1/3	0	1/3

So being told that Bob is cleaning means that Bob has a 0 % chance of getting off, and relatively Charlie has twice the chance than Alice of not cleaning… Bob was the most depressed about this news, and ate 15 litres of low-fat yoghurt – no wonder he was Mullered by the end of the day…

Right, if you want further discussion, go and look at Bayes Theorem

https://en.wikipedia.org/wiki/Bayes%27_theorem

That's all folks! Now it's time to make my exit before anyone makes me their escape goat.

Sources:

https://en.wikipedia.org/wiki/Monty_Hall_problem https://en.wikipedia.org/wiki/Three_Prisoners_problem https://en.wikipedia.org/wiki/Bertrand%27s_box_paradox

PS By the way, you have spent the last twenty minutes talking to a goat – I suggest you find your marbles once again!!!

Risk Assessment

Hazard: Coins

Description: Coins could go into people's eyes if flicked.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Keep control of coins. Call a first aider in the event of injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Bertrand the Goat

Description: Goat or doors could be dropped and slipped on.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Make sure goat / doors are not on the floor. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Doors

Description: Paper cuts from overexcited kids grabbing the doors quickly

Affected People: Kids, but also anyone handling the doors

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Keep the kids under control, watch they don't lunge for the doors etc. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-01-18 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk)

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2020-01-07 - Matthew Le Maitre (msl54@cam.ac.uk), **Check 2**: 2020-01-27 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-22 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-02-15 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-16 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2024-02-15 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2024-02-15 - Lauren Mason (llme34@cam.ac.uk)

Near IR webcam

Use a modified webcam to see into the near infrared. - There's a whole spectra of light beyond the visible, why not see one side of it through a modified webcam?

Last initially checked on 2024-01-30 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-01-31 by Joshua Wu (jw2311@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Darkroom needed**
- **Electricity needed**
- Laptop
- Small grey box containing:
- Webcam (modified)
- Lights (Incandescent and compact fluorescent)
- Coke
- CD
- Shaver (blades removed)
- Paper with CHaOS logo written with different pens
- Paper with words written one with letter in different pens which contains a hidden message
- Small white remote control

Experiment Explanation

What is it?

Take a normal webcam, remove the IR filter and replace it with crossed polars or a piece of exposed colour film and hey presto you have a near IR camera. Practical point: the webcam has a focusing ring in front of the lens, which may be turned during an event, causing the image to become blurred. If this happens, ask a committee member to show you how to focus it (there is a knack, and if you do it wrong you can jam the focus).

What is light/ IR light?

The light most of us are really familiar with is white light. But that's actually a mixture of different colours. Most of the time we can't tell that, but sometimes we can see these colours split up, like in a rainbow.

Do you know the colours of the rainbow? Ask them to tell you! [Red -> Orange -> Yellow -> Green -> Blue -> Indigo -> Violet (basically purple!)]

It turns out that there are more kinds of light than our eyes can see. Some kinds of light are "redder" than red is - we call that kind of light "infra-red" . You might have seen images from cameras that can detect this kind of light, perhaps watching animals at night on TV, or police chase criminals with helicopters. At the other end of the rainbow there are other kinds of light that we can't see. These are more blue / more purple than violet, and we call this kind of light "ultra violet".

It's weird to think that there are kinds of light we can't see, but not all kinds of eyes detect the same light. For example, some people can't tell red and green apart, which is called "colour blindness". Another example: some insects, such as bees, can see UV light. Some types of flowers have extra patterns in UV, so this helps them find the nectar in the middle of a flower! (How cool is that?!)

But what about wavelength/ spectra?

Add this extra level of detail with caution: it can be too much detail to take in if they've never thought about IR/UV before, and you can overwhelm them. You can come back to this later on once you'rve showed them some of the cool things you can see with the IR camera!

EM Spectrum: we call all the kinds of light (including UV, IR, visible) "electromagnetic radiation". One way of understanding this is to say that all these kinds of light have different sizes of wavelength. There are some charts in the box that you can point at when you explain this. Start with the rainbow: Red light waves are wider/longer than blue light waves. Following on from that, infra-red has longer waves than red light; UV has a shorter waves than blue. If you go further outside that you can see microwaves (that you can cook with) and radio waves (which can hold information, like music). These have a longer wavelength, much longer than infra-red. If you go the other way you get to X-rays - these have smaller waves than UV!

What do I look at with the camera?

Firstly, plug the *new* camera into a laptop and use VLC player (open up the video devices settings and select USB input owtte). [Or maybe do ->Open Capture Device (Ctrl+c)-> PC Camera this sometimes also works] [The camera often lags or gets stuck, the best solution is closing and reopening VLC]

Things to look at:

Coke is transparent, as are some plastics (shaver casing, sample of smoked glass).

Bank notes have lines. Try looking at the Queen's head on a £5 or £20 note (old ones or new polymer ones both have the same effect!)

CD can be used as a diffraction grating to produce a 'rainbow' - shifted position.

Incandescent vs compact fluorescent - about the same luminosity in visible, former is much brighter under IR (Note: This looks more convincing if you give the fluorescent bulb 30 seconds or so to reach full brightness).

Different materials - some black clothing appears white under IR, often patterns on clothing disappear.

On the paper with the CHaOS logos, one shows up in IR and the other doesn't (written in different pens) - there is also the Normal/IR vision one with the same effect.

The laptop screen appears blank.

Remote control- uses IR, point at the camera while pressing buttons. Many camera phones lack IR filters so can test this on parents phone use it to see light from the end of the remote control.

Crookes' Radiometer

A Crookes' radiometer has four vanes suspended inside a glass bulb. Inside the bulb, there is a good vacuum. When you shine a light on the vanes in the radiometer, they spin – in bright sunlight, they can spin at several thousand rotations per minute!

The vacuum is important to the radiometer's success. If there is no vacuum (that is, if the bulb is full of air), the vanes do not spin because there is too much drag. If there is a near-perfect vacuum, the vanes do not spin unless they are held in a frictionless way. If the vanes have a frictionless support and the vacuum is complete, then photons bouncing off the silver side of the vanes push the vanes, causing them to rotate. However, this force is exceedingly small.

Over the years, there have been many attempts to explain how a Crookes radiometer works: Crookes incorrectly suggested that the force was due to the pressure of light. This theory was originally supported by James Clerk Maxwell, who had predicted this force. This explanation is still often seen in leaflets packaged with the device. The first experiment to test this theory was done by Arthur Schuster in 1876, who observed that there was a force on the glass bulb of the Crookes radiometer that was in the opposite direction to the rotation of the vanes. This showed that the force turning the vanes was generated inside the radiometer. If light pressure were the cause of the rotation, then the better the vacuum in the bulb, the less air resistance to movement, and the faster the vanes should spin. In 1901, with a better vacuum pump, Pyotr Lebedev showed that in fact, the radiometer only works when there is low-pressure gas in the bulb, and the vanes stay motionless in a hard vacuum. Finally, if light pressure were the motive force, the radiometer would spin in the opposite direction, as the photons on the shiny side being reflected would deposit more momentum than on the black side where the photons are absorbed. This results from conservation of momentum - the momentum of the reflected photon exiting on the light side must be matched by a reaction on the vane that reflected it. The actual pressure exerted by light is far too small to move these vanes but can be measured with devices such as the Nichols radiometer. Another incorrect theory was that the heat on the dark side was causing the material to outgas, which pushed the radiometer around. This was effectively disproved by both Schuster's and Lebedev's experiments.

A partial explanation is that gas molecules hitting the warmer side of the vane will pick up some of the heat, bouncing off the vane with increased speed. Giving the molecule this extra boost effectively means that a minute pressure is exerted on the vane. The imbalance of this effect between the warmer black side and the cooler silver side means the net pressure on the vane is equivalent to a push on the black side and as a result the vanes spin round with the black side trailing. The problem with this idea is that while the faster moving molecules produce more force, they also do a better job of stopping other molecules from reaching the vane, so the net force on the vane should be the same.

The greater temperature causes a decrease in local density which results in the same force on both sides. Years after this explanation was dismissed, Albert Einstein showed that the two pressures do not cancel out exactly at the edges of the vanes because of the temperature difference there. The force predicted by Einstein would be enough to move the vanes, but not fast enough.

The final piece of the puzzle, thermal transpiration, was theorized by Osborne Reynolds in an unpublished paper that was refereed by Maxwell, who then published his paper which contained a critique of the mathematics in Reynolds's unpublished paper. Maxwell died that year and the Royal Society refused to publish Reynolds's critique of Maxwell's rebuttal to Reynolds's unpublished paper, as it was felt that this would be an inappropriate argument when one of the people involved had already died. Reynolds found that if a porous plate is kept hotter on one side than the other, the interactions between gas molecules and the plates are such that gas will flow through from the cooler to the hotter side. The vanes of a typical Crookes radiometer are not porous, but the space past their edges behaves like the pores in Reynolds's plate. On average, the gas molecules move from the cold side toward the hot side whenever the pressure ratio is less than the square root of the (absolute) temperature ratio. The pressure difference causes the vane to move, cold (white) side forward due to the tangential force of the movement of the rarefied gas moving from the colder edge to the hotter edge.

There are lots of cool things to look at according to this: http://www.hoagieshouse.com/IR/

Link to UV

This experiment often links well if placed near UV or demonstrated as a pair. You'll find the lights in IR can be too bright to see UV florescence. If separate demonstrations try and place slightly further apart or use the boxes as a screen if paired then switch off when moving across.

Risk Assessment

Hazard: Lightbulbs (glass)

Description: If the lamps are knocked over, the bulb may shatter and cause cuts.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Take reasonable level of care with lamps. Do not place near desk edge. Prevent children playing with lamps. Call first aider in case of injury

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Incandescent light

Description: Incandescent light gets hot if left on, causing burns or possibly fire.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Do not allow children to touch lamps, do not place too near the darkroom wall, or any flammable object. Turn off between demonstrations.

In the event of broken glass, move public away and clear up mess carefully as soon as possible. In the event of injury, call first aider.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Fluorescent bulb

Description: Compact fluorescent bulb contains (very small) quantity of mercury.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Ensure lamp is stable and not easy to knock over. Consider using LED bulb rather than fluorescent bulb for the energy efficient one if available. If lamp becomes broken, keep the public well away from the area, and ventilate area where breakage occurred. Take usual precautions for collection of broken glass. Do not use a standard vacuum cleaner for cleaning up dust; instead, pick up pieces/dust with a damp cloth or damp paper towels, or sticky tape for the smallest dust. Place materials, including the cloth/towels, in a sturdy closed container to avoid generating dust. After you have picked up all that you can, then vacuum the area. Finally, ventilate the room where the breakage occurred.

Call first aider in case of injury

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Lightbulbs turned on in a darkroom

Description: Lightbulbs can appear very bright when just switched on in dark room. Eyes are not used to that brightness, so people may be dazzled.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 1, Overall: 3

Mitigation: Warn children/visitors not to look directly into the lamps when you switch them on.

After Mitigation: Likelihood: 2, Severity: 1, Overall: 2

Hazard: Electrical cables

Description: Trip hazard.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Try to keep cables out of thoroughfare. If cables must be placed somewhere people are likely to be walking, tape them down.

Call first aider in case of injury

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Out-of-date Coke

Description: Children may drink the Coke – possible stomach upset.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Do not let children drink the Coke. In the event of drinking, call first aider. Coke bottle is sealed with tape.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Crooke Radiometer

Description: May fall and smash - possibility of cuts

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Keep excitable children away from the radiometer. Don't let them touch the radiometer - there's no need to. Keep it in a safe place, either in sight, or away and consider taping down. If the radiometer does smash, clear up immediately and clear the area until safe.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-13 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2014-01-21 - Holly Davis (hd308@cam.ac.uk), **Check 2**: 2014-01-22 - Brett Abram (ba305@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-07 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk)

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-01-17 - Lucy Hart (ljfh2@cam.ac.uk)

Check 1: 2019-01-01 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-01-23 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-01-30 - Lavinia Finalde Delfini (lf465@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-13 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-01-30 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-01-31 - Joshua Wu (jw2311@cam.ac.uk)

Non-Transitive Games

What's the best option in games of chance? - Some games really aren't fair. Even if your opponent knows your exact move you can still beat them. Explore some of these games and find out there might not be a sensible best choice.

Last initially checked on 2024-02-15 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Lauren Mason (llm34@cam.ac.uk)

Tags

Games

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Many sets of 4 non-transitive dice:
  - Orange - 2,2,2,2,6,6
  - Yellow - 3,3,3,3,3,3
  - Green - 1,1,1,5,5,5
  - Blue - 0,0,4,4,4,4
- A Microsoft box, which has the same dice
- A set of Grimes Dice (seems to be missing)

Experiment Explanation

Currently copy-pasted from aka.ms/ntdice; TODO write our own or switch back to Grime Dice...

About the dice

First of all, let us examine the dice in detail. Here we have 'flattened' the dice to show the numbers on each of the faces.

- Orange - 2,2,2,2,6,6
- Yellow - 3,3,3,3,3,3
- Green - 1,1,1,5,5,5
- Blue - 0,0,4,4,4,4

We see that the choice of numbers is unusual. But in all other respects these are normal, fair dice. If we pick two of the dice and roll them, we can see which comes up with the higher number. We will say that the die with the higher number is the winner. Notice that each of the numbers 0, 1, 2, 3, 4, 5, and 6 appears on only one of the dice, which means that when we roll one die against another, there can never be a draw.

First, suppose you roll the orange and yellow dice. Two thirds of the time the yellow die will come up with a higher number than the orange die. We say that the probability that the yellow die will win is two thirds. If we make a large number of such rolls and keep track of which die wins, then there is a very high chance that the yellow die will win more often than the orange die.

Likewise, two thirds of the time the blue die will win against the yellow die, and two thirds of the time the green die will win against the blue die. So, yellow beats orange, blue beats yellow, and green beats blue.

It therefore seems as if the green die has the highest chance of winning and the orange die has the lowest. But now for the surprise: if you roll the green die with the orange die, then two thirds of the time it is the orange die that will win!

These are known as *non-transitive* dice. 'Transitive' means that if A beats B and B beats C then A beats C. We see that these dice do not have this property. One way to visualise this is to arrange the dice in a circle, such that each die beats the previous one.

Yellow beats orange, blue beats yellow, green beats blue and orange beats green.

This is rather like the game of "rock, paper, scissors" in which scissors beats paper, and rock beats scissors, but paper beats rock.

A simple game

You can use this non-transitive property to play a game with a friend. Invite them to examine the dice and then to select any one of them. Without telling them the secret, you now select the next die in the sequence, and then you make, say, 9 rolls against your friend, and keep note of how many times each of you rolls the higher number. Over a sequence of 9 rolls it is very likely that you will roll a higher number more often than your friend.

How the dice work

Look first at the orange die, and notice that it has four copies of the number 2 and two copies of the number 6. Two-thirds of the time, when we roll the orange die it will give a 2, and one third of the time it will give a 6. Therefore, if we roll the orange die against the yellow die (which always gives a 3), the yellow die will, on average, win two-thirds of the time, and will lose one-third of the time. You can repeat this game several times, each time allowing your friend to choose their die first.

Now look at the blue die, and notice that it has four copies of the number 4, and two copies of the number 0. When we roll it against the yellow die, it will therefore give a 4 two thirds of the time, in which case it wins, and a 0 one-third of the time, in which case it loses.

Now suppose we roll the green die against the blue die. The green die has three copies of the number 1 and three copies of the number 5. To work out the probability that the green die will win we first note that there is a probability of 1/2 that the green die will give a 5, in which case it is certain to win against the blue die. Likewise, there is a probability of 1/2 that the green die will give a 1, in which case there is a probability of 1/3 that it will win. The overall probability that the green die will win is then given by multiplying the probabilities:

$$\left(\frac{1}{2} \times 1\right) + \left(\frac{1}{2} \times \frac{1}{3}\right) = \frac{2}{3}$$

Finally, consider the probability of the orange die winning against the green die. There is a probability of 1/3 that the orange die will produce a 6, in which case it is certain that the orange die will win. There is similarly a probability of 2/3 that the orange die will produce a 2 in which case there is a 1/2 chance that the orange die will win. The overall probability of the orange die winning is again obtained by multiplying the probabilities:

$$\left(\frac{1}{3} \times 1\right) + \left(\frac{2}{3} \times \frac{1}{2}\right) = \frac{2}{3}$$

Bonus story from Microsoft!

Warren Buffett once challenged Bill Gates to a game of dice. "Buffett suggested that each of them choose one of the dice, then discard the other two. They would bet on who would roll the higher number most often. Buffett offered to let Gates pick his die first. This suggestion instantly aroused Gates' curiosity. He asked to examine the dice, after which he demanded that Buffett choose first." Buffett was using a set of non-transitive dice!

Grime Dice (which we seem to have lost...)

At some point we should buy a proper set from MathsGear.

There should be a set of dice in the box with the following numerals: - red - 9,4,4,4,4,4 - blue - 7,7,7,2,2,2 - olive - 5,5,5,5,5,0

(They're slightly larger than normal so we can move onto 5 dice later using the same ones)

Take turns with your opponent to pick a dice and see who can roll the highest number. Try a best of three or five to decide which dice to pick, if they pick first you can always beat them. What you'll find is Red > Blue > olive > Red. Get them to construct two of the chain and ask them to guess what happens with the third pairing. Most will think that it's going to be transitive and Red will beat olive, however it isn't! Easy way to remember the order is increasing word length.

Any easy way to relate this is to rock, paper, scissors. Here Rock > Paper > Scissors > Paper. When we pick at different times this games becomes very unfair. With the dice there's no certainty but you can explain by playing multiple times you make it more likely.

You can take some maths and try and work out the winning probability. Red beats Blue if we get a 9 straight away, that's probability 1/6. If we get a 4, 5/6 probability, then we win when Blue gets a 2, probability 1/2, these are 'independent events' so we can get a total probability of 1/6 + 5/12 =7/12 > 1/2. You find this is the same for all pairings.

If they've understood flip it around and let them beat you. Then move to two dice and keep going first. You'll want to increase the number of rolls to make it a best of 5 at least. You'll notice that in fact the order swaps around when you look at the totals. It should decrease to about 57%.

Lets add in 2 more dice. We want to be able to beat 2 players simultaneously

- yellow - 8,8,3,3,3,3
- magenta (pink) - 6,6,6,6,1,1

There's an alphabetical chain and a word length chain. Alphabetical chain has a higher win probability if there's only one player. If there's two you can find a unique dice to beat both.

This analogues Rock,Paper, Scissors, Lizard, Spock (from The Big Bang Theory TV show) with new rules

Scissors cuts Paper, Paper covers Rock, Rock crushes Lizard, Lizard poisons Spock, Spock smashes Scissors, Scissors decapitates Lizard, Lizard eats Paper, Paper disproves Spock, Spock vaporises Rock, (and as it always has) Rock crushes Scissors.

In this game the doubling of dice reverses the word length chain and the alphabetical chain remains more or less the same apart from the fact red and olive flips technically but remains very close to 50-50. Overall 59% win chance.

For beating two players we're at 44%. You may think that's bad as you still lose fairly often but you only lose to both 22.7% of the time. Consider a game where both opponents pay £1 and you'll pay out £1 to anyone who rolls higher. For 100 rolls you make £88 on the games you beat both on 44 rolls, lose £46 when you lose to both on 23 rolls and the rest of the time you make nothing (but don't lose anything either). So you're £42 in profit!

Inspired by the experiment here: http://singingbanana.com/dice/article.htm

If you have a spare table this is a very easy experiment to float with by only going up to the Rock-Paper-Scissors part of the experiment. Demonstrate you can always win and sometimes "better than" isn't transitive.

Risk Assessment

Hazard: Dice

Description: Children swallowing or choking on dice.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Don't use with small children and keep the dice attended. Call first aider if child swallows, if choking encourage child to cough.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Dice

Description: Dice could be a slip hazard if dropped on floor.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Keep an eye on where any dice go, and try to confine them to a desk or fixed area. Do not let multiple unattended children use dice at the same time. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Rock Paper Scissors

Description: Kids getting too enthusiastic and attacking others when playing rock paper scissors

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Encourage kids to be calm. Make them stop if they are being silly / don't play RPS with them Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2017-02-09 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2018-01-02 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-02-05 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2020-02-05 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-22 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-05 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk)

Check 1: 2023-02-05 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-16 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2024-02-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Lauren Mason (llm34@cam.ac.uk)

Organ Vest

A velcro apron with detachable 3D organs, to show what's inside your body. - See if you can correctly place body organs using this wearable felt and velcro vest.

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- Apron
- Organs as listed below.

Experiment Explanation

This game can be tailored to the particular child, and depending on how old they are you can just either ask them to put the organs in the right place, or talk about each one in a little more detail.

I usually do the organs in the following order (getting more difficult as the game progresses) and talk about/ask the child what each one is for:

HEART: Ask them to look at the colour and guess what goes inside it. Tell them that it acts as a pump, and is needed to push blood around the body.

Keen: could go into why blood is needed etc. Ultra keen, try and grab a spare stethoscope and find their their heart beat at the appropriate place.

LUNGS: Talk about breathing; try and get them to link up lungs to the mouth with the trachea (NB trachea does not currently exist as a component of the vest, but you can talk about it anyway!). Interesting fact: If the inner surface of the lungs could be stretched out flat, they would occupy an area of around 80 to 100 square meters – about half of a tennis court!

DIGESTIVE SYSTEM: Try and get them to link it all up, and explain what it does in terms of breaking your food down into smaller bits so it can be used to re-build things inside your body. Also talk about what happens in the end, and try and get them to guess what it comes out as (usually good for getting a giggle, but be warned sometimes the kids come up with very rude words much to the embarrassment of everyone around...)

KIDNEYS/ BLADDER: Get them to link them up and talk about what happens when you drink too much water etc. Get them to try and guess what's in the bladder by its colour (also often gets another giggle). A surprising number of kids know about kidneys, or at least that they exist- ask them about why there are 2, whether they think we could survive with just 1-some may know people who have had kidney transplants etc.

LIVER: Difficult one to explain. I usually go along the lines of it's like a big factory in your body where things are broken down and important things like stuff in your blood is made. Ultra keen: talk about it also being needed to break things like poisons and alcohol, and try and mention what might happen to the liver for instance in alcohol poisoning.

INTERESTING FACTS / TIPS: Small intestine is 7m long, but is coiled up to fit inside the body. Furthermore, due to villi total surface area is 2000 square meters = half a football pitch.

By the time you turn 70, your heart will have beaten two-and-a-half billion times (figuring on an average of 70 beats per minute) = 175 million litres of blood = 50 Olympic swimming pools!

The liver is able to regenerate to a certain extent, so you can donate part of your liver and the donor and acceptor will both be fine.

Risk Assessment

Hazard: Vest

Description: Risk of small children tripping on apron whilst wearing.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Do not allow children to run around while wearing vest. Be more aware if vest is especially long on the child. In case of accident, call a first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Vest used by multiple children

Description: Germs could spread between children using the vest

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Don't let children lick the items / the vest. Wipe off spit etc if child drools over vest.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2012-01-11 - Elizabeth Mooney (erm40@cam.ac.uk), **Check 2**: 2012-01-23 - Ashley Smith (ashley.smith@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-06 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-25 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-08 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-10 - Alisha Burman (arb95@cam.ac.uk)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-07 - Natalie Cree (nc434@cam.ac.uk)

Check 1: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-12 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-03 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-12 - Beatrix Huissoon (beh37@cam.ac.uk), **Check 2**: 2020-01-27 - Samuel Amey (sra44@cam.ac.uk)

Check 1: 2021-01-07 - Samuel Amey (sra44@cam.ac.uk), **Check 2**: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2022-01-26 - Hayoung Choi (hc585@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-02-15 - Amy Migunda (aom36@cam.ac.uk), **Check 2**: 2023-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Penguins, Poo and Populations

Counting when we can't count - How can we count the number of penguins, there's far too many? Investigate several ecological techniques to use statistics to help us out.

Last initially checked on 2024-01-30 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk)

Tags

Ecology

Stats

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- 100ish uniquely identified ducks
- A whiteboard
- A dozen penguins, with markings on the base
- Satellite poo photos
- Plastic area grid
- Giant calculator

Experiment Explanation

If we're studying animals in the wild then it'd be useful to know how many there are. We'll look at some techniques ecologists use. One key thing to think about is tradeoffs, mainly between how accurately we need to know the population and the costs in time and money of working it out.

We want to estimate how many ducks are in the pond, take out a large handful and hide them away so the numbers are at random. Kids may try and count, it works fine for rubber ducks, but they'll have issues if they try with real ones! They move around, all look the same, are right in the middle of the pond, fly off or are hiding. In reality we'll have to make do with an estimate! There's two ways of doing this. [you may get some people guessing based on the numbers on the bottom, this is also very interesting but not in the context of ducks (which rarely come uniquely numbered). It's called the German tank problem and you can explain if you know about it, even though it's not related to ecology!]

Capture Recapture

One way we could do this is via sampling. Take a sample of ducks (around 12-16 works well if you've removed a dozen or so) and mark on the whiteboard which numbers you saw. Replace the ducks and mix well. This represents our first sample and we've now made sure our next sample is 'independent' by shuffling it. Take another sample of ducks and count how many are in both. We then need to do some maths, the sample size over total number of ducks will be our probability of picking any given duck from the first sample in sample 2. So if we times this by the sample size it gives how many ducks we'd expect to see both times. Doing the product of sample sizes divided by the number in both gives us our estimate. You can now ask questions about the population. Drawing a Venn diagram may be useful. Can we say anything about the minimum size? Yes, it's at least the number of unique ducks we saw… What about the maximum? Nothing at all, however we can think about it, if there were lots of ducks we'd not get any repeats and if there were only a few more than the sample size we'd get mostly repeats. Other ways to improve include making the sample size bigger. (Presumably with a vague prior on duck populations you could use Bayesian inference to get the most likely population size?)

You can talk about the effects of sample size on the estimate: what do you think increasing it does? Increase variance or uncertainty. Why don't we take big samples? It's expensive.

You can also talk about bias: if you don't mix, you'll probably get some bias.

This is where you might see marked, chipped or collared animals as part of these estimates.

Can also talk about quadrats.

Biased Sampling

This is a quick demo to talk about it and isn't majorly about animals. Take an opaque bag with 20 small balls and 5 large of different weights. Tell people they can pick a sample to guess the weight of the bag of balls. Tell them there's 25 balls in it, but don't mention the different types. People will gravitate to picking bigger balls so it'll bias their sample and throw their weights off.

Penguins by poo

Even capture recapture gets expensive if we want to estimate penguins. Why? They're far away, not good infrastructure, it's chilly, etc. So we want to find a better way. As penguins live on ice sheets which are white we can use photos to pick them out. Show some photos from a satellite (a few are actually drone photos but very similar). It's hard to count penguins in this as they move and are slightly camouflaged. Huddles are confusing due to varying density. So we count the amount of poo! You can pick it out in the photos. So how might we estimate the number of penguins. Count the area of poo, use the grids over the picture to work out the poo area. We now need to work out poo area a penguin produces! Here are some penguins, lift them up to reveal their poo areas. You'll need to take a sample and average. You'll also notice the babies are a source of bias… This is similar to before. If you do the maths you can estimate the population. Where are the errors? Where did our sample come from, zoos is a nice controlled environment for it, but might not give the best accuracy for wild penguins - different food and environment. There's also the depth factor which we ignore. Our measurements weren't perfect for the area either, however satellites can do much better.

Risk Assessment

Hazard: Ducks/penguins/balls/other small objects

Description: Child may swallow or choke on these small objects if put in their mouths.

Affected People: Children

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: Inform them they are rubber/plastic and not edible. Keep track of all the ducks. Most items are too large to cause ingest easily. Call first aider if child swallows, if choking encourage child to cough.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Ducks/penguins/balls/other small objects

Description: Trip hazard if dropped.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Keep track of all the ducks. Pick up if dropped. Don't let children run around.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Whiteboard Pens

Description: Children could be tempted to lick the pens and become sick as a result.

Affected People: Children

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Monitor the pens and don't let very small children use them (at least without supervision). In case of licking, call first aider, or tell parent to contact GP if child feels ill later.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: The Squeak

Description: Children may loudly squeak ducks, especially in people's ears.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Remove squeakers if necessary. Don't allow children to have extended contact, keep track of ducks currently off the table. Don't let ducks be squeaked around ears. Sit person down if required after ear squeaking.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2018-12-07 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-02-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-02-05 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2021-01-22 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-05 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-02-10 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2023-02-12 - Joshua Wu (jw2311@cam.ac.uk)

Check 1: 2024-01-30 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk)

Platonic Solids

Explore the five platonic solids and other 3D shapes. - Making 3D shapes out of 2D ones. Look at how angles combine to tessellate and then form 3D corners.

Last initially checked on 2024-02-15 by John Leung (cfl35@cam.ac.uk) and double-checked 2024-02-15 by Charlotte Marshall (csm69@cam.ac.uk) ## Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Polydron kits (we have 2 sets of platonic solids and a 'small' set of Archimedean solid pieces)
- Selection of Solids
- Some laminated cards that came with one of the sets

Experiment Overview

Polydron kits are a great way to build up 3D shapes. They should easily and intuitively clip together. The goal of this experiment is to build 3D shapes and talk about them mathematically.

The basic key concepts for all ages should be that of faces, vertices and edges. Hopefully, they'll be able to name many of the 2D faces and some of the 3D shapes at the end too.

There are a lot of different types of 3D shapes you can make, but in this experiment, we want to focus on some mathematically nice ones. Some key ``nice'' properties are: **Convex** - This basically means if you connect any two points on the surface with a line it stays within the shape. We don't want shapes that bend back on themselves weirdly, no matter how much people might build them. **Platonic** - A special type of 3D shape where all their faces are exactly the same, the faces are all regular (same angles and sides) and the same number of faces meet at each vertex. There are only five: the Tetrahedron, Cube, Octahedron, Dodecahedron and Isocohedron. **Archimedean** - A special type of 3D shape that's less restrictive than platonic. Faces don't have to be exactly the same but each vertex needs to look the same.

Experiment Stories

These are two ideas of a story to use when demonstrating this, one targeted at younger and one at older groups. You will likely want to adapt this, there are a bunch of topic suggestions below which can inspire a theme.

Younger Story (by Lake)

With younger groups, you will likely find it harder to motivate the definitions of `Platonic'' and`Archimedean'' since they are quite abstract. However many younger children will be happy building away and there's an opportunity to sneak in facts relating to what they're doing.

You may find that young children get attached to the shapes they make. One way to deal with this is to have a special area to ``save shapes''. You may want to actually save any shapes that are interesting to talk about however unfortunately we don't have enough pieces to keep Barry's giant rocket that uses nearly every pentagon. It's worth emphasising we need to keep the pieces and it'll get broken down eventually, they need to leave the shape at some point and it's time for other people to have a go. It's also an experiment children can easily get absorbed in doing none maths things, don't be afraid to tell them to see something else or that someone else wants a go.

Pre-built Platonic Solids - If you have an example of each of the 5 built ask them to compare it to what they've built. What's different about them? What might the shapes be useful for? (dice) Would their shapes make good dice?

Octahedron Challenge - Ask them to build an octahedron, often they'll make a triangular bipyramid (two triangular pyramids joined together). You can use these two shapes to get an idea of symmetry. The bipyramid clearly has a right way up, however turning the octahedron every way looks the same. There are clearly a lot more symmetries. Or platonic solids all have a lot of symmetries.

Truncation - This is a good way to combine two types of shapes but still make something symmetric. You can also link to the football. A football is likely to take a while to build so you may want to avoid this in schools.

Filling 3D Space - The cube is the only regular solid that tesselates 3D space.

Prisms and Antiprisms - These are cool to mention and build. You can then link to the fact that you can chop an icosahedron into a pentagonal anti-prism and two pentagonal pyramids, leading to its other name a ``gyroelongated pentagonal bipyramid''.

Older Children Script (by Tom)

For older children, I like to focus on the ``about maths'' aspect. To do this I usually start by showing a cube. I ask what they think is special about a cube, and what properties we might see as nice or interesting. You can then start guiding them to the definition of Archimedean. Adding in a tetrahedron usually gets the key properties so you can write down the definition. I usually mention here these shapes make good dice and other properties that make them useful.

For mathematicians, once we've got a definition there are a few natural questions. First off is usually ``How many shapes satisfy this property?''. So take some guesses. They've seen at least 2 shapes so can guess anywhere between 2 and infinity. Once guesses are in, ask how they might find out if they are correct. You can do some building to show there are at least 5.

For uninterested groups, I tend to end here by claiming there are no more.

I then tend to do a guided proof there can't be a sixth. How many shapes are needed to make a corner? (at least 3) What happens with 3 hexagons? What happens with 4 pentagons?

Where short on time or interest is now dropping I'll end here, everything past is just bonus content for the still engaged.

Following the how maths works theme I usually then talk about relaxing the definition. If you're interested in the symmetries of the shapes you can find some very symmetric shapes with different faces, so let's drop that condition but instead make sure each corner looks the same.

It's worth asking again how many shapes like this there are. Produce a few new examples to show there are definitely new ones. It turns out the answer is infinite. We can show this nicely by producing an infinite family, the prisms. If students look harder they may also find the anti-prisms. Mathematicians like to keep asking how many, and the next question here is how many are there which aren't prisms or antiprisms?

From here you can talk about truncation and how that affects symmetries. Chirality and what actually counts as different shapes or ask the question in higher dimensions or other generalisations.

Other Topics

These are an assortment of topics. This experiment is quite open-ended and you will likely want to vary what you do for different ages. The topics below are mentioned in some of the above-suggested scripts.

Proof only 5 Archimedean Solids (12+)

For simplicity of notion in the explanation I'm going to use Schlafli symbols {p,q} where p is the number of edges each face (e.g., for triangular faces $p = 3$) has and q is how many faces meet at a vertex (e.g., for a cube $q = 3$). These leave {3,3} {4,3}, {3,4}, {5,3} and {3,5} as our platonic solids. You are unlikely to want to talk about these with children but mathematically they're convenient.

Try building things up, at a vertex the things that meet must have angles less than 360 degrees or else they won't fill space. You can easily try making each $\{p,q\}$ into a 3D shape. Doing this we eliminate several options: having $q < 3$ makes no sense as at least 3 shapes must meet to form a vertex; then anything with $p > 5$ can't have 3 (or more fit together) at a corner as the angles are too big; finally, {6,3} encodes a tessellation of the plane by hexagons, so isn't 3D. Similarly {4,4} and {3,6} are tessellations, leaving us with only five options. It turns out all of these work, you can show this by making them or getting out the dice.

The above proof (using Schlafi symbols) is completely formal and completes the proof. In fact, this was an interview question for Queens' maths applicants.

PLUS - You can also do a topological proof using Schlafli symbols. Using Euler's formula and the following fact: $pF = 2E = qV$, you can bound things by eliminating F and V in Euler and then getting $\frac{1}{q} + \frac{1}{p} = \frac{1}{2} + \frac{1}{E} > \frac{1}{2}$. Then as $p, q > 2$ we can find the only five possibilities. Again this just shows there are at most five, by giving the shapes we show there are at least five. We need to check this as we could have introduced new false solutions when doing this manipulation or reasoning.

Euler's Formula (10+)

We can talk about Euler's Formula. The concept of face, edge and vertex (corner) should be easy to explain. Then get them to count up the number of each (hide the curvy-edged shapes). Now consider the magic formula, $V - E + F$, if you keep on trying it you should always get two!

Prisms, Antiprisms, Truncation and Archimedean Solids (Any)

Archimedean Solids are the next step from platonic, removing the requirement that all the faces are the same. There are two infinite classes the prisms and Antiprisms (which have a belt of triangles and are slightly skew). These are sort of Archimedean but we exclude them as there's a prism and an anti-prism for each -gon, thus infinitely many in each class. Then let's look at other ones. There's between 11-17 (roughly should double check) depending on your definition of 'the same', i.e. allowed isometries.

The easiest to find are the truncated platonic solids, you get these by slicing corners off the solids, this doubles the number of sides and creates new faces. This gives 5 Archimedean Solids.

You can also form some manageable ones with vertex patterns (3,4,5,4), (3,5,3,5), (8,6,4), (3,4,3,4), (4,4,4,3). There's also a very large one with the pattern (10,6,4) notable for how large it is. Patterns describe the number of sides in each shape clockwise around a vertex.

Chirality (PLUS)

here are a few weird 'Archimedean Solids' which depend on your exact definition. There are two alignments of the shape (4,4,4,3) which has a belt of squares around the middle, this is formed with either the triangles aligned or not, the number of belts changes. There are also two snub shapes (3,3,3,3,4), (3,3,3,5), these expand the cube and dodecahedron with a belt of triangles. These two have a chirality which you can change by folding the net up and down.

Dual Solids (PLUS)

Dual solids take faces ⇔ vertices. We do this by placing a vertex in the centre of each face and an edge between these vertices if the faces touch. Tetrahedrons are self-dual. Cubes and Octahedrons are a dual pair. Isocehedrons and Dodecahedrons are a dual pair. One can view this operation as swapping $p \Leftrightarrow q$ in the Schlafli symbol.

Hexaflexagons (PLUS)

You can link this to hexaflexagons by talking about symmetry groups. It may be easier to start with symmetry groups of faces and then move to the 3D shapes. You can talk about order and associativity. See the Hexaflexagons experiment for more info.

Tesselations and Curvature (PLUS)

Talking about tessellations, there's a fairly interesting link as the platonic solids biject with tilings of the sphere (positive curvature) by projecting. The boundary cases {3,6}, {4,4} and {6,3} are plane tessellations and then any other $\{p,q\}$ defines tessellations of hyperbolic surfaces (negative curvature).

Nets

Once you've built a shape, detach a few edges and flatten it out to form a net. A net is a 2D representation of a 3D shape. There are a few interesting questions you can ask. How many different nets does a cube have? I think there are eleven, up to symmetries, but I may be wrong. Try the same for an open cube (one face missing).

4D Platonic Solids

This is a bit higher level but can be cool/mind-blowing. We don't currently have print-outs but you can show the animations on a CHaOS laptop or tablet to visualise them. https://math.ucr.edu/home/baez/platonic.html

Footballs

This is a good topic for football-mad kids. Ask what shape a football is. A ``classic'' football shape is actually a truncated icosahedron, made up of 12 pentagons and 20 hexagons and with a bit of bulge from air pressure is quite close to being a sphere. This 32-panel ball was introduced in the 1960s, before that balls were even less round and due to materials were quite heavy. If you've seen more recent World Cup balls often they have complex panels, this is from advances in manufacturing allowing more complex designs. The perfect football would always be a perfect sphere, however, they deform when being kicked and reducing this is part of the modern design improvements. There are also 24-pannel balls (using curved shapes) and 42-pannel balls (these replace the hexagons with 30 trapeziums). There are currently no photos of footballs printed but these could be added.

History

The platonic solids have been historically important, with Greek philosophers believing they corresponded to the five elements (we now know of more than 5 elements). The tetrahedron, cube, octahedron, dodecahedron and icosahedron correspond to fire, earth, air, ether and water. Of these none are elements, especially ether which doesn't exist. Kepler also believed the platonic solids formed shells on which the planets orbited, while close (coincidentally), it's not true either.

Risk Assessment

Hazard: Plastic pieces

Description: Children swallowing or choking on plastic.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep the experiment attended at all times. Do not give small plastic parts to very young children (or let them take them).

Call first aider if child swallows, if choking encourage child to cough.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Polydron pieces

Description: Fingers could get caught in them.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Keep a close eye on children using them. Advise caution.

Call first aider in case of injury.

After Miigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Larger polygons

Description: Larger polygons, especially the decagon, may fit over the head of a child. May cause strangulation if looped around neck and pulled.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: Keep decagons out of reach of small and/or badly behaved children (they aren't really necessary for the Platonic solids, but may be useful for some of the more general solids that you might build with older children).

Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk), **Check 2**: 2020-01-27 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-28 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2021-01-22 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2022-02-05 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-02-12 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2023-02-18 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2024-02-15 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2024-02-15 - Charlotte Marshall (csm69@cam.ac.uk)

Polarisation

Discover how polaroid filters block light as you turn them round - Experiment with the properties of light as certain filters block light, but only in certain directions!

Last initially checked on 2023-12-23 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-01-06 by Lucy Bland (lb831@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Darkroom preferable**
- **Electricity needed**
- Blue light box
- Two polaroid filters.
- Some bits of clear polythene
- Rulers, set squares etc, for bending.
- Some pieces of calcite
- A partially dismantled LCD screen
- Card model for demonstrating birefringence
- Slinky
- A bunch of photographic CPL (see explanation)
- PLUS only:
- Two circularly polarising glasses
- Michel-Levy Chart + diagram of LCD screen and of twisted nematic structure

Experiment Explanation

Overview

Demonstrating the use of polarisers with crossed polars, polythene strips, plastic rulers and a light box.

Possible activities: - Demonstrate how crossed polars work by rotating two pieces of polaroid with respect to each other and looking through them to see how the light changes. - Looking at stressed plastics under polarisers. - Demonstrate the colour change when a strip of polythene is stretched when viewed under the polariser material.

Other things to talk about: - LCDs and how they work.

Tips for demonstrating: - Let the children experiment with different objects under the polarisers as this will keep their interest. - Use paper strips with waves drawn on to help to demonstrate how polaroid filters work.

Basic Procedure and Explanation

1. Show them the light box and the polarising filters

- The box gives out "normal" white light. Experiment generally works best if set on the floor/ somewhere low enough that everyone can easily see from directly above.
- Take the top piece of polariser and give it to them, get them to look at it in the light. What does this look like -> grey piece of transparent plastic.
- Put the polariser on the light box the way round so light can get through. Still look normal?
- Get them to rotate the polariser around, and see what happens… This normally gets their interest. Get them to turn it upside down.
- Ask what is happening: looks almost black one way round, turn it 90 degrees and it looks bright again

2. Introduce the idea of light as a wave

Do they know what a wave is?

- Ask them what types of waves they know about: sound, water, etc.
- Can they make a wave along their arms? (An awesome dance move if you can pull it off!)

Light behaves like a wave, this wave can be in all directions

- Explain that light is a wave using a wave sketch on a bit of paper
- Light can wobble in different orientations - polarisations. It can wobble up-down, side-to-side, and everything in between
- You can imagine this as a 2D wave like the one sketched on the paper (Yes, we know that there's a second component of the wave, but if you consistently talk about the same component of the wave the explanation is right..)

Polarising filters are like grills that let light through in only in some directions

- Using your fingers as a grill demonstrate what the polariser looks like. Get them to try and get the piece of paper in the through the grill parallel and perpendicular to the grill, i.e. in the two different polarisations.

- Only half the light can get through - this is why the plastic looks slightly darker normally.

- Then add another grill parallel to the first which will allow the light from the first grill to get through. Rotate it by 90 degrees to demonstrate that light can't get through with any orientation. This makes the polariser look black.

- You'll have lots of hands available, you can show the effect of as many twice as many polaroid filters as you have people! You can show that if the light passes through the first filter if it stays at that orientation it can't get through the second one.

Demonstrating polarisation with a slinky

If you have the space and at least 3 people, then instead of using finger grills, you can illustrate polarisation using the slinky: - Get someone to hold each end of the slinky. - Tell one of them to shake their end up and down, sending waves along the slinky. Then have them shake the end from side to side, sending waves with a different polarisation. - Get someone to stand with their legs on either side of the slinky, acting as a polarising filter. Now when waves are sent down the slinky, only up-and-down waves can pass through. - You can then stand over the slinky as a second polarisation filter, and show that nothing changes. - Then, sit down with one leg above the slinky and one below it, so that the filters are crossed. Now no waves can get through both filters!

3. Twisting the direction of the light

Demo with the filters

- Ask them what you would have to do to the light (wave drawn on paper) between the crossed polars to get it through. They normally tell you to twist it.
- You can introduce a third polar at 45 degrees to do this (current kit only has two though, unless you use the sunglasses)

Polythene (bags) can twist light

- The polythene normally doesn't affect the light but if you stretch it, it will twist the light.
- Let them have a go at stretching the polythene strip in the light box under the polaroid filter (this can take a while as they find it fascinating!). You should see many colours.
- The different colours twist the light by different amounts. So pick a red bit (best as they know what colour you get if you mix blue and green). You may rotate red by 90deg so it will get through, blue by 180deg so it won't, and green by 360deg so it won't...
- Now get them to look at a red bit while you turn the polariser through 90deg - it should now look turquoise... Now the polars are parallel so red is twisted 90deg so it doesn't get through, blue is by 180deg so it does... -> turquoise light gets through.

Plastic rulers can twist the light

- Put a ruler between crossed polars, you should see lots of colours. These are because they are made by injection moulding, so the plastic is effectively stretched in manufacture.
- The place where the most stretching happens is where the plastic was squirted in - you should be able to see this and you can probably see the rough bit where the sprue was attached.
- There are some rulers that have been cooked, and you should see the shape has changed most in the place where there was the most stress.
- You can also bend the ruler and see stress. A ruler with a crack in it should concentrate stress.

Calcite crystals can twist light

- The crystals of calcite twist light as it travels through, so can appear lighter or darker than the background when placed between the crossed polarisers.
- If v. keen can try and explain birefringence - section below.
- Calcite crystals make double images! The images can be blurry so this may be hard to see. Try looking through the crystal at a line drawn on paper or the numbers on a ruler.
- Light slows down and travels at a different speed in some materials, so the light path bends (refraction). In calcite the speed is different for the two polarisations (birefringence - see below), so the bending is different for the two polarisations. This means there are two paths for the crystal and so you see two images (double refraction).

CPLs

- Photographic circular polarisers (CPLs) are directional. In the direction of photographic usage, they feature a linear filter (distal of the sensor), followed by a quarter-wave plate (proximal) The latter turns the (now) linearly polarised light into circularly polarised light.

4. Uses of polarisation

Possible uses of polarisation (you don't have to mention all of these!):

In physics: light reflecting from a surface or scattered from a material is partially polarised, and polarising sunglasses use this to cut out glare.

In chemistry and materials science: certain molecules rotate polarised light, and we can use this to identify and analyse substances.

In engineering: observing a material undergoing stress through crossed polars

In biology: some animals (such as certain insects) use polarised light for navigation, since the sky is naturally polarised, and even humans can observe polarised light with practice due to a quirk of biology:
https://en.wikipedia.org/wiki/Haidinger%27s_brush

In geology: certain minerals give different colours when placed between crossed polars (see Michel-Levy chart in box)

3D cinema glasses (there's some in the box) use circular polarisers. More info:
http://en.wikipedia.org/wiki/Polarized_3D_system#Circularly_polarized_glasses

5. Extension: LCD screens- how they use polarisation

The black object with a window and several buttons is an LCD which has had the polarisers removed (and the wiring completely mangled) so you can see that they work through polarisation. Look at it in normal light, then in between the crossed polarisers.

The display consists of two pieces of glass with a 'liquid crystal' in between. This consists of long rod shaped molecules which move around at random like a liquid, but are all aligned like a crystal. There are lines scored on the glass and the liquid crystals tend to align along them, the lines on the top are at 90 degrees to those on the bottom, so the molecules twist as you move through the liquid crystal.

If polarised light passes through the liquid crystal the light rotates by 90 degrees, however if you apply a voltage between the two glass plates by pressing the buttons, the rods rotate so they are end onto the light and stop rotating the light.

So by applying a voltage you can turn on and off the rotation of the light, which with 2 polarisers means you can make it go from clear to black, and by patterning some wires on the glass you can produce a display. which are used everywhere from watches to TVs. This is why if you look at a monitor through a polariser the image can disappear by rotating it.

PLUS Explanation

This explanation is intended to serve as an addition to the main explanation.

Additional points to include when demonstrating to taller than average children (use your own judgement as to how interested the students are, and which topics are appropriate to their subject area - sometimes it might be better to stick to the main explanation):

Malus's Law

For students interested in maths and physics, you can derive Malus's Law for the intensity of light transmitted through a polarising filter - which is that the transmitted intensity is cos^2(θ) relative to the incident intensity, where θ is the angle between the axis of the polariser and the polarisation of the light - using a fairly simple argument which doesn't require too much maths.

Show the students that you can write an arbitrary polarisation as the sum of two polarisations, one parallel to the axis of the polariser and one perpendicular to it, using arrows (draw a right-angled triangle). Since the length of the side parallel to the axis is cos(θ) times the length of the hypotenuse, the amplitude is reduced by cos(θ). Intensity is amplitude squared (possibly use the analogy that kinetic energy depends on velocity squared), so the intensity is proportional to cos^2(θ).

If they're especially keen you can get them to sketch this. To explain why the curve is smooth and not pointy when it hits the x-axis, you could talk about x vs x^2.

Birefringence

The box contains two pieces of card, with waves drawn on them, which slot together to form a model which can be used to demonstrate birefringence. By explaining that in certain materials one polarisation will travel slower than the other (possibly with reference to a drawing of a polymer structure, to explain why this happens), you can then demonstrate with the model that if one of these polarisations is shifted by half a wavelength the overall polarisation will rotate by 90°. You may need to explain that an arbitrary polarisation can be broken down into components parallel and perpendicular to the slow axis of the material.

You can then explain that, since the rotation depends on the second polarisation being shifted by a integer-plus-half multiple of the wavelength, only certain wavelengths of light will be transmitted through the second filter. This accounts for the colours observed - an extinction spectrum. You can use the Michel-Levy chart to show how the colour depends on the thickness of the material. The sellotape board is a good prop for explicitly showing this dependence, since the colours only change when pieces of tape cross over.

You can also expand on what sort of materials exhibit birefringence - typically these are materials with some sort of preferred direction (anisotropic), such as polymers in which the molecules are aligned in a certain direction (e.g. due to injection moulding - this can be seen in the pieces of ruler) or certain crystal structures.

The calcite is more strongly birefringent and thicker than the rulers: if you place the calcite over a line and look through it, you should see the line splitting into two (provided the calcite is clear enough!). This could be related to the difference in 'speed' between the two axes corresponding to a difference in refractive index. The difference in refractive index, through Snell's law, creates a difference in the angle of the light leaving the block, causing two images to be seen (Double Refraction).

LCD Screen

The box contains a diagram of a twisted nematic structure (as found in a liquid crystal), as well as the construction of an LCD screen - use this to explain how it operates.

The liquid crystal molecules in the screen, under normal conditions, take the structure of a helix with a 90° twist from top to bottom. This will rotate polarised light passing through by the same angle. However, if a voltage is applied to the crystal, the molecules instead line up with the electric field, breaking the structure and preventing the rotation of polarised light. This causes a liquid crystal sample between crossed polars to go dark. This can then be exploited to build a display. You could comment on how the screen uses ambient light, and not backlit, being energy efficient.

Circular Polarisation

You can also use the model to demonstrate how circularly polarised light is possible - by shifting one of the pieces of card by 1/4 of a wavelength, you can show the direction of polarisation rotates around as you move along the wave. Use this to explain how 3D glasses work, and ask them why it's beneficial to use circular polarisation and not linear polarisation in that scenario.

Brewster's Angle

If there's time, and the conditions are right, you could comment on the Brewster Angle. At this angle unpolarised light incident on a reflective surface will be reflected with a plane of polarisation parallel to the surface. If there is a shiny horizontal surface (metal is best) in the area, you could ask them to look at it through a linear polariser (ideally polarising sunglasses if there are any to hand). With the polariser in a certain orientation, the glare should be greatly reduced. This is how glare reducing sunglasses work.

Risk Assessment

Hazard: Broken objects (i.e. rulers)

Description: Possible cuts from sharp edges.

Affected people: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Do not allow children to bend items to point where they are likely to break. Remove items which are broken.

Call first aider in event of injury. Stop experiment if required.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Light box and cables

Description: Box is a trip hazard if placed on the floor. Electrical cables also present a trip hazard.

Affected people: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Make sure equipment is safely and securely placed, at the side of the dark room out of the way of where people are walking. Do not allow the power cable to run across a walkway. Ideally tape down cables if necessary.

Call a first aider in the event of an emergency.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Light box

Description: Electrical hazard

Affected people: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: See electrical parts RA

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Light box (bulbs heating up)

Description: Possible burns due to contact with hot surface.

Affected people: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Turn off box between demonstrations to prevent excessive heating, or otherwise monitor for overheating and be prepared to take a break and let it cool down. Do not let children touch the light box.

Call a first aider in the event of an emergency.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Fast moving slinky.

Description: Someone could get hit by the slinky or trip over it.

Affected people: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Don't have the slinky across somewhere people will be walking, and make sure that no one is standing where they could be hit.

Call a first aider in the event of an emergency.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-02 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Oliver Snowdon (oliver.snowdon@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-16 - Jachym Sykora (js973@cam.ac.uk)

Check 1: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-01-21 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-07 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-16 - Charis Watkins (czrw2@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2017-12-08 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2019-01-01 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-19 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-19 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-18 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-20 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-13 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2023-12-23 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-01-06 - Lucy Bland (lb831@cam.ac.uk)

The Potato Game

Learn about potato blight and other plant diseases - It's not just animals that catch diseases, plants can also get sick! Find out how these diseases affect farmers, the environment and our food supply.

Last initially checked on 2024-03-15 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-03-15 by Lauren Mason (llm34@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Biology

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- Fake Potatoes (at least 10 big, 60 small and 100 tokens)
- Fake Money (denominations of £2000, £1000, £350)
- Weather Spinner Printout (or a four sided dice)
- Coffee beans, rice, kitchen scales (to be found), and 4 lidded Tupperware.

Experiment Explanation

Plant Diseases The first aim is to introduce children to the idea of plants getting diseases, what might cause them, what effects it could have on us, and how we can treat them, etc. Here are some ideas of leading questions you could ask: - Can plants get diseases/sick? - Yes! - What might cause a plant to get sick? Bacteria, fungs, virus, environmental factors, pests - What might a sick plant look like? - Losing leaves, unusual colour, unusual growth, mold, (see photos) - Have you seen a diseased plant? What symptoms did it have? - mouldy fruit, cankers on trees - How might we treat plant diseases? (How do we treat human diseases?) - antibiotics, fungicides, quarantine, and (hopefully not in humans) selective breeding, genetic modification - What impact might plant diseases have? (food security/environment/forests/other animals) - famine, food production, trees dying off cause loss of forests/habitats/carbon sink - Why are plant diseases important? - we want to stop the above - Can you name any plant diseases? potato blight, ash dieback, Botrytis cinerea (fruit mold), rose black spot, citrus canker - What might affect how we treat plants? - money! cost of treatment has to go into the food prices. Also the law, some treatments are banned as they have side effects on the environment (e.g. killing bees, polluting rivers)

Crop Loss Game This is an optional demo to highlight crop loss in some common household crops. You might want to do this first if you do it. For each crop, the idea is the full Tupperware represents the total potential harvest and they need to pour into the other how much they think is lost to plant diseases. One student can pour for each crop and everyone else can guess if they think it should be higher or lower. You can use the scales and these numbers to calculate the correct amounts. The aim is to emphasize how much crop loss affects people - from the world's poorest farmers to consumers who rely on these crops as a key part of their diet. What effects do they think this loss has on supermarket prices (or shrinkflation).

Rice - up to 30% loss to diseases and another 10% to pests. Rice blast is a particularly severe disease caused by a fungus. Rice is the staple food for more than half the world's population and is particularly important to the worldest poorest farmers. The poorer someone is the more of their calories come from rice. Increases in rice costs have caused riots.

Coffee - up to 60% loss. Coffee Rust is a fungus causing orange patches on the leaves resulting in a lack of photosynthesis. Currently endemic in all coffee-producing countries. Severe rust makes it uneconomical to grow coffee. Fungicide can be used but is too expensive for smaller farmers. Rust didn't use to affect high-altitude plantations, but possibly due to global warming, rust has spread higher. "Arabica" coffee is more desirable to consumers (and thus gets more money) but is more susceptible to rust. "Robusta" is more rust-resistant but gets much lower prices.

(Note we don't currently have any cocoa beans but they'd be a natural expansion) Cocoa Beans - up to 100% Frosty pod can wipe out entire plantations. It's a fungus that eats the insides and outsides of cocoa pods. Currently confined to Southern and Central America but has not yet reached Africa. If it does the world cocoa production would be devastated.

Identifying Diseases This is an optional section featuring some printouts of different plant diseases and healthy plants for comparison. You may wish to link these into the questions at the start (for instance if students are struggling to think of symptoms). (Currently work in progress but these would be good pictures to have then add some more details) Coffee / Coffee Rust Cocoa Beans / Frosty Pod Rice / Rice Blast Potatoes / Late Blight (Tubers + Leaves) Tomatoes / Late Blight Potatoes / Nemotodes (Tubers + Roots) Ash / Ash Dieback Cirtus / Citrus Canker Roses / Rose Black Spot Apple / Brown Rot Tobacco / Tobacco Mosiac Virus Apple / Crown Gall Disease Barley / Powdery Mildew (maybe some pest photos for differences too)

Potato Blight If potato blight hasn't been mentioned yet you might want to bring out a fake potato and ask what it is and any diseases. People may well have heard of the Irish Potato Famine even if they don't know the disease. Some key facts: - Potato late blight is caused by the pathogen Phytophthora infestans. It's an oomycete, which are often described as 'water moulds' and are closely related to algae. - It infects potatoes (surprise) but also tomatoes. - Early symptoms are, dark spots appear on leaves and stems. Then, white mould appears under the leaves (Image 2) and the whole plant can quickly collapse. - Infected tubers (the bit we eat) develop dark patches that are brown beneath the skin and then rapidly decay into mush. - The disease caused the Irish Potato Famine (1845-57). Potatoes were the Irish staple crop and the loss caused over 1 million deaths and another 1 million people left Ireland due to the food shortages. - While that strain has died out other strains of P. Infestans cause around $5 billion of potato losses each year. - P. infestans produces spore pockets called sporangia. The sporangia on leaves (white bit of picture) can also be blown through the wind and enter soil as leaves are washed. - Sporangia can produce zoospores under wet and cool conditions. Zoospores are able to swim through water and soil. When they contact another plant they can infect it. - P. infestans also produces oospores which have thick walls and can survive over winter, reinfecting the next crop when planted. - Oospores are sexual, allowing different strains to mix increasing diversity. - Sporangia can complete thier life cycle in 5 days. They start to form when temperatures are above 10C and humidity above 75% for 2 days. Wind can help spores spread long distances. Farmers monitor for these conditions. How to avoid the disease: - Farmers can avoid the disease by completely removing infected plants as soon as they are discovered. - Ensure seeds come from disease-free areas. - Spraying fungicides. Although this is expensive and encourages resistant oospore varieties. - Plant blight resistant potato varieties. Although there are many strains and each variety is only immune to certain strains, so is vulnerable to others. - Farmers can look at the weather to predict when is the highest risk.

The Potato Game We're now going to play a game to show how hard it is to balance protecting crops with making money. You're all going to be farmers and make the same decisions with the goal of making as much money as possible.

How it works.

Each farmer has one field in which they can plant potatoes in. They each start with £4050 in cold hard cash. (Ideally 3 x £1000 notes, 3 x £350 notes as these match the payments they'll need to make) The game will last three months, in each of which some potatoes will die. Each child will start with 100 potatoes. You probably need to set an exchange rate between big/small/tokens.Big potatoes are worth 25, small potatoes 5, and tokens 1. You will need to act as the bank and exchange down potatoes as they get blighted. There are a series of "resistant" flags which will denote who has planted resistant potatoes. It costs £3000 for resistant and £2000 for standard. Each month farmers will spin the weather spinner which will predict the amount of blight risk that month. Players can then opt to spray fungicide or not spray, spraying will reduce their potato loss that month. It costs £350 to spray. The following table says how many potatoes are lost in each risk/spray/resistant combination.

Weather	Sprayed	Resistant	Standard
Low Risk	Yes	2	3
	No	4	6
Medium Risk	Yes	7	15
	No	12	20
High Risk	Yes	13	23
	No	16	27
Very High Risk	Yes	15	28
	No	25	31

At the end of the game (3 months) you should pay out for the potatoes left and see who's got the most money. Each potato is worth £100 (so big ones are worth £2500 and little ones £500).

How to Play In a school you probably want to group into two teams (more than 3 players is fairly chaotic). Be careful of the potatoes as children will steal them.

If you try and play it properly you probably want some mechanism to restict acess to resistant potatoes (only so many bags of each) and fertilizer (only bags for half). Otherwise everyone kind of ends up with the same number as they all do the same thing.

Game Explanation The game works on the assumption that you can grow 50 tonnes of potatoes per hectare and the crop value is £200/tonne. Each fake potato is 0.5 tonnes. For advanced groups you could talk about changing these paramaters. What would happen if there was a collapse in potato prices over the growing season, what factors do you think would cause this? What other factors aren't included in the game? The weather will also affect growth and thus the price you get for the potatoes - so high-risk weather might lead to bigger crops. There's also supply and demand which will factor in.

Risk Assessment

Hazard: Eating fake Potatos

Description: Eating foam can cause choking. The tokens are pretty small.

Affected People: Children

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: Supervise particularly small children closely with potatoes. Don't do the full game with very young children (it's too complicated anyways).

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Food items

Description: People may be allergic to coffee or rice.

Affected People: all

Before Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Mitigation: Warn people about coffee/rice before doing the experiment. Airbourne rice/coffee allergies are extremely rare and most allergies require physical contact allowing someone else to take part in that demo. Demo can be skipped if allergy known.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2023-06-22 - Tom Webster (tw432@cantab.ac.uk), **Check 2**: 2023-07-02 - Timothy Wong (chw55@cam.ac.uk)

Check 1: 2024-03-15 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-03-15 - Lauren Mason (llm34@cam.ac.uk)

Prism Goggles

Demonstrate how the brain adapts to changes in environmental input using prism goggles. - See how quickly your brain adapts by wearing our prism goggles whilst playing a target-hitting game.

Last initially checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk) and double-checked on 2024-01-31 by Peter Methley (pm631@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Floating

Equipment Needed

This experiment can take place outdoors - Prism goggles (currently on loan from Steve Edgely, Dept of PDN) - Small objects to aim at box (e.g. beanbags) - Box (e.g. small blue experiment box, bigger one if working with younger children!)

Experiment Explanation

Interim explanation copied from http://www.umich.edu/~nkids/Neurokids_Program/Lessons_files/NeuroKids-Prism%20Goggles%20Lesson.pdf

Intro/Background

The following is an example of what the leader might say during the introduction, including some specific questions to keep the kids engaged. It does not need to be repeated verbatim, and probably will contain more information that is necessary to explain.

Can anyone describe what learning is? Scientists like to say that "Learning is the way we acquire information about the world", but this can mean a lot of things, information can mean things like phone numbers, friends names, times-tables, but it can also be things like friends faces, how to make a free throw, or how to draw a picture. When scientists over the last century have thought about learning, they realized something very important, and that is that some kinds of learning are require conscious activity and others happen unconsciously, and they refer to these kids of learning as explicit and implicit learning.

Consciousness can be tricky to talk about, maybe you think you know exactly what we mean by conscious and unconscious activity, but lets look at it a different way. If we asked you to describe how you learned that 6x8 is 48, you could probably describe how math works, that if you took a bunch of M & M's and made a square with 6 rows of 8 M&M's each that you could count each one and make 48. Some things that we learn are easy to talk about, but others are more difficult, take free throws for example, somebody probably showed you how to hold the ball, but how exactly do you know how to make the shot? Scientists look at it this way, times tables and correct free throws are both kinds of information that can be learned. The type of information that you can easily think about and describe is termed explicit {think explained-explicit}, and the kinds that you kind of just do are termed implicit {less easy to remember, think implied}. Now in everyday life not everything fits nicely into one category or the other, but for today we're going to stick with that definition.

When you learn something new individual cells in your brain change. One thing that scientists are currently studying is where in your brain specific cells are changing. Were going to show you a little game that will change a few cells in a part of your brain called the cerebellum. One thing that your cerebellum helps you do is compare what you see with what your body is doing. You have lots of sensors in your muscles that keep track of where your body is. If you move your arm, you know where it's moving even if you cannot see it, or aren't paying attention. A copy of this, along with a lot of other information goes to your cerebellum.

Your cerebellum helps you by comparing what you want to do with what you actually did. So if you're playing a beanbag toss game, and you throw a beanbag at a target then you either hit the target or miss the target. Part of your cerebellum is working like a little computer, and each time you throw a bag, it keeps track of how close you were to the target. It takes the information about how much you missed the target by and uses it to change the way your arm moves the next time you throw.

When you play the beanbag toss game, were going to move where the target appears to be, so you will end up throwing it further away from the target than you would expect, but if you take enough throws your cerebellum will do the work for you and change the way your arm moves without you even having to think about it. And your throws will get closer and closer.

Activity

- Volunteers will lead groups of 4-6 students.
- Students will be trying to throw a beanbag into a target.
- Each student will first get an opportunity to practice a few throws and then they will be given a pair of Prism Goggles.
- Prism Goggles distort the field of vision to about 20 degrees in one direction and make it very difficult to hit the target and beanbags will probably be thrown all over the place.
- Other students that aren't participating can help collect stray beanbags.
- While wearing the goggles, each student should get 20-30 attempts to hit the target.
- Students should be encouraged at this time to "let their brains adapt to the situation" rather than manually adjusting where they aim (many students will attempt to adjust their aim).
- After they begin to consistently hit the target, ask the student to remove the goggles and throw again.
- Many of the students will accidentally miss in the opposite direction.
- Some students may not show these effects of compensation.
- Allow each student to have his turn to wear the glasses and try the experiment.

Discussion

- Once we put on prism goggles, there are two ways to adjust and hit the target.
- One strategy is explicit, we tell ourselves that our aim is off and try to throw the beanbag where we think the target is, rather than where it appears. This type of strategy quickly adjusts our performance, but requires us to guess where the beanbag should be thrown. For students that use this strategy, when the goggles are removed, and they are asked to throw again, they will not experience an opposite shift in their aim.
- When using the implicit learning strategy we throw the beanbag where the target appears to be. This strategy requires several attempts, each time we throw a beanbag, our brain makes a tiny adjustment, in a brain circuit that we do not have conscious control over. The adjustments last for a while which is why after removing the prism goggles, our aim has been adjusted in the opposite direction, and takes a few more trials to re-learn.

Some questions to ask {feel free to add your own}:

- Is one kind of learning better than the other? {each have their own benefits, think about the attention demands of explicit learning}
- What is an example of an activity that is more effectively learned implicitly/explicitly? {maybe something like soccer/friends names}
- Why would we want to learn things without having to pay attention to them?
- Are there any subjects in school that are best learned implicitly? {foreign language}

Risk Assessment

Hazard: Goggles

Description: Child becomes disorientated wearing goggles or on removing them and is more likely to fall over.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Ask child to stand still on one spot if they are wearing the goggles. If they feel dizzy, remove the goggles and tell them to sit down on the floor. Do not allow them to run around wearing the goggles. Remember that they may be equally disorientated on removing the goggles - do not allow them to run off immediately and again make them sit down if they are dizzy. Ensure the surrounding area is resonably clear, particularly of sharp objects and is on level ground away from any sharp drops, to prevent injuries and falls. Call first aider if necessary.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Small objects

Description: Small objects being thrown towards target escape and present a trip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Keep an eye on the whereabouts of the objects, do not get too many out at once. Where possible, use objects such as beanbags which will not bounce and roll all over the floor. Do not set up the experiment in a throughfare. Call first aider if necessary.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Various activities

Description: Small objects to be thrown towards target, and attempts at high-fives - may hit other people.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Do not allow children to collect objects while the subject is still throwing them. Position the experiment so that other people are not in the firing line. Use soft, light objects where possible. Warn children to high-five gently. In case of accident, call a first aider.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Dropped objects

Description: Child picking up objects from floor may hit head on nearby objects due to lack of peripheral vision.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Demonstrate away from obstructions - especially shelves/tables/sharp corners - as far as possible. Pick up balls for child if hazards are nearby. Try to stand between child and hazard. Make sure child takes off goggles before picking up objects. Call first aider if necessary.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2012-11-27 - Elizabeth Mooney (erm40@cam.ac.uk), **Check 2**: 2012-11-27 - Beatrice Tyrrell (bet23@cam.ac.uk)

Check 1: 2014-01-07 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-26 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-08 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2015-01-09 - Kym Neil (kym.e.neil@gmail.com)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-21 - Natalie Cree (nc434@cam.ac.uk)

Check 1: 2017-02-01 - Joanna Tumelty (jt574@cam.ac.uk), **Check 2**: 2017-02-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-27 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-02-03 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2019-01-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-27 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2022-01-23 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-20 - Emily Wolfenden (elw74@cam.ac.uk), **Check 2**: 2023-01-21 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk), **Check 2**: 2024-01-31 - Peter Methley (pm631@cam.ac.uk)

Projective Dobble

The maths of Dobble - Introduction to axiomatic maths and projective geometry via the card game Dobble. Learn how to make your own Dobble decks by constructing the “axioms of Dobble” from the rules, then developing methods to build these.

Last initially checked on 2023-02-19 by Emma Crickmore (elc75@cam.ac.uk) and double-checked on 2023-02-19 by John Leung (cfl35@cam.ac.uk)

Tags

Active (Experiment has working equipment at the time of last update, and is available for events.)

Games

Pure Maths

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Equipment Needed

- Requires the printouts as follows:
- 4 x symbol cards (14 symbols)
- Railway Track picture
- Fano Plane Picture
- 3x3 Grid Extension Picture
- Fano Plane Dobble Deck (7 cards)
- 3x3 Dobble Deck (13 cards)
- (optional) Dobble Deck (55/57 cards)

Experiment Explanation

Dobble (or Spot it!) is a card game that’s similar to snap. A Dobble deck contains a set of cards, each card has several symbols (normal Dobble is 8 per card, kids 6) on it and the unique property that any two cards share exactly one symbol. To play reveal one card, players look at it, then reveal a second, the first to shout the symbol matching wins. The winner claims the first card, the second card stays face up and the game continues with a new card revealed. Try playing a few games using the deck with 4 symbols.

We now want to link everything back to maths. Dobble has some interesting properties and we want to study decks of Dobble cards. To do so we need to say the rules we want Dobble decks to have, these are called axioms. In maths axioms are our basic assumptions about any objects, so our axioms of Dobble better be true of any deck of Dobble cards. Our first axiom is simple:

1. For any two cards there exists exactly one symbol appearing on both cards.
2. Each card has the same number of symbols.
3. No symbol is repeated on a single card.

We’ll discover our next axioms by trying to make Dobble Decks with an increasing number of symbols. Dobble with only one symbol is boring. We just have lots of copies of the same card! We don’t like this so we stop it.

4. Each card is different.

This does allow us to have a deck with only a single card (if you like this or not depends, we'll introduce another axiom later to stop it). When we get to two symbols we need to make sure we're actually using them.

5. Each symbol appears on at least one card.

With these rules so far our Dobble decks only have a single card, but when we get to three we get our first (slightly) interesting Dobble deck. This looks a bit like Dominoes. So with 3 symbols and 2 per card we get our first Dobble Deck!

Now with 4 symbols and 2 per card we can't quite have dominoes like before but we can do something (laminated example). With one symbol in common between all three cards. This makes a very boring game of Dobble, so we add another rule.

6. For any symbol, there's a card without that symbol. (If you want to allow 1 card decks you'll need to rephrase this)

What about 4 symbols and 3 per card? Have a try and whatever happens it seems like axiom (1) keeps failing, we can't get exactly one symbol. But we'll actually need to prove it! If we have three symbols and two cards then there are six symbols we need to pick however there are only 4 symbols available. Since we need to stick to (3) we end up with two symbols in common. This argument is called the pigeonhole principle. Formally we'd argue there's a symbol on both cards, 4 remaining slots and 3 symbols that can be used (as by (3) the repeated one can't appear again) thus by pigeonhole there's a repeat.

Now we move up to 5 symbols and 3 per card. We can get two cards but then get stuck trying to make a card without the common symbol. So if we move to 6 symbols we get a 3 card deck! But we can actually do better. We can add a fourth card by taking the unmatched symbol from each and making a new card.

So far we've found nice Dobble decks at 3 and 6, is there anything special about these? It turns out the triangular numbers have an important link and we can make Dobble decks with a triangular number s of symbols per card we can make $(s+1)$ cards using $T(s)$ symbols using the same pattern.

Projective Geometry

Lots of times in Maths we want to take our axioms (which describe a thing we want to find out about) and then show some kind of object we understand satisfies those axioms. For Dobble one such setting is that of geometry. We'll now start interpretting our original Dobble axioms but in a geometric sense. Instead of saying "symbol" we're going to say "point" and instead of "card" we're going to say "line". A line has lots of points much like a card has lots of symbols. A deck is now a collection of lines. So now our axioms become.

1. For any two lines there exists exactly one point appearing on both lines. (i.e. Every pair of lines has a unique intersection)
2. Each line has the same number of points.
3. No point is repeated on a single line.
4. Each line in the collection is different.
5. Every point has at least one line passing through it.
6. For any point, there's a line not passing through that point.

This roughly lines up with what we expect of geometry with a few exceptions. To make sense of (2) we insist on their being only a limited number of points, for instance just imagine a grid of points where if you go off one end you wrap around and appear at the same point on the other side. Then the only problem is (1), we have parallel lines which can never meet!

This requires us to take an alternative idea of geometry, mathematicians call this projective geometry. Look at the picture of the train tracks. It looks like the parallel tracks eventually meet on the horizon. In projective geometry they do. The general rule of projective geometry is our equivalent axiom (1) holds. Look at the Fano Plane diagram which has 7 points and 7 lines. Notice that because we this new axiom (1) we don't end up with straight lines when we try and draw it on our normal (non-projective) piece of paper.

Our first challenge is to lay the symbols out so each line matches up with a card. Try this with the Fano Plane deck. You'll find you're able to make the cards into a triangle shape, then add a card in the middle. Our final line ends up being a circle. However we never said our lines had to be straight. Here each "card" corresponds to a "line" as in our axioms.

The next concept that makes projective planes interesting is duality. This means swapping "lines" and "points". We can actually do this. Try lying out the cards in the deck so each "card" is now a "point" and every "line" has some "symbol" in common. We call this duality.

We can also make projective planes from usual planes by introducing some new "points at infinity" for each direction we could head towards infinity in. On a 3x3 square grid this is up, right up diagonal, right, right down diagonal. While we could go down to infinity as we wrap around that's the same as going up.

Now let's show how we make a Dobble deck from a grid like this. We work through each of the parallel lines in those four directions. For each of the three parallel lines we choose a symbol and place that on all 3 cards, we also place this symbol on the "point at infinity" for this direction. This gives us 4 symbols on all our finite cards and 3 on all our "point at infinity" cards. However the easy way to solve this is to add a new infinite symbol to these four "points at infinity" cards. This represents the "line at infinity".

The actual game of Dobble is made in this fashion! It just uses a 7x7 grid and there are more points at infinity corresponding to making "knights moves" in different directions. You can lay out an actual game of Dobble like this and try it. Sadly with 8 symbols per card and 57 symbols you can get 57 different cards, however a commercial game of Dobble only has 55.

When the cards are printed out I'll add some cool tricks about duality. You should be able to find the dual symbol to a card then choose a card, look at it's dual symbol, find all cards with that symbol on them, then look at the duals of all these cards and that should be the symbols on the original card (careful if it's dual to a symbol on it's self "self-dual"). This is an example of taking the dual of a dual and coming back.

We can also show take theorems in projective geometry and find them in Dobble. For instance Pappus' Hexagon theorem says take two lines, pick three points on both lines, draw the lines between pairs these, the three points of intersection form a line. (See picture). If you do this in Dobble pick two sets of three cards that share a symbol. for each pair find the (unique) card sharing both symbols. The three cards you get from this all share a symbol.

Risk Assessment

Hazard: Laminated card

Description: Edges of plastic may be sharp, which could lead to cuts or minor injuries. Young children may try to put them in their mouth, leading to spread of infection.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Make sure sharp corners on the cards have been rounded out. Don't let very young children who could potentially hurt themselves handle the cards.

After Mitigation: Likelihood: 2, Severity: 1, Overall: 2

Hazard: Cards

Description: Cards could be dropped and slipped on.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Make sure cards are not on the floor. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2023-02-19 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-19 - John Leung (cfl35@cam.ac.uk)

Psychedelic Milk

See the amazing patterns made by food colouring and detergent in milk. - A little milk, a little food dye, a little washing-up liquid... and an amazing display of colour. See the stunning swirling effects from disrupting the surface tension.

Last initially checked on 2024-01-04 by Andrew Marriott (asm206@cam.ac.uk) and double-checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Chemistry

Equipment Needed

- Some milk (usually have UHT in stores)
- A few colours of food colouring
- A few drops of washing up liquid
- A fairly flat bottomed bowl

Experiment Explanation

Taken from Dave's Naked Scientists explanation:
http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/psychedelic-milk/

In a nutshell

Investigate how reducing surface tension can lead to pretty patterns that move in milk using food colouring and washing up liquid.

How to set up the experiment

1. Add about 1cm depth of milk to the bottom of your bowl.
2. Pour a few drops of each colour of food colouring onto different places on the surface of the milk (be sparing)
3. Add a drop of washing up liquid somewhere in the bowl.
4. The food colouring moves! You should find that at first the food colouring moves away from where you added the washing up liquid, and then it starts welling up from below the surface of the milk, forming beautiful patterns.
5. After a minute or so and everything has stopped moving, add another somewhere else.

What you need to know during the event

1. Milk is mostly water, and water has a property called surface tension. This is because all the water molecules are strongly attracted to other water molecules, but not to air. Therefore the water molecules try to make the surface (the interface between the water and air) as small as possible. This is why raindrops are approximately spherical - the shape with the minimal surface for its volume.

2. The food colouring is less dense than the milk so it floats on the surface. This is because the milk has lots of substances dissolved in it such as calcium, making it more dense than the food colouring (which is almost entirely water).

3. Washing up liquid is designed to reduce the surface tension so water can dissolve fats and grease. This means that where you add the washing up liquid, the surface tension is much weaker than everywhere else. The surfactant spreads across the surface away from the drop, making the rest of the surface shrink.
4. The food colouring is forced downwards and there is a current below the surface flowing back towards the washing up liquid pulling the food colouring along. It then floats back up to the surface producing beautiful patterns.

Want to know more?

A washing up liquid molecule is made up of a water loving head and a water hating tail, so when you add it to water the molecules arrange themselves over the surface - head inwards. The water is strongly attracted to the heads of these molecules, so is now stops trying to reduce its surface area, and the surface tension is far weaker.

The bubbles in washing up liquid are not originally there - they get added because people associate bubbles with cleanliness...

Risk Assessment

Hazard: Surfactant (I)

Description: Could get in eyes and result in irritation.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: If children get their fingers in the washing up liquid, tell them not to put their fingers near their eyes and ensure they rinse it off.

If washing up liquid gets into an eye, demonstrator must call a first aider and may perform an eye wash if trained and confident to do so.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Surfactant (II) and other liquids

Description: Could be harmful if ingested

Affected People: All, particularly small children who try to ingest things

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Use a relatively harmless surfactant (standard washing up liquid) and watch the kids so they don't try to lick their fingers or drink any part of the experiment. Food colouring probably shouldn't be ingested in large quantities, and the milk has likely been in the cupboard for a while.

In the event of an incident, call a first aider.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Spilled milk (or water)

Description: Slip hazard.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: All spills should be cleared up immediately. Call first aider in case of injury. Don't cry over it.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-20 - Catherine Collett (chc47@cam.ac.uk)

Check 1: 2012-12-12 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2013-12-15 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-02-16 - Benjamin Lai (bl337@cam.ac.uk)

Check 1: 2014-12-27 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-02 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-12-30 - Haydn James Lloyd (hjl43@cam.ac.uk), **Check 2**: 2016-01-16 - Charis Watkins (czrw2@cam.ac.uk)

Check 1: 2017-02-09 - Haydn James Lloyd (hjl43@cam.ac.uk), **Check 2**: 2017-02-09 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2018-01-01 - Georgia Harris (grh37@cam.ac.uk), **Check 2**: 2018-02-04 - Giedre Sirvinskaite (gs508@cam.ac.uk)

Check 1: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-04 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-30 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-31 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2021-01-12 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-17 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2022-01-31 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2023-02-06 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2023-02-07 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-01-04 - Andrew Marriott (asm206@cam.ac.uk), **Check 2**: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk)

Red Cabbage

Making a natural pH indicator. - We use a little red cabbage juice to find out more about acids and bases in the world around us.

Last initially checked on 2023-12-31 by Andrew Marriott (asm206@cam.ac.uk) and double-checked on 2024-01-12 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Chemistry

Equipment Needed

- Red cabbage
- Knife
- Rolling pin or other mashing device
- Large bowl
- Cups
- Vinegar or lemon juice
- Bicarbonate
- Absorbent white paper - scientific/coffee filter paper are good, kitchen roll less good
- Litmus paper
- Pipettes

Experiment Explanation

Overview:

Cabbage juice is used as a pH indicator to demonstrate the concept of pH. Paper dipped in cabbage juice will change colours when dipped in an acid (vinegar/lemon juice) or base (bicarb).

Tips for demonstrating: - If the kids want to, let them take home the pH paper! - Adding indicator to the liquids gives a much better colour change than using the filter paper.

Basic Procedure and Explanation:

Before Event:

1. Cut up half a head of red cabbage (start with less - you may only need a quarter of a head if using warm water).
2. Crush it using a rolling pin. Put crushed cabbage in a bowl/cup with water and mix. The cabbage juice extracts better in warm water - but make sure to use a safe temperature. **DO NOT USE HOT/BOILING WATER**. Strain the liquid into another cup, and you should have a bluish/dark purple liquid – this is your natural indicator. When added to acids it should go pink, and in alkalis or bases it should go blue/green.
3. Set up cups with cabbage juice, lemon juice/vinegar, bicarb in water and water.

At Event:

4. If the cabbage still needs to be crushed/strained into a cup, ask the kids to help you.
5. Dip a strip of paper into the juice and explain that this juice will act as a pH indicator – in other words it will tell us whether something is acidic or basic.
6. Ask them if they can name some acids/bases. (Lemon juice, bicarb, vinegar, orange juice, etc)
7. Ask them if they know what pH is?

- Tailor your explanation to the age of the child
- pH scale is a logarithmic scale defined by pH = -log10[H+] – for older kids
- pH is a number that tells you how acidic or basic something is [neutral substances, such as water, have a pH of seven, acids (vinegar/lemon juice) have a pH of less than seven, and bases (sodium bicarbonate) have a pH of more than seven].

8. Explain that the cabbage juice will turn blue/green when dipped in a base and pink when dipped in an acid.
9. Show them your "mystery" liquids (vinegar, water and bicarb/water) – ask them to use the indicator paper to determine which one is an acid/base.
10. Discuss why the indicator paper doesn't change colour when dipped in water as it's neither an acid nor a base - explain the concept of neutral substances.
11. You can also use a pipette to add a couple of drops of acidic/basic solution to the cup with cabbage juice in to make that change colour.
12. Ask them what will happen if you add an acid and base together. Try mixing lemon juice and bicarb, then testing the pH.

Other things to talk about:

1. Structure of atoms

- Get kids to simulate and atom by having one kid be the nucleus and the others be electrons that orbit the nucleus
- Talk about how electrons have negative charge and protons in the nucleus have positive charge
- Can they explain how the electrons orbit rather than flying off? Get them to think about magnets attracting each other if struggling
- Talk about how acids are solutions with free protons and how this allows most indicators to gain a proton/H+ in acidic conditions to change colours (contrast with how red cabbage loses an OH group as described below)

2. How can the cabbage juice act as an indicator?

- Red cabbage contains coloured pigments called "anthocyanins" which have antioxidant properties
- In acidic conditions they lose an –OH group, and gain it in basic conditions
- Most indicators gain an H+ in acidic conditions and lose in again in basic conditions
- This change in the physical structure will change the wavelength of light reflected, and so it changes colour

3. Why does the cabbage juice appear colourful?

- Pigment molecules absorb specific wavelengths of light, determined by their structure
- Rest of the light passes through / reflected; the transmitted & reflected light makes up the colour that we see
- With older kids (KS3/4) - could talk about excitation of electrons, energy levels etc?

Risk Assessment

Hazard: Knife

Description: Sharp knives may cause cuts.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Only demonstrators to use knives to cut cabbage, which should be done before the event starts. Knives to be kept concealed and out of reach for the duration of the experiment. Knife to be sheathed when not being used.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Lemon juice/vinegar/bicarb

Description: Lemon juice/vinegar and bicarbonate of soda irritant to eyes

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Only use small amounts, avoid pouring out more reagents while demonstrating.

If in contact with eyes, wash with emergency eye wash provided if trained and confident to do so. Call first aider if necessary.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Lemon juice/vinegar/bicarb

Description: Children eating/drinking bicarbonate, lemon juice or vinegar.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Don't leave children with experiment unsupervised. Put all unnecessary reagents back in the box and always leave the experiment safely packed away when closed.

If ingested, advise parents that reactants are all edible, but to seek medical attention if child is feeling unwell as reactants may have been in box for unknown amount of time.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Liquids

Description: Mixing acidic and alkali solutions would result in a reaction, causing bubbles to form. Spillages may be a slip hazard, but are unlikely to happen since acid and base used are weak.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Do not mix the solutions in large quantities.

Clear spills promptly, use wet floor sign if needed.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Hot water

Description: Cabbage juice extracts better in warmer water - demonstrators may be tempted to use hot water to prepare the indicator solution. Hot water carries a risk of serious scalds if spilled on a child / demonstrator.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Do not use hot water or a kettle under any circumstances. Test water before use - as a guide, water temperature should be comfortable to immerse your hand in for an extended period of time. If the water is too hot, allow the solution to cool before proceeding with the experiment. Keep the stock of solution out of reach of children and in a place where it can't easily be knocked over.

Call a first aider in case of injury. More severe burns may require hospital treatment.

After Mitigation: Likelihood: 3, Severity: 1, Overall: 3

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-20 - Catherine Collett (chc47@cam.ac.uk)

Check 1: 2012-12-13 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2012-12-16 - Rachel Chapman (rc506@cam.ac.uk)

Check 1: 2014-02-03 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-02-16 - Benjamin Lai (bl337@cam.ac.uk)

Check 1: 2014-12-27 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-02 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-12-27 - Charis Watkins (czrw2@cam.ac.uk), **Check 2**: 2015-12-28 - Haydn James Lloyd (hjl43@cam.ac.uk)

Check 1: 2017-02-09 - Tim Morgan Boyd (tmb58@cam.ac.uk), **Check 2**: 2017-02-09 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk)

Check 1: 2018-01-17 - Georgia Harris (grh37@cam.ac.uk), **Check 2**: 2018-02-04 - Giedre Sirvinskaite (gs508@cam.ac.uk)

Check 1: 2019-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-01-11 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-07 - Holly Smith (hs606@cam.ac.uk), **Check 2**: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2020-12-27 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2021-01-17 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-23 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2022-01-29 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-19 - Joshua Wu (jw2311@cam.ac.uk), **Check 2**: 2023-01-20 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2023-12-31 - Andrew Marriott (asm206@cam.ac.uk), **Check 2**: 2024-01-12 - Asmita Niyogi (an637@cam.ac.uk)

Renewable Energy: Uses of Electromagnetism

Making power using wind and water! - Explore how we can use the power of electromagnetism to power our day to day lives!

Last initially checked on 2024-02-08 by John Leung (cfl35@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Electricity

Magnetism

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- Generating power
- Small ammeter and coil. Bar magnet of some sort that fits through the hole
- Green rotating generator. Clamps to attach it to a table.
- Wooden box with bulbs/handle/generator
- (these are taken from the electromagnetism experiment)
- Invitica Renewable Energy Kit
- This has a base station, a extension piece, wind turbine, water turbine, solar panel (not that useful for this) and some plastic tubing. There's also a manual explaining how it links into curriculum. The base station has 4 inserts which you can use, an ammeter, a buzzer, a light and some gear things.

Experiment Explanation

Lives in Electromagnetism Box. Commonly done alongside Electromagnetism and Lenz's Law.

1. Generating Power

There are 3 different power generating bits, in increasing level of usefulness.

Magnet, coil and ammeter This has a coil of copper wire attached to a small ammeter. When you wave a magnet through the hole in the middle of the wire you get a reading on the wire. Some things to talk about/do with it are: - What are the objects? Coil is made of copper wire, this is a good electrical conductor. The setup as a whole is an electrical circuit (components linked together in a circuit). The meter looks like it might measure something (cf weighing scales), it measures the amount of electrical current (or just electricity) going round the circuit. - Do we get more electricity by moving fast or slow? Does it work if we're not moving at all? - Is this very much electricity? The scale on the ammeter is microamps (the funny squiggle is the Greek letter mu), talking (or asking questions about) millimetres, metres and kilometres is a good warm-up to explaining that microamps is a small unit. Older kids might know that fuses have amp ratings on them. - What do the positive/negative readings mean? It tells us which way the electricity is going round the circuit, notice that it changes if we move magnet in a different direction, or swap north/south poles. - How can we get more electricity? Good ideas are moving faster (and moving in circles is easier than up/down), stronger magnet or more coils.

This then leads nicely onto the next bit...

Rotating generator (green) This has most of the improvements suggested above (show to them the larger magnet, more coils), and if you spin the handle fast enough it will give you enough electricity to light a bulb. Things to talk about:

- The faster you spin it, the brighter it is.
- Does it matter which way round you turn it? No.
- [more advanced]If the bulb is an LED rather than a filament bulb then it will only light half of the time, with frequency=rate of turning the handle. This is because the current is alternating ('going backwards and forwards') and it only lights when the current is going one way.

Generator in a box This is a better version of the previous one, but it's all hidden in a box which means visitors can't see what is going on as well. There are two bulbs that can be switched on or off, and also a voltmeter/ammeter. Things to do:

- Start someone off turning the handle and then increase the wattage of bulbs turned on gradually. They will find that it gets harder to turn as you do this. Talk about needing to put extra energy in to get more light out (the energy is coming from them, **not** from the magnet/coil which just convert kinetic/moving energy into electrical energy)
- [More advanced]Look at the ammeter/voltmeter. When a bulb is fully lit how do those readings compare to the wattage of the bulb (P=IV).

Generating in real life Power generation: How many watts are the bulbs you have at home? If it's this hard to turn a handle to make 10W of bulbs light, how hard would it be to power all the bulbs in your house? How about all the bulbs, TVs,... in town X? This is really where our power comes from, what better ways are there of turning the handle (wind farms are the easiest example for small kids - Hamster in a wheel. This is like bike light dynamos! Sadly hamsters don't travel in our boxes very well. - Wind power. You can try the model turbine with a hair dryer or fan. - Water power. We use these in dams where the water flows down and through a turbine. To use this put one end of the tubing on a tap and the other in the sink, this model the water flowing down hill. Fossil fuel and nuclear power plants use the same sort of turbine, but powered by steam rather than water.

There's also the solar power but that uses a different principle - semiconductors.

Risk Assessment

Hazard: Coils and wires

Description: Possible overheating could result in burns.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Do not put too much current through a coil/wire, if it is getting hot, turn it down. If there is a burn, run under tepid water for ten minutes, call a first aider. In event of fire, follow procedure in venue RA (raise alarm, evacuate).

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Powerful magnets

Description: Magnets may shatter, possibly leading to cuts.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Warn visitors if you give them a magnet. Use the minimum number of free magnets. Keep the magnets under control. Cover with tape to reduce impact, and contain any shards. Pad edges of magnet to reduce finger trap.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Rotating parts in generators

Description: Children could trap fingers in the rotating parts.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Keep kids' fingers away - if it needs pushing it should be done on the axle, not the armature. Contact a first aider in the event of an injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Generator

Description: Visitor or demonstrator catching fingers in generator as they turn the handle on the generator.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Place generator on flat surface so visitors can't catch their fingers underneath so easily. Tell visitors to hold only the rotating part of the generator handle and not the entire handle. Keep control of the visitors at all times and don't let them get overexcited while turning the handle.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Heavy generators

Description: Generators falling on people.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Use clamps to keep generators firmly attached to table, ensure table is stable; Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Water spill from turbine

Description: Water could leak from the water turbine if tubing is not secure enough, or during disassembly. People can slip on the spilled water.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Secure tubing to tap with gaffer if necessary. Keep an eye on turbine and keep children away from surrounding area. If water is spilled, stop the demonstration, use a wet floor sign, and clean up.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Risk Assessment Check History

Check 1: 2018-11-06 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2018-12-12 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre

(msl54@cam.ac.uk)

Check 1: 2020-01-30 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-30 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-12 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk), **Check 2**: 2022-02-09 - Vanness Lai Wye Junn (vwjl2@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-12 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-02-08 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Resonance

What is the link between earthquakes and cello strings?

Last initially checked on 2024-01-11 by Asmita Niyogi (an637@cam.ac.uk) and double-checked on 2024-01-30 by Lauren Mason (llm34@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Electricity needed**
- For earthquakes (large blue box):
- Earthquake table (wooden box with handle)
- Sections of tower for the above, made of perspex, magnets and springs.
- Dog on a swing.
- Optional:
- Pan pipes
- Tuning fork
- Whirly woo
- Spare springs, mass hanger

Experiment Explanation

It's a collection of experiments illustrating resonance: the Earthquake Table lets you build towers and see what happens to them when vibrated near the resonant frequence, the Dog On A Swing gets across the basic idea of resoanance, the Giant Pan Pipes show how resonant air makes music, and the 'cello is a string driven by an oscillating electromagnet, which gets excited at resonance.

Overview:

When you shake things too quickly or slowly, nothing much happens, but if you shake them at just the right rate - the rate they naturally shake at if you push them - the shaking builds up and builds up.

Possible activities: - Trying to make the tower fall over by wobbling it at just the right rate. - Comparing this to pushing a dog on a swing. - Hitting or blowing across the pan pipes to make a noise. - Hitting the tuning fork and talking about its resonant frequency - Putting your ear to the pan pipes - they make a noise even when not hit or blown (not sure if this works with small pan pipes?) - Whirling the whirly woo so that it makes a sound (check the whirly woo is working before demonstrating, if no sound can be heard there may be a hole that needs covering with tape)

Other things to talk about: - Building design to withstand earthquakes. - Seismic waves. - How wind instuments work - Resonance in cars, taps etc.

Tips for demonstrating: - Everyone enjoys turning the handle on the earthquake table. Try to make people, even little children, take turns. - The experiment links well with Seeing Sound, and can share equipment and demonstrators.

Basic procedure and explanation:

- Start by getting someone to turn the handle of the earthquake table slowly. A tower three blocks high works best. It shouldn't shake very far. Then ask what they think it will do if they shake it much faster. Will it wobble more?
- It doesn't (or, at least, not much). Now get them to try an intermediate speed. It should be possible to get the tower shaking a long way at just the right speed. You may need to practise doing this to show unconvinced children with poor handle control.
- Try to explain why this happens. The swing is useful here: to make someone swing higher, you push them once every time they come past, so that they build up a little bit more each time. Get the kids to do this to the dog. Also show them that pushing at the wrong rate means that you're sometimes speeding him up and sometimes slowing him down, which is why it doesn't work properly. Then show them that it also works when you wobble the base of the swing: just the right rate makes the dog swing high.
- The kids may then be able to explain why the tower swings most at a particular frequency, and you might want to talk about designing buildings to withstand earthquakes.
- The pan pipes make a sound if you blow across (not into) the ends, or hit them with bats or bits of card. Explain that this is the air inside shaking, and link in with the Seeing Sound experiment if it's about. It's possible to use the slinky spring to get across the idea of a standing wave.
- The pan pipes also make a sound when you put your ear next to the end and listen. This is becasue any sound in the room at the right frequency is magnified by the resonant pipes.
- The whirly woo only makes a sound when you rotate it at the right frequency. Similar ideas to the above but 100x more exciting for kids than a panpipe.
- Hit the tuning fork and explain that the note that you hear corresponds to the resonant frequency of the tuning fork. Again, draw a parallel to the swing and that the note you hear is the frequency at which the tuning fork 'likes' to vibrate. With older kids you can talk about how initially the fork is vibrating at lots of frequencies but all the ones which aren't the resonant one decay quickly, like how the swing's amplitude quickly decays if you push it at the wrong frequency.

Other things to talk about:

- All sorts of things can resonate, and we'd often rather they didn't. Many people will have heard about the millenium footbridge in London, which wobbled as people found themselves walking in step with the wobbling. It had to be closed, and was fixed by fitting damping, which is also the way a car's suspension tries to avoid resonating. Going further back, the Tacoma Narrows bridge failed catastrophically due to resonance with the wind.

Science background for demonstrators:

Anything that you know about resonance will come in useful for this experiment. Most things can be modelled as damped, driven harmonic oscillators, yielding a second-order differential equation with a sinusoidal right-hand side and a familiar set of solutions. Trying to go into mathematical detail with little children is a mistake, though. Even the words 'resonant frequency' can be off-putting.

You may like to note (so to speak) that the pan pipes are tuned to a pentatonic scale.

Risk Assessment

Hazard: Box on table

Description: Falling box or tower blocks could hit children on the head, hands or foot.

Affected People: Public

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Tape the box to a table, and not so high that falling tower blocks could hit children on the head. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Finger trap

Description: Finger trap between the handle of the box and the table on which it's mounted, or between magnets.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Mount the box with the handle far enough clear of the table that there's no possibility of a finger trap. Be careful when setting up/packing away. Call a first aider in the event of an emergency.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Whirly woo

Description: Child or demonstrator hitting someone with the whiry woo while swinging it.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Make sure there is a clear space in which the whirly woo can be used. If the children seem too excited, demonstrate the whirly woo yourself. Swing the whirly woo above your head so that it is above the height of the children watching and so can't hit them. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Pan pipes

Description: Multiple people blowing on them could transmit diseases.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: If public are offered to use it, make sure they don't actually touch the ends of the pipes when blowing. Consider wiping the ends of the pipes with some anti-bac wipes when they're done. Consider having only one person (the demonstrator) using the pipes.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Mass Hanger

Description: When oscillating the mass hanger on a spring, it can jump off near resonance and may land on someone's hand or foot.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Ensure that people keep their hands out of the way from under the mass hanger. Perform at low height over a table rather than over the floor. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-14 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-26 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-12 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-05 - Joanna Tumelty (jt574@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-01-20 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2019-01-01 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2019-12-16 - Lucy Hart (ljfh2@cam.ac.uk), **Check 2**: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-20 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2021-01-21 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2022-01-23 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-01-28 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-12 - Johan Kidger (jpk51@cam.ac.uk)

Check 1: 2024-01-11 - Asmita Niyogi (an637@cam.ac.uk), **Check 2**: 2024-01-30 - Lauren Mason (llm34@cam.ac.uk)

Rocks and Fossils

A box of rocks and fossils - Find out about explosive volcanoes, shiny crystals, and the exotic animals that lived millions of years ago.

Last initially checked on 2024-01-31 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Margaret Johncock (mllyj2@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Geology

Active (Experiment has working equipment at the time of last update, and is available for events.)

CHaOS+ (More complex explanations suitable for older children are available)

Equipment Needed

This experiment can take place outdoors In this box there should be:

- DK fossil book
- DK rocks and minerals book
- viewer (a magnifying glass on a stand)
- Old hand-lens
- Box 1 - Clear plastic box with the main rocks and minerals collection in
- Box 2 - Orange plastic box with rocks, minerals, gem stones and fossils in
- Small box of plant fossils
- Laminated visual aids including some activity sheets
- Larger rocks (4cm to fist sized) in bubble wrap, includes granite, gneiss, basalt, limestone and sandstone
- 2 large plant fossils; not usually needed.

1. White box: Main rock and mineral collection

Row 1 - Minerals

- A1 – Quartz
- B1 – Feldspar (Microcline)
- C1 – Mica (Muscovite)
- D1 – Mica (Biotite)
- E1 – Calcite
- F1 – Hornblende

Row 2 – Igneous Rocks

- A2 – Vesicular basalt
- B2 – Obsidian
- C2 – Dolerite
- D2 – Rhyolite
- E2 – Andesite
- F2 – Granodiorite

Row 3 – Metamorphic Rocks

- A3 – Mica Schist
- B3 – Slate
- C3 – Quartzite
- D3 – Gneiss
- E3 – Garnet Schist
- F3 – Marble

Row 4 – Sedimentary Rocks

- A4 – Sandstone
- B4 – Shale
- C4 – Arkose Sandstone
- D4 – Conglomerate
- E4 – Breccia
- F4 – Limestone

Rows 5 and 6 – Misc.

- A5-6 – Peridotite (lherzolite)
- B5-6 – Basalt with peridotite (harzburgite) xenoliths
- C5-6 – Iron Meteorite
- D5 – Orthopyroxene (Bronzite)
- D6 – Eclogite
- E5-6 – Gabbro
- F5-6 – Pipe rock (bioturbated metamorphosed sandstone)

2. Orange box: Rocks, minerals, gemstones and fossils

- A1 – Pyrite (Fool's Gold)
- B1 – Magnetite
- C1 – Tektite and Flint
- D1 – Agate
- E1 – Crackle Quartz
- F1 – Quartz
- A2 – Calcite
- B2 – Aragonite
- C2 – Marble
- D2 – Tiger's Eye, Jasper, Mookaite
- E2 – Peacock Ore
- F2 – Amethyst
- A3 – Turtle Shell
- B3 – Nautiloid (straight-shelled)
- C3 – Gastropod
- D3-4 – Connemara Marble
- E3-4 – Amethyst
- F3-5 – Assorted Gems
- A4 – Steam Coal
- B4 – Shark Teeth
- C4 – Echinoid
- A5 – Crinoid stem
- B5 – Mosasaurus Tooth
- C5 – Coral
- D5 – Bivalves
- E5-6 – Woolly Mammoth Bone
- F5-6 – Trilobite
- A6 – Brachiopod
- B6 – Dinosaur Bone
- C6 – Ammonites
- D6 – Goniatites

Experiment Explanation

Note: If you're confident with demonstrating and know your geology give this kit a go through, and please write down the bits that work and don't work, as well as suggestions for more samples to get. (A sheet of paper that stays in the box would be great!)

Ways to do this demo

1. Spread out some or all of the rocks, and get people to ask you about any that they are interested in. There are some pieces of paper in the box that let you categorise them into igneous, sedimentary, metamorphic, minerals and fossils if you fancy it.

2. 'Journey to the Centre of the Earth': use the larger rocks to do a virtual journey to the centre of the earth from the surface (sandstone, limestone, basalt) to the crust (granite, gneiss), to the mantle (xenoliths in bag - green peridotite and black pyroxenite) to the core (meteorite in bag). Will help to draw this out on whiteboard/ paper etc.

3. 'Where do rocks come from?': use the larger rocks. Talk about igneous rocks erupting at the surface (gives small crystals as they cooled really quickly - 2018 Iceland Basalt) versus cooling intrusively (large crystals, slow cooling, the granite). Sediments: think about where we get sandstone (deserts, rivers, beaches) or limestone with shells in it (the bottom of the sea).

4. 'What is a rock made of?': Find a large, coarse-grained rock (the Shap granite is particularly good for this), get them to have a look with the hand lens and spot the different kinds of minerals. Then have them match the minerals in the rock with the hand-specimens of isolated minerals. From here you can go on to talk about how the rock is formed; what grain size/shape means, or compare it to a rock of the same composition but different texture (e.g. granite, rhyolite and felsic gneiss) or same texture but different composition (e.g. granite, diorite, gabbro).

5. Get people to sort the rocks into igneous, sedimentary and metamorphic, possibly using the labelled pieces of paper as a guide. You can also bring in the concept of the Rock Cycle, talking about how rocks can change from one type to another through metamorphism, melting+solidification, erosion+deposition+lithification.

6. 'Guess how old these rocks are': Use the larger rocks and ask children to put them in age order - which they will invariably get wrong! Then put them in the right order and talk about where the rocks came from. (Basalt: 2018 eruption in Iceland - younger than the kids!; Granite: about 50 million years old, Lake District; Gabbro: 60 million years, Skye; New Red Sandstone: Triassic, 250 million years, Cheshire; Brachiopod limestone: Ordovician? 450 millon years; Pipe Rock: Cambrian, 530 million years, Skye; Lewisian Gneiss: 3 billion years old from northwest Scotland - oldest rock in the UK!, Meteorite: around 4.5 billion years old, start of solar system.

7. Mix of the above, or talk about whatever you want.

Summary of 'highlights' from the collection

Igneous Rocks (Box 1)

This is an activity that explains how igneous rocks (formed from molten magma, which is called magma below ground and lava above ground) can be made of similar starting materials but form different rocks because of different cooling rates. Obsidian (B2) cools very fast, often in water, forming a volcanic glass rather than any crystals, essentially a frozen liquid (may know from Minecraft or Game of Thrones…) Pumice (A2) cools quite fast in air, fine crystals that can only just be seen floats on water because of all the trapped air bubbles Granite (F2) cools slowly underground, has big crystals made out of Quartz (A1 – used in microchips), Feldspar (B1) and Biotite Mica (D1)

Sedimentary Rocks (Box 1)

This activity aims to show how sedimentary rocks form and how they turn into metamorphic rocks (morph means change) under high temperatures and pressures. Sandstone (A4) → Quartzite (C3) Mudstone (B4) → Slate (B3) → Schist (A3), very high T and P, silly word…, contains muscovite mica Limestone (F4), made of crushed up dead sea creature shells → Marble (F3), often used in kitchen surfaces, we eat off dead sea creatures!

Interesting Points (Box 2)

This sheet just offers some interesting rocks and fossils to look at and describe F5, F6 – Trilobite, ancient ancestor of woodlouse, extinct, hard eyes made out of calcite $CaCO_3$ in A2 B5 – Mosasaurus tooth, a Mosasaurus is huge, as big as a room, extinct A1 – Pyrite, fools gold, thought it was gold but actually FeS, Iron and sulphur (stinky egg smell) B1 – Magnetite, magnetic! You can talk about palaeogeographic reconstruction / magnetostratigraphy / magnetic stripes at mid ocean ridges. D1 – Agate, crystallised out from pools of dissolved silica in lava E1 – Crackle Quartz, same as box 1 A1 but impurities give colour C1 – Tektite, meteorite hits ground and mixes with rock on ground and explodes out across the globe A2 - Calcite: demonstrate double refraction, as explained in detailed information below.

General Demonstration Advice

This demonstration consists of a large number of different rocks and fossils, which may seem a little bewildering at first. Don't worry, I've studied Geology for three years and I still don't know much about some of the specimens we have. If you've done IA Geology/Earth Sciences or something similar, you should know enough to demonstrate a decent number of the rocks and fossils. If you need help on specific specimens, there is a list of contents with each set, I've prepared this guide to hopefully give additional explanation, and there are books on fossils and minerals in the box too.

I like letting the children hold the rocks and fossils, and look at them under the magnifying glass, as I feel it makes things a lot more interactive. This is fine; just make sure they're careful with them, as the fossils in particular are quite fragile. If you do hand things out, make sure to keep an eye on them, because otherwise the specimens (especially the more exciting ones) do slowly disappear… It might be best not to let the smallest children handle them, for the sake of the fossils and the children's windpipes.

There are a few ways to go about this demonstration, which you can vary depending on the venue you're demonstrating in, and what suits you best. You could keep the boxes closed and only bring out specimens one or a few at a time which you want to talk about, or you could leave out all or lots of them, and let the children lead the demonstration a little more. I find the second option more interesting, and it tends to draw children in more easily in a public event, but I might keep most of the specimens in their boxes at a school, especially if the children want to just grab everything in sight! However you choose to do demonstrate, you don't have to talk about anything you're not confident about. You can either leave specimens in their boxes, or admit you don't know much about them if children ask.

One thing I find interesting about this experiment is the variety of opinions about geology. Some children will think rocks are really boring, while others will love fossils or crystals, and want to talk to you all day! It can be really rewarding convincing people that rocks and fossils are interesting, or talking to a child who is fascinated by everything you say, but if sometimes you'll talk to kids who really don't want to know. I usually try showing them the bits I think they'll find most interesting, but in the end I might just send them to another experiment if they're clearly not getting anything from this demonstration.

You can use the specimens as links to talk about almost anything you (or the children) want. A lot of them come from the Atlas Mountains in Morocco, so I might use this to talk about continental drift and mountain-building, as they were formed by the collision of Africa with Europe. I often end up talking about the rock cycle and how fossils are formed and preserved (or not). I also like talking about the structure of the Earth, and why it's hotter underground. The visual aids are there to help you with this sort of thing, especially if like me you end up rambling about something completely unrelated with a group of intelligent and interested children! If there's anything else you feel would be useful to include, by all means mention it to a committee member, write it in the tour diary, or even print it yourself - this experiment is still relatively young, so any input would be appreciated.

I should perhaps include a warning that you may occasionally have to deal with people, who do not believe in evolution, think crystals have healing powers, or something similar! Unfortunately it's unlikely you'll manage to persuade them against these beliefs, but you could have a go!

The rest of this guide provides brief details about each specimen, and some ideas about what to talk about with each one, but remember, this guide is in no way complete, and there are probably interesting things I have left out or simply don't know about plenty of the specimens. We've included the box of plant fossils in this experiment box, which can also be demonstrated as part of the Plant Evolution experiment (biology). There are some notes to go with this, but you'll probably only want to use these if you've studied plants at some point. It's fine to just leave them in the box and use the rest of the kit.

Most of the specimens are not individually labelled. Refer to this document, or the laminated card with pictures, to help you identify things, or ask a committee member / geologist.

The explanation below is very long and detailed, but it has useful information about the specimens - i.e. read this if you want to find out something specific about a particular sample

---

Detailed Specimen Descriptions

The Fossils (mostly in orange box):

At some point it is a good idea to ask children if they know what fossils are and how they form. If they aren't too sure, explain how hard parts of animals – teeth, bones, shells – can be buried under layers of sediments, and eventually become fossilised. However, plants, footprints, tree sap and excrement can all be fossilised too. The fossil we see may be as it originally was, it may have recrystallised, or it may be an imprint. The details of fossilisation processes are actually very complicated, but fortunately a general idea of what happens is sufficient. The book in the box explains this for a general audience, so it's probably worth a look through.

Wikipedia says that: "Fossils (from Latin fossus, literally"having been dug up") are the preserved remains or traces of animals (also known as zoolites), plants, and other organisms from the remote past. The totality of fossils, both discovered and undiscovered, and their placement in fossiliferous (fossil-containing) rock formations and sedimentary layers (strata) is known as the fossil record. The study of fossils across geological time, how they were formed, and the evolutionary relationships between taxa (phylogeny) are some of the most important functions of the science of paleontology. Such a preserved specimen is called a "fossil" if it is older than some minimum age, most often the arbitrary date of 10,000 years ago.

Hence, fossils range in age from the youngest at the start of the Holocene Epoch to the oldest from the Archean Eon at several billion years old. The observations that certain fossils were associated with certain rock strata led early geologists to recognize a geological timescale in the 19th century. The development of radiometric dating techniques in the early 20th century allowed geologists to determine the numerical or "absolute" age of the various strata and thereby the included fossils.

Like extant organisms, fossils vary in size from microscopic, such as single bacterial cells only one micrometer in diameter, to gigantic, such as dinosaurs and trees many meters long and weighing many tons. A fossil normally preserves only a portion of the deceased organism, usually that portion that was partially mineralized during life, such as the bones and teeth of vertebrates, or the chitinous or calcareous exoskeletons of invertebrates. Preservation of soft tissues is rare in the fossil record. Fossils may also consist of the marks left behind by the organism while it was alive, such as the footprint or feces (coprolites) of a reptile. These types of fossil are called trace fossils (or ichnofossils), as opposed to body fossils. Finally, past life leaves some markers that cannot be seen but can be detected in the form of biochemical signals; these are known as chemofossils or biomarkers."

An awkward question I have been asked a few times is how do we know that a given fossil is 50 million years old? This is a hard one to answer, since most of the fossils are old enough to be dated using Uranium decay series. If children are old enough to understand Carbon-dating, you can make an analogy with this, otherwise you may have to make do with talking about relative dating using layers of sedimentary rocks and volcanic ash. The timeline should be useful for talking about ages of various fossils, since large numbers of years become a bit meaningless, but saying that something lived twice as long ago as the first dinosaurs impresses most children.

Bivalve

These molluscs have lived in a huge variety of situations. They can be marine or freshwater, live in deep or shallow water, above or buried in the seabed, or even swim like scallops or attach themselves to rocks along the coast like mussels (both kinds of bivalve) do. Their shell consists of two usually symmetrical halves called valves, but some bivalves, such as Gryphaea (or Devil's toenails) have one valve much bigger than the other. They have been around since the Cambrian.

Amber

Amber is fossilised tree resin (not sap apparently, although I'm not entirely sure what the difference is). Animal and plant material is often preserved in amber, particularly insects which have become stuck in the resin. As far as I know, this is the only way in which insects can be preserved, as their exoskeletons are simply too weak to be fossilised normally. Children may have seen Jurassic Park, in which the DNA of a dinosaur is extracted from blood that a mosquito has drunk before becoming trapped in resin and fossilised. This idea has some basis in fact, since the preservation of fossils in amber is so good that fragments of DNA may be recovered. Unfortunately, unless we've found a new piece of amber, there are no insects in this one.

Gastropod

Gastropods are another group of animals which have lived in various different situations. They can be freshwater, marine, or even live on land (e.g. the snail), and have been around since the Cambrian. They can be recognised by their coiled shell. I often just use the words "sea snail" here, since I'm not sure the word "gastropod" will add much, but it's up to you.

Shark Teeth

The box contains a variety of shark's teeth. These are some of the most easily recognisable fossils we have. There is an opportunity here to talk about why sharks have such sharp, and often serrated, teeth, as well as why they are such common fossils (sharks have many sets of teeth and frequently lose and replace them). Sharks have skeletons made from cartilage, which makes them unlikely to be preserved, and have been around for more than 420 million years. One of the teeth is from a shark related to the Megalodon, which some children may have heard of. It lived roughly 28 to 1.5 million years ago, could grow up to around 20 metres in length, and had huge impressive jaws!

Brachiopod

These shelled organisms used to be far more common, occupying many of the marine environments which bivalves do today. Their shells are made from two halves, or valves, which tend to be different, and can be distinguished by a mirror plane down the centre of each valve. They have been around since the Cambrian, and were most common during the Paleozoic.

Ammonite

These marine molluscs had spiral shells and were alive during the Mesozoic- the same time as the dinosaurs. These should not be confused with Nautilus, an animal with a spiral shell more closely related to the straight Nautiloids. They can be told apart by the position of the siphuncle – a tube used to move water between the shell's chambers and control buoyancy – which runs along the outer edge of ammonites' (and all ammonoids') chambers, but through the centre of Nautiloids'. Ammonites vary in size from a couple centimetres to a couple metres, and are commonly found on the Dorset and Yorkshire coastlines.

Goniatite

These are another type of ammonoid (the subclass to which ammonites belong) which rarely exceeded 15cm in diameter. They can be told from ammonites by their simpler suture line (the line where the divisions between chambers make contact with the edge of the shell) and lived earlier than ammonites – during the late Paleozoic.

Trilobite

These are an extinct class of arthropods which lived during the Paleozoic, though they declined towards the end of it. Trilobites were some of the first animals to evolve hard parts (which is why they are also some of the earliest fossils that are regularly well-preserved) and eyes. Their hard shell meant that they could roll into a ball to protect themselves (as I think this specimen is doing). Their eyes were made from calcite crystals which had to be orientated correctly to avoid a double-image (you can demonstrate the double-image with the calcite crystal in the minerals box). Some had their eyes on stalks, while others were blind. Most moved over the sea-bed, but some swam, and they could be predators, suspension feeders or scavengers. The name trilobite refers to their three "lobes" – one that resembles a spine down the middle of the trilobite, and one on each side of it. I usually liken trilobites to woodlice to help children to imagine them.

Triceratops Bone

Whole fossilised bones, and especially whole skeletons, from land-dwelling animals are pretty rare, as they will only be buried and fossilised in an area where deposition is taking place, such as the sea or a delta; much of the land is being eroded. If the animal does not die in a place where its bones are quickly buried, the bones may be separated from each other, bashed around, or even fragmented before finally being buried. This is probably what happened to this piece of triceratops bone. The small holes are most likely where the marrow used to be. Triceratops was an herbivorous dinosaur with three horns on its head (two above its eyes and one on its nose), a large bony frill, and a beak-like mouth. It walked on four legs and grew up to 9 metres long and 3 metres high. It belongs to a suborder of dinosaurs called ceratopsians, which had similar features, but different numbers of horns. There is discussion as to whether the horns were primarily for defence against large predators such as Tyrannosaurus Rex, or for fighting amongst each other for mates. Triceratops lived at the very end of the Cretaceous, which provides an opportunity to talk about the mass extinction at the end of this period which wiped out the dinosaurs (one of several that have been identified throughout the Earth's history). A lot of children will know the most popular theory- that the Earth's collision with a huge meteorite caused the extinction. Far fewer may know about the less popular hypothesis, that an enormous set of volcanic eruptions covering half of India in lava flows known as the Deccan Traps in less than a million years contributed to this extinction event, or may even have been the primary cause. Both of these events happened, but there is debate as to which was the main cause of the mass extinction.

Mammoth Bone

This fragment of woolly mammoth bone has much bigger holes in it than the Triceratops bone. This implies that it had a lot bone marrow, which led a scientist I was talking to to suggest that it might be from a femur (thigh bone). Most children will have seen Ice Age, so describing woolly mammoths as "Manny the big hairy elephant from Ice Age" seems to work quite well. These animals lived from roughly 150,000 years ago until 10,000 years ago, although a race of dwarfed mammoths continued to live on Wrangel Island (about 200km north of Siberia, just inside the Arctic Circle) until about 4000 years ago. There is debate as to what led to the extinction of mammoths and other large ice age mammals such as sabre-tooth tigers and giant beavers around 10,000 years ago. The main hypotheses are hunting from humans and climate change; although in reality it may have been a combination of the two.

Mosasaurus Tooth

From the canine-like shape of the tooth, we can tell that this is from a carnivorous animal. Mosasaurus was a huge sea-reptile that reached 15-20 metres in length (I like to compare this something real, like the length of the room I'm in). It was alive during the late Cretaceous, and was another victim of the mass extinction at the end of this period.

Echinoid/Sea Urchins

The sea urchin is a member of a class of animals called echinoids. Echinoids are related to star-fish and tend to have a similar five-fold symmetry, though this may be less obvious depending on the specimen. During life, sea urchins are colourful balls of spikes that live on the sea-bed, feed mainly on algae, and can be found shallowly enough in warm seas such as the Caribbean that people occasionally step on their spines (which can hurt a lot!). The spines are designed to protect sea urchins against predators. They fall out within several days of the animal dying, leaving fossil sea urchins with tiny holes where each of their spines were attached during life.

Coral

Coral have been around since the Cambrian, but the kind we know today (called Scleractinian coral) such as this fossil only evolved during the Triassic when the old Rugose and Tabulate corals became extinct. Corals (with the exception of some Rugose corals) are colonial organisms which form huge coral reefs. These can be hard to explain to children; I find it helps if they've seen Finding Nemo. I like to use coral to talk about continental drift, as I have found fossil coral in the Lake District- clearly not the warm shallow sea favoured by these organisms.

Turtle Shell

The oldest known turtles lived during the Triassic. The fossils we have are individual plates (or scutes), many of which together would have made a whole turtle shell. There is an opportunity here to talk about the usefulness of having a huge shell you can hide inside.

Straight Nautiloid

Nautiloids have been around in one form or another since the late Cambrian, and are today represented by the spiral-shaped Nautilus (mentioned in Ammonite). Straight Nautiloids are often cut and polished to be sold by crystal-sellers. The animals that lived inside these shells were predatory and squid-like, but from a different sub-class to squids.

Crinoid/Sea Lily

Sea lilies are crinoids which are attached to the sea bed by a stalk. Crinoids have lived since the Ordovician, and, despite their name and plant-like appearance, are actually animals. They use their arms to trap small particles of food.

Plant fossils (from 'Plant Pollinator Game')

All the fossils came from the Dover area and illustrate the horsetail point at 400 million years ago, NOTE, the ferns are seed ferns, which developed after seeds evolved, they are not the spore producing ferns we see today and evolved with the horsetails. The sketch of a horsetail on the timeline should help the children envisage what Annularia and Calamites looked like.

- Alethopteris: these are the leaves of seed fern (which are now extinct). The leaves are relatively long and thin and end in more of a point compared to neuropteris.
- Neuropteris: also leaves of an extinct seed fern. These are the fat leaves with blunt, rounded ends, most of the leaves in the fossils are neuropteris.
- Annularia: also called Asterophyllites - don't think there is a difference. These are the leaf whorls of an extinct horsetail. (The leaves are spread concentrically about a point). There is only one of these in the fossils.
- Calamites: the stems of the horsetail. Can be recognised by the segmented stems. These are related to the modern horsetail.

The Minerals (In the orange and white boxes):

Wikipedia says that: "A mineral is a naturally occurring solid chemical substance that is formed through biogeochemical processes and that has a characteristic chemical composition, a highly ordered atomic structure, and specific physical properties. By comparison, a rock is an aggregate of minerals and/or mineraloids and does not have a specific chemical composition. Minerals range in composition from pure elements and simple salts to very complex silicates with thousands of known forms."

The colours of many minerals such as quartz and calcite are determined by the presence of impurities, particularly transition metals. Whether they dissolve or precipitate in a particular setting depends on the solubility of the mineral in groundwater, which depends on a number of things, including temperature and pressure. The growth of crystals in this way can be likened to the growth of salt/sugar crystals in a bowl of salty/sugary water left out to evaporate, except that it is changes in temperature/pressure etc that mean that the water is over-saturated and a mineral will precipitate rather than the evaporation of water. This is how geodes (balls of crystals) of amethyst, quartz etc can form in water-filled cavities deep underground.

The most impressive crystals I have heard of are the 12m long crystals of gypsum (which is softer than fingernails) in the Cave of Crystals in Mexico, which is essentially a giant geode.

See book for more detailed notes than those I have included.

Major rock-forming minerals

A selection of the most common minerals which make up the majority of rocks in the Earth's crust.

Calcite

Calcite is a form of Calcium Carbonate ($CaCO_3$), and is one of the two main minerals (along with aragonite) from which shells are made. It is rare to see such well-formed calcite rhombohedra as the one in the box. One of the crystals is opaque, probably due to small amounts of impurities.

Calcite is strongly birefringent, which means that it has different refractive indices for light oscillating in different directions. This means that light entering a calcite crystal splits up into two beams polarised in the directions of the highest and lowest refractive indices, causing a double-image if you look through it. The reason is that the CO_3 groups are aligned in parallel planes, with a high electron density on each oxygen which will slow down light travelling in that plane (see the Polarisation experiment). You can demonstrate this by placing a clear calcite crystal on top of a piece of paper with a dot on it, and rotating the crystal. You should see one image stay still while the other moves around it. If you borrow a polarising filter from Polarisation, you should see that the two images are polarised at right-angles to each other.

Limestone is mostly made up of calcite, and this can recrystallise during metamorphism, or calcite can form stalactites and stalagmites in limestone caves. It often cements together other sediments if it has precipitated from the water trapped between individual grains of sediment, forms veins particularly in fractures in rocks, and can be found in some mantle-derived rocks. It is harder than fingernails but softer than steel (Mohs hardness of 3), and is colourless and transparent with no impurities. I find a lot of children assume that calcite and quartz are the same thing because they are both clear- this is an opportunity to talk about other ways of telling different minerals apart such as crystal shape, hardness and birefringence.

Feldspar (Microcline)

Feldspars are the most common mineral in the Earth's crust – almost two thirds may be made from feldspars. They most commonly grow from magmas during crystallisation, and can crystallise in veins (e.g. as part of impure quartz veins) and some metamorphic rocks at temperatures around 600°C. They are also found in some sedimentary rocks, but as they are much softer than quartz, are worn down far more quickly in high energy environments. There are two main groups of feldspars: alkali and plagioclase feldspars. Alkali feldspars, such as orthoclase and microcline, tend to be pink in hand specimen, and are the pink blocky minerals found in some granites.

Mica (Muscovite and Biotite)

Micas are a group of sheet silicates, which means that their molecules are arranged in flat layers. This is why they have such a perfect cleavage (flat shiny surface, yes I know the word is hilarious) and grow in sheets. In fact, you can take tiny individual flakes off these micas, though I wouldn't recommend it if you want them to last! Micas all have OH in their chemical formulae, and thus are described as hydrous minerals – this means that they require the presence of water to grow. If the micas form from cooling magma, the magma must have some dissolved water. For example, granite (but not the one in this box) often has muscovite and/or biotite. If the micas grow as a result of metamorphism (putting rocks under heat and pressure), the OH will come from other hydrous minerals such as chlorite, or even from mud.

Muscovite is a white mica (appears silvery in hand-specimen), and biotite is a dark brown mica (appears shiny and black in hand-specimen). They form in similar circumstances.

Amphibole (Hornblende)

Hornblende is a type of dark-coloured mineral called an amphibole. These have two cleavages at 56° to each other, which you can see if you look at one shiny surface of a crystal, and then rotate it through 56° in the correct direction. Hornblende is found in many igneous rocks of intermediate silica content, and some metamorphic rocks such as amphibolite.

Pyroxene (Bronzite)

Pyroxene looks superficially similar to amphibole and is common in less silica-rich (mafic and ultramafic) igneous rocks such as gabbro, basalt and lherzolite, as well as high-grade metamorphic rocks of similar composition, such as eclogite. In hand-specimen, its crystals are typically more elongated than amphibole, and have two cleavages meeting at 90°. This particular sample is an orthopyroxene (hence its cuboidal shape) known as bronzite (due to its bronze-like metallic lustre), from the Black Cuillin in Skye.

Quartz

Pure quartz is SiO_2. It is very hard (Mohs hardness of 7) - harder than steel – which is why most sand is made up predominantly of quartz, as softer minerals wear away more quickly when battered by waves on the coast or the winds of the desert. Quartz is the main ingredient of window glass, usually in the form of sand. It can be formed in a variety of ways, including as a metamorphic or igneous mineral, a cave deposit, or as quartz veins in fractures in rocks. It can crystallise in fluid-filled cracks and holes underground to form geodes – balls of quartz crystals. Pure quartz is clear and colourless, but often quartz has impurities which change its colour, and can make rose quartz (pink), smoky quartz (grey) and other varieties. Quartz is piezoelectric, which means that it distorts when a voltage is applied across it, and can generate its own voltage when the applied voltage is removed as it returns to its original shape. This sets up a circuit with a frequency determined by the resonant frequency of the quartz crystal, and is used to keep time accurately in watches.

The specimen in the pink box has a well-formed ("euhedral") crystal shape, whereas the one in the white box does not, probably because many crystals have grown together in the same rock.

Various types of quartz

Quartz can form in a huge variety of different situations, leading to different crystal sizes, shapes and colour. Pure quartz is transparent or translucent white (explained above), but there are several other interesting forms of quartz in the box.

Amethyst

Amethyst is a variety of quartz which is purple in colour due to impurities including transition metals such as iron and titanium. Discussing the similarities in crystal shape may help to convince children that this is indeed the same mineral as the transparent quartz, apart from these impurities.

Tiger's Eye

It is thought that Tiger's Eye is a gemstone which used to be blue asbestos (also called crocidolite), a fibrous mineral. During metamorphism, the asbestos is dissolved, and quartz precipitates in its place. This replacement allows the quartz to maintain the fibrous nature of the asbestos; some of the iron oxide in the asbestos is left behind, and becomes an impurity in the quartz, giving it its golden colour. This leads to Tiger's Eye's appearance of parallel layers with slightly different golden shades that reflect the light in different ways.

Agate

Agate is yet another form of silica (since the crust is mostly made up of silica it shouldn't be too surprising that there are so many forms of it). This most commonly forms in water-filled cavities, where the silica precipitates on the walls of the cavity as layers of tiny crystals of quartz and moganite (a polymorph of quartz, so also $SiO2$). The multi-coloured banding is due to the different impurities in each band.

Crackle Quartz

The colours in this crackle quartz are man-made. They are added by heating up quartz in dye, allowing the dye to permeate along cracks between see-through grains in the sample. This is a good opportunity to extend the discussion into melt production, generation and storage in rocks, with the more interested members of the public.

Red Jasper

Jasper is an impure form of silica (SiO_2), quite similar to chert (see Flint/Chert under sedimentary rocks). Its colour varies according to the impurities, and the red colour in this jasper is probably due to ferric iron.

Mookaite

Mookaite is an impure form of silica, and in fact a kind of chert (see Flint/Chert) formed from sediments which have a very high proportion of microfossils from zooplankton called radiolaria. Radiolaria make their tiny skeletons out of the silica dissolved in water.

Other Minerals

Pyrite

Pyrite is also known as Fool's Gold due to its similarity in physical appearance to gold. It is found in quartz veins, coal beds, sedimentary and metamorphic rocks, as well as a replacement mineral in some fossils. It is associated with other oxides and sulphides, and often forms during diagenesis- low pressure and temperature alteration to deposited sediments during early compaction which may result in recrystallisation and precipitation of minerals. Its chemical formula is FeS_2. Note the cubic crystal shape.

Red Aragonite

Aragonite is the other main form of Calcium Carbonate from which animal shells are made. It is metastable and will revert back to calcite over 10s to 100s of millions of years and means that aragonite fossils are often replaced by calcite. It is often found in sedimentary rocks and cave deposits. The red colour is probably due to impurities such as iron.

Magnetite

This mineral began its life with CHaOS with the label "Haematite". However, not only does the colour seem slightly wrong, but, more importantly, haematite cannot be made into as strong a permanent magnet as the pieces in the box. Therefore, Dave worked out that this must be another iron oxide: magnetite (Fe_3O_4).

Magnetite is an early mineral to crystallise from most magmas, and is stable to high temperatures, so can be found in small amounts in a lot of different kinds of rocks. The small black octahedron is the ideal natural crystal shape of magnetite; the smooth 'pebbles' have been artificially polished. There are also some samples of the Skye gabbros which contain enough magnetite to attract the other magnets.

When found naturally, magnetite may be weakly magnetised, but not to the same degree as those in the box – these have been artificially magnetised. However, in rocks with a lot magnetite, such as the basic igneous rocks of Skye, even the natural weak magnetism can be enough to offset compass needles and confuse hikers! Small, elongate, single crystals of magnetite are the best magnets due to the difficulty in switching the polarity of such a small magnet in one fell swoop. Magnetite crystals have been found in bacteria, as well as the brains of some animals (including pigeons and us). They are thought to be useful for navigation, using the inclination and declination (3D direction) of the Earth's magnetic field as a reference.

When magnetite crystallises in an igneous rock or settles in a sediment, it aligns itself with the Earth's magnetic field, giving magnetite-bearing rocks a natural magnetism. This can be measured to work out the latitude at which the rock was originally formed. Because the Earth's field swaps its poles every hundred thousand years or so, the sequence of magnetic reversals can help to work out the age of a rock. Magnetic reversals found near mid-ocean ridges on the sea floor were a major piece of evidence that led to the development of plate tectonics.

Lepidolite

Lepidolite is a lithium-rich mica, a major source of rubidium (which was first discovered in this mineral) and caesium. It can be found in pegmatites (granites with crystals larger than an inch, which is thought to be due to the presence of water), as well as other granites and high-temperature quartz veins. Like all micas (see muscovite and biotite), it is a sheet silicate with one well-developed cleavage plane, and contains OH, so can only form from magmas containing dissolved water. There has lately been considerable interest in extracting the lithium from the lepidolite-bearing granites of Cornwall, mainly for the manufacture of lithium-ion batteries.

Moonstone

Moonstone is a gemstone formed by the intergrowth of two kinds of feldspar – albite and orthoclase. These are minerals which crystallise during the cooling of magma. The two minerals may grow together in such thin flat layers that they are close enough to the wavelength of optical light to scatter it, producing a milky glow in the presence of light, said to resemble moonlight. This is called adularescence.

Peacock Ore

Peacock ore, also called Bornite, has the chemical formula Cu_5FeS_4. It can be found in igneous rocks, contact metamorphic rocks (those heated up by a nearby igneous intrusion such as a magma chamber) and shales. It is an important copper ore and is iridescent.

The Rocks (in white box):

You might want to talk about rocks in general, and define what they are. (Ask something like "Can anyone describe what a rock is like?") Depending on the age of the kids, they might be able to name rocks such as limestone, chalk and marble. ("Does anyone know the names of any types of rock?") You could ask where rocks are used (old buildings mostly). You could say that newer buildings aren't made of quarried rocks as man-made materials like brick and concrete are cheaper.

Warning to geologists: you may have to resist the urge to murder people who name some of the specimens as "just a normal rock". The box should contain a key to these rocks and rock-forming minerals, and I will use the same numbering system.

I like to ask people to describe each rock: there's a lot that you can deduce by simple observation of things like crystal size, colour and texture.

Igneous Rocks

Basalt

Basalt is an extrusive igneous rock. This means that it formed from the cooling of lava which flowed from a volcano. It has cooled quite quickly to allow only small crystals to grow (you can make out some shiny surfaces under the magnifying glass, although the bigger crystals may have started to grow in the magma chamber – most of the crystals will be too small to see). The main difference between basalt, andesite and rhyolite is composition. Basalt is more iron and magnesium-rich and less silica-rich than rhyolite; andesite is intermediate between the two. When magma cools in a magma chamber, iron-rich and silica-poor minerals crystallise first and fall to the bottom of the magma chamber. This means that the remaining magma becomes more silica-rich, iron-poor, magnesium-poor, and therefore lighter. The system becomes more complicated if new (SiO_2-rich, Fe-poor) magma is injected into the magma chamber, or if crustal material from the edges of the magma chamber (SiO_2-poor, Fe-rich) is assimilated into the magma. Thus in general magma moves slowly from basaltic to andesitic to rhyolitic composition until it completely solidifies, is erupted, or is mixed with new material. Magma of basaltic, andesitic or rhyolitic composition may erupt as lava.

Most of our basalt samples contain gas bubbles (vesicles), which have come out of solution as the pressure drops, near the surface. In some cases, the bubbles are filled with white minerals that formed later as mineral-laden water flowed through the solidified rock - the mineral-filled vesicles are known as amygdales.

Andesite

See Basalt for how extrusive igneous rocks are formed. Andesitic lava will only flow in a non-explosive eruption if it does not have a high volatile content (see Pumice).

Rhyolite

See Basalt for how extrusive igneous rocks are formed. Rhyolitic lava will only flow in a non-explosive eruption if it does not have a high volatile content (see Pumice). It forms a glass if cooled quickly (see Obsidian) and so only thick rhyolitic lava flows would cool to make rhyolite like that in the box. The larger crystals in this rock would have formed in the magma chamber, and didn't fall to the floor of the magma chamber due to the high viscosity of rhyolitic magma (and perhaps also because of a similarity in density between the crystals and the magma). The rest of the rock is composed of tiny crystals (called groundmass) which formed when the lava cooled subaerially. Igneous rocks form by the solidification of magma in a magma chamber (intrusive) or on the surface of the Earth (extrusive). Magma = underground, lava = above ground

Obsidian

(Most children will have heard of this from Minecraft. In the game you can make it from adding lava to water, which is close to the truth, but emphasise that the game isn't factually accurate.)

Obsidian is a type of volcanic glass. During crystallisation, it takes time for the molecules to arrange themselves into a given crystal structure. If a liquid is cooled quickly enough (such as when window glass is made it is cooled quickly in water), there will be no time for this to happen, and so the resulting solid, called a glass, will have the molecular structure of a liquid despite being solid. Obsidian is made when lava cools very quickly and becomes a glass. This is most likely to happen to thin rhyolitic (very silica-rich) lava flows, as other compositions of lava would have to be cooled more quickly than could naturally happen. Obsidian is metastable at the Earth's surface, and thus none has been found older than the Cretaceous, as, particularly in the presence of water, it changes into another rock type, perlite.

Obsidian is archaeologically interesting, because it is hard, and can easily be made very sharp (I think the hand specimen already has some fairly lethal edges), and so was used (particularly by Mesoamerican civilisations such as the Maya) to make knives and other tools, though not as frequently as flint/chert due to its comparative rarity. It could also be polished to create rudimentary mirrors. Obsidian is still occasionally used to make surgical scalpels, as it can reach a sharp edge only a few nanometres thick, much sharper than a steel blade (although it is much more brittle).

Pumice

Pumice is solidified magmatic froth. Magma has dissolved volatiles such as water and CO_2, and these are more soluble under high pressure than low pressure. For a volcano to erupt there must be a build-up of pressure which forces the magma up towards the surface. When the volcano begins to erupt, this pressure is rapidly released, and so the volatiles are no longer as soluble in the magma. This means that bubbles of water and CO_2 will form, and as they travel in the magma up to the surface from the magma chamber, the pressure drops even more, so that more volatiles exsolve. Because the gas is much more compressible than magma, the bubbles grow even more as the pressure decreases. This creates a froth of magma and gas analogous to opening a fizzy drinks bottle.

If the magma travels quickly to the surface so that pressure is quickly released, and there is a high volatile content, and the magma is sufficiently viscous (e.g. andesite), then the bubbles may not fully escape the magma. There may be so much gas expanding so quickly that the magma fragments, creating an explosive eruption, as ash and pumice are thrown high into the air, creating an eruption column which may rise high up into the atmosphere or fall back to earth and form an ash flow (also called a pyroclastic flow). The pumice is solidified froth, which cools so quickly that it is technically a glass (it has no mineral structure, see Obsidian). Pumice often has so much gas inside it that it floats on water (this one does), and some people use it to rub the dead skin off their feet, as all the vesicles (bubbles) make its surface very rough.

Examples of explosive volcanoes which erupted pumice include Vesuvius, Mount St Helens and Krakatoa. They tend to be mature hotpspot volcanoes or subduction zone volcanoes (formed when old ocean floor sinks underneath another plate) because these have water-rich, silica-rich (and therefore viscous) magmas. The other extrusive (erupted) igneous rocks in this box are from non-explosive volcanoes.

Granite

This is an intrusive igneous rock – a rock formed when magma trapped underground in a magma chamber cooled and solidified. Other intrusive igneous rocks include gabbro, which has the same composition as basalt, and diorite, which has the same composition as andesite. Granite has the same composition as rhyolite. Its larger crystal size is due to its slow cooling rate. There are four major types of crystals to see in the large granite specimen (the Shap Granite / G5a):

- Quartz – the translucent, glassy grey ones
- Orthoclase feldspar - the large, reflective pink-brown rectangular crystals. Note the simple twinning.
- Plagioclase feldspar – the small, rectangular white ones
- Biotite mica – the shiny, flat black ones

There may also be small amounts of pyrite and hornblende (present in the small granodiorite). All the minerals mentioned are in this box. Granites can have much bigger crystal sizes than this, and those with crystals more than 2.5cm in size are called pegmatites. These are thought to have grown in the presence of water, which furthers the growth of existing crystals by inhibiting the nucleation of new, small crystals.

Gabbro

This is another coarse-grained, intrusive igneous rock, but with less silica and more Fe+Mg than granite (the same composition as basalt). These gabbro samples were collected from the Black Cuillin in the Isle of Skye and are around 60 million years old (associated with the opening of the North Atlantic). The major minerals present in these samples are:

- Pyroxene: elongate, black, slightly metallic crystals with flat, reflective faces at 90°.
- Plagioclase feldspar: Rectangular white or grey crystals
- Magnetite: Generally irregularly-shaped, grey, metallic crystals. In some samples there is enough magnetite to attract the artificially-magnetised magnetite in the pink box.

Peridotite (Lherzolite and Harzburgite)

Peridotite is a coarse-grained, ultramafic (very SiO_2-poor) rock, and is what most of the upper mantle is made of. The major minerals are:

- Olivine: translucent lime-green; glassy. This is what gives peridotite its unique colour (and name - gem-quality olivines are called peridots)
- Pyroxene: black and shiny.

The more pyroxene-rich peridotites are known as lherzolites and are thought to make up most of the upper mantle. Once these rocks have partially melted at plate boundaries, much of the pyroxene is removed and the rock becomes a pyroxene-depleted harzburgite.

Pyroxenite

This is a coarse-grained rock consisting of mainly pyroxene. In some theories, pyroxenite exists as isolated 'blobs' in the upper mantle.

Metamorphic Rocks

When sedimentary and igneous rocks experience high temperature and/or pressure they change, becoming metamorphic rocks. Five of the metamorphic rocks (slate, phyllite, mica schist, garnet schist, gneiss) could have been made from the same protolith (original rock) – a shale. Very high pressure is usually associated with orogenic (mountain building due to continental collision) belts, whereas high temperature may be due to depth of burial, or the presence of a nearby magma chamber.

Slate

Mudstone (or shale) is a sedimentary rock made up of clay minerals and silt-sized particles (which are finer than sand) of other minerals such as quartz. A slate can be made from the compaction of mudstone. This is a lower metamorphic grade than phyllite, the difference being that a slate has not experienced new crystal growth. The silt and clay minerals have aligned themselves in response to the pressure they have experienced, creating this characteristic slatey cleavage. It is this cleavage (a foliation along which the rock tends to break) which allows slate to be broken into the big flat slabs used for roof tiles.

Phyllite

Further metamorphosis of a mudstone can produce a phyllite. The clay minerals become unstable at a lower pressure than the quartz, and so if shale put under sufficient heat and pressure, they will start to change into other minerals – usually green chlorite and silvery micas. These tend to be aligned so that their cleavage is perpendicular to the direction of maximum compaction, leading to the shiny surfaces you can see.

Mica Schist

When metamorphosing mudstone at yet higher temperatures, the mica crystals become larger and we start to see biotite instead of chlorite, leading to this very shiny, glittery rock.

Garnet Schist

This is rather like the mica schist – it is also a metamorphosed shale in which recrystallisation has occurred, producing crystals visible to the naked eye. However, the large crystals in this specimen are of a mineral called garnet. This is a very dense mineral, and consequently is most likely to form under a lot of pressure (decently higher pressure than would be required to form the mica schist). This means that this garnet schist probably formed deeper in the Earth's crust than the mica schist, but otherwise is rather similar in its formation.

Gneiss

Gneiss has undergone a higher grade of metamorphism than a slate or schist, but is also usually made from shale. The high pressure and temperature conditions allow the rock to develop compositional banding perpendicular to the direction of maximum compaction. For this to occur, there must be both diffusion and recrystallisation happening. This allows the rock to have bands of white felsic (SiO_2-rich, Fe-poor) and dark mafic (SiO_2-poor, Fe-rich) material.

Quartzite

Quartzite is metamorphosed sandstone. Since sand is often largely made up of quartz, it is simply formed by the recrystallisation of this quartz under high temperature and pressure.

Marble

Marble is metamorphosed limestone. Since limestone is mostly made up of carbonate minerals (calcite, dolomite etc), so marble is predominantly composed of carbonates which have recrystallised under high temperature and pressure. Kitchen surfaces are often made of Marble, so you can tell them they're eating off dead sea creatures to add interest.

Connemara Marble

Connemara Marble, which comes from the region of Ireland of that name, is not technically a marble. It is a serpentinite breccia.

Ultramafic rocks are close to the composition of the mantle, are brought up from the mantle in magma, and tend to contain a lot of a mineral called olivine. Heat and the presence of water can metamorphose olivine into another mineral, serpentine, transforming the rock into serpentinite. A rock made from broken up pieces of serpentinite is a serpentinite breccia, such as this Connemara marble (see Breccia). The main other minerals in this rock are carbonates. The green colour is common in ultramafic rocks, probably due to nickel and reduced iron.

Sedimentary Rocks

Bits of sand, mud, dead organisms (which may become fossils) and other matter fall to the bottom of lakes, seas and rivers. As more layers of this sediment accumulate, the buried sediment gets squashed together, a lot of the water is squeezed out, forcing the sediments together into a sedimentary rock. During this compaction (which at a much lower pressure than metamorphism), minerals such as quartz and calcite that may be dissolved in the water may recrystallise between the sediments to form a cement, holding them together more securely.

Not all sedimentary rocks are made beneath bodies of water – for example, some sandstones are formed in deserts. However, they must all be formed by the compaction of grains of sediment together during burial.

If you can see layers in any of these rocks, it is probably the bedding, which is formed by the deposition of each new layer of sediment.

Sandstone

Sandstone is a rock composed almost entirely of sand grains which have been compacted together. They can form in a range of environments, including deserts, rivers, deltas, lakes or seas. Due to the currents or waves required to transport sand, softer minerals are often broken down before deposition, leading to very quartz-rich sand in many cases, as quartz is a very hard mineral. The red colour in the large specimen is due to haematite - an iron oxide that forms in oxidised, terrestrial environments and helps to cement the quartz grains together into a solid rock. The well-rounded grains that are all the same size indicate that they has been in motion (probably blown by the wind) for a long time, bashing into each other and leading to the rounded shape.

Arkose Sandstone

This is a rock formed by the burial and compaction of sand with the softer minerals still intact. By definition, there should be at least 25% feldspar, but other minerals such as micas and calcite may also be present. To prevent the breakdown of these minerals physically or chemically, the sand must be deposited fairly rapidly (for example at the base of a mountain range where a river slows down and spreads out, called an alluvial fan), preferably in an arid environment. A likely source rock for the required feldspar-rich sediments is an igneous rock such as granite.

Shale

Shale (or mudstone) is a rock composed of silt-sized grains and clay which have been compacted together. They are formed in low-energy environments, as currents and waves would wash away such small grains of sediment, and carry in and deposit heavier grains such as sand. This includes very slow rivers and deep lakes or seas.

Conglomerate

This rock is made up of pebbles, so must have been deposited in a particularly high energy environment, such as a beach with strong waves or a fast-flowing river. The pebbles are from fragments of rock which have been eroded, and then bashed into a smooth shape by the river or the waves. There may also be finer material if a river has quickly changed from being fast-flowing to slow-flowing.

Breccia

Breccia is made up of angular fragments of rock which have been eroded and deposited by a landslide or a river, without enough time spent in the river to be smoothed into rounded pebbles.

Limestone

Limestone is a sedimentary rock made up mostly of carbonates. This may be organic – from the shells of animals and the skeletons of microfossils – or inorganic – from calcium carbonate which has precipitated from sea/lake water where the water is oversaturated in calcium carbonate (this happens because to solubility of calcium carbonate in water is dependent on a number of things including pH and temperature).

Flint/Chert

Chert is made from microcrystalline silica (SiO_2), and often contains impurities and occasional fossils. Flint is a particular type of chert that has formed within chalk. It is not yet well-understood why the silica in these sediments has localised in this way, but is probably to do with dissolution and reprecipitation of silica in the buried sediments before the water has been squeezed out by compaction. It is thought that the shape of flint/chert nodules may be related to burrows in the sediment, and the source of the silica is likely to be either skeletons of tiny zooplankta such as diatoms and radiolaria, or sponge spicules, which are all made from silica.

Flint and chert are also very interesting from an archaeological perspective due to two important properties. The first is their ability to be hammered (or "knapped") into hard sharp blades, which led to them being used as the main material for tools by Stone Age people. The second is that when iron (or a mineral containing iron such as pyrite) is struck against flint, it produces sparks which can be used to light a fire. In general flint was better for these purposes than chert as it tends to be harder and more pure.

References for Images:

- The Rock Cycle – By Kreislauf_der_gesteine.png:Chd at de.wikipedia derivative work: Awickert (Kreislauf_der_gesteine.png) [CC-BY-SA-3.0 (www.creativecommons.org/licenses/by-sa/3.0)], from Wikimedia Commons
- Map Plate Tectonics http://vulcan.wr.usgs.gov/Glossary/PlateTectonics/Maps/map_plate_tectonics_world.html
- Earth Structure – adapted from Earth-G-force.png: derivative work: KronicTOOL (Earth-G-force.png) [CC-BY-SA-2.5 (www.creativecommons.org/licenses/by-sa/2.5)], via Wikimedia Commons
- Geologic Time Scale – adapted from United States Geological Survey [Public domain], via Wikimedia Commons
- Fossil map – By jmwatsonusgs.gov [Public domain], via Wikimedia Commons
- Volcano X-Section – adapted from MesserWoland (own work created in Inkscape) [GFDL (www.gnu.org/copyleft/fdl.html), CC-BY-SA-3.0 (www.creativecommons.org/licenses/by-sa/3.0/) or CC-BY-SA-2.5-2.0-1.0 (www.creativecommons.org/licenses/by-sa/2.5-2.0-1.0)], via Wikimedia Commons
- Mosasaur Skeleton – By Mike Beauregard from Nunavut, Canada (Prepare To Meet) [CC-BY-2.0 (www.creativecommons.org/licenses/by/2.0)], via Wikimedia Commons
- Sea Urchin (echinoid) – Copyright ©2003 Daniel P. B. Smith. Licensed under the terms of the Wikipedia copyright.
- Straight Nautiloid – By Nobu Tamura email:nobu.tamura@yahoo.com www.palaeocritti.com (Own work) [GFDL (www.gnu.org/copyleft/fdl.html) or CC-BY-3.0 (www.creativecommons.org/licenses/by/3.0)], via Wikimedia Commons
- Crinoid Anatomy – By William I. Ausich (http://www.tolweb.org/Crinoidea/19232) [CC-BY-3.0 (www.creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

PLUS Explanation

This experiment has no explicit PLUS explanation. It's more a case of how much of the above detail you discuss with the kids.

Risk Assessment

Hazard: Small pieces

Description: The smaller samples are a choking hazard for small children if ingested.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Ensure that small samples are not in the reach of small children. Keep an eye on children with samples and make sure they don't put things in their mouths. Would advise keeping the very small gemstones in their plastic bag. Call a first-aider in event of ingestion.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Shattered samples

Description: Dropping samples may cause them to shatter, producing sharp edges and possibly dust for some samples.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Keep fragile samples in clear plastic bags for protection and to prevent dust if breakage occurs. If any samples do break, carefully remove the broken bits from display to avoid people cutting themselves. In case of injury call first-aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Samples with scary shapes

Description: Children may be trypophobic (i.e. afraid of samples with many holes/pores) or scared of some of the fossil creatures.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Take care with woolly mammoth bone, turtle shell and vesicular basalt. If a child is distressed, put away the sample, assure the child that it's just a rock, and allow them to calm down elsewhere.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Heavy samples

Description: Could cause injury if dropped

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Ensure children do not pick up samples that are too heavy for them. Keep all heavy samples over the table or close to the floor; do not allow children to hold them where they could be dropped on feet. Call a first-aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2011-12-22 - Hannah Ford (hf257@cam.ac.uk), **Check 2**: 2012-01-14 - Adam Casey (ac675@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-02-11 - Alex Davies (ad578@cam.ac.uk)

Check 1: 2015-01-19 - Matthew Kemp (mk775@cam.ac.uk), **Check 2**: 2015-01-19 - Elizabeth Pearmain (ejp69@cam.ac.uk)

Check 1: 2016-01-20 - Tim Morgan Boyd (tmb58@cam.ac.uk), **Check 2**: 2016-01-23 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2017-01-11 - Roxanne Armfield (rea41@cam.ac.uk), **Check 2**: 2017-02-07 - Matthew Kemp (mk775@cam.ac.uk)

Check 1: 2017-12-19 - Roxanne Armfield (rea41@cam.ac.uk), **Check 2**: 2017-12-27 - Matthew Kemp (mk775@cam.ac.uk)

Check 1: 2019-02-02 - Helen Gildersleeves (hcg31@cam.ac.uk), **Check 2**: 2019-02-03 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2020-02-05 - Helen Gildersleeves (hcg31@cam.ac.uk), **Check 2**: 2020-02-06 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-06 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2022-02-09 - Sophie Miocevich (srm81@cam.ac.uk)

Check 1: 2023-02-15 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-17 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2024-01-31 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Margaret Johncock (mllyj2@cam.ac.uk)

Rolling Down Hills

Racing jam jars down a gentle slope, to see how filling them affects the speed. - Find out about rotational mechanics by racing jam jars of differing weights downhill.

Last initially checked on 2023-12-23 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-01-06 by Lauren Mason (lb831@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

CHaOS+ (More complex explanations suitable for older children are available)

Physics

Equipment Needed

- *In the box there should be:*
- Empty jam jar
- Jar half full of water
- Jar full of water
- Full jar of jam
- *You will also need:*
- Gentle slope - Large wooden board. There is one dedicated to this purpose, but if that cannot be found, the archbridge base should work instead if not in use.
- A couple of things of obvious different weights to drop that won't break. Two rolls of gaffa of different sizes works nicely.
- Foam block/thick pad/sleeping mat - something soft to place at the bottom of the ramp to stop the jars escaping. The foam covering lungs works. Alternatively use an opened t-shirt box to catch the jars. Hitting the t-shirts gives them a soft landing. Some padding around the sides of the ramp is needed in case the jars roll off the ramp.
- (Optional) Some sort of release mechanism to release all the jars at the same time.

Experiment Explanation

Race the jam jars down a slope to see which one is faster.

In a Nutshell

Show people that rotational motion is a bit weird - you have to account for the distribution of mass not just the overall properties.

Setup

Not much to do. Place the ramp on the floor (if using a board then use a couple of jars/ spare box or find something else to hold the back end up). If using an opened t-shirt box to catch the jars, place at the bottom of the ramp, or if using foam, place about 10cm past the end of the ramp (taping it down helps if its small).

The Experiment

Gain attention by telling people they'll be racing jars down a hill. Explain what's in the jars.

First, bring out the drop test objects and ask kids which one is heavier (they can feel this for themselves) and ask which one will hit the ground first if they're dropped from the same height at the same time. Both should hit at the same time (demonstrate a couple of times, from different heights if necessary). Get them to tell you what force pulls things down. The heavier something is, the stronger the gravity. BUT, the heavier something is, the harder it is to get it to move (it's not as easy to pick up something heavy). These effects cancel each other out so all objects fall under gravity at the same rate.

Now ask them to think about what will happen on the ramp - if gravity doesn't care how 'heavy' things are, should the weight of the jars make any difference? Will they all reach the bottom at the same time? Feel free to prompt some more (why do you think X, what might cause Y) if the group is old enough to engage.

Let the kids pick up the jar of jam and the empty jar to get a feel for the weights, and then race! (if the kids are eager and you can get them to release when you say, then they can hold the jars and let go when you tell them to. Alternatively, a pole or stick can be used as a release mechanism). The jar of jam should beat the empty jar.

It looks like the heavier jar wins but this makes no sense since we've already seen gravity doesn't care about weight. What is the difference between falling and rolling? When falling (or sliding on the slope), the jar stays one way round (in one orientation) whilst moving. When rolling, as well as moving down the slope, the jar is also spinning. This is what changes things. Gravity needs to put in extra effort to get the jars spinning as well as going down.

Get the kids talking about it a bit and then ask them if they've been on a roundabout/ merry-go-round/ turntable thing at a park. Does it just start spinning on its own without any pushing? What about pushing the thing if someone else is on it - is it easier to make it spin fast if the other person is in the middle or at the edge? (You can also try to connect this to Spinny Chair experiment if it is also out.) Exactly the same thing is happening here with the jars. The empty jar has almost all of its mass concentrated in a very thin layer of glass a long way from the axis of rotation whereas the one full of jam has a lot of mass quite close to the middle. It's therefore much 'easier' to make the full jar spin than the empty jar (could be worth mentioning, to reinforce the idea that weight is irrelevant, that if there were no friction the jars would all slide (not roll!) down the hill in the same amount of time).

Next try the jar of jam vs the jar of water. The jar of water wins, why? What's the difference between the water and the jam? Answer: Jam is sticky, but water isn't. When the jar of the water rolls down, the water doesn't have to spin, only the jar, whereas in the jar of jam both the jar and jam are spinning. This means the jar of water can go faster.

The interesting case of the half-full jar and the jam jar can now be the ultimate race. The jam jar has the extra weight, but the half-full water jar doesn't have to spin as much, so you can get the kids to bet on which will win. This one is actually quite close, so you'll have to see which wins on the day!

In conclusion for linear motion the distribution of mass is irrelevant, only the total, whereas for rotational motion it's not just the mass that matters, its position is important as well.

PLUS Explanation

First, bring out the drop test objects and ask kids which one is heavier (they can feel this for themselves) and ask which one will hit the ground first if they're dropped from the same height at the same time. Both should hit at the same time (demonstrate a couple of times, from different heights if necessary). Get them to tell you what force pulls things down. The heavier something is, the stronger the gravity. BUT, the heavier something is, the harder it is to get it to move. These effects cancel each other out so all objects fall under gravity at the same rate.

Explain that we are ignoring air resistance (or get them to tell you that). Use Newton's second law to explain how mass doesn't affect acceleration under gravity. It seems odd that the inertial mass term in Newton's second law happens to be the gravitational mass. Einstein used this empirical fact in his 'Equivalence Principle' where he equates the gravitational force experienced by an observer to the same force that would be experienced if the observer were accelerating. This then lead to his Theory of General Relativity: The currently used theory that describes the effect of gravity.

These effects can also be understood if the falling masses are described by their energies. As the mass falls, gravitational potential energy is converted into kinetic energy, but again (use equations to show) the speed at which they fall is the same.

Now ask them to think about what will happen on the ramp - if gravity doesn't care how 'heavy' things are, should the weight of the jars make any difference? Will they all reach the bottom at the same time? Feel free to prompt some more (why do you think X, what might cause Y).

Let them pick up the jar of jam and the empty jar to get a feel for the weights, and then race! A pole or stick acts as a good release mechanism. The jar of jam should beat the empty jar.

It looks like the heavier jar wins but this makes no sense since we've already seen gravity doesn't care about weight. What is the difference between falling and rolling? When falling (or sliding on the slope), the jar stays one way round (in one orientation) whilst moving. When rolling, as well as moving down the slope, the jar is also spinning. This is what changes things. Gravity needs to put in extra effort to get the jars spinning as well as going down.

When two objects fall through the air under gravity we only need to consider their centre of mass motion. However, when the jars roll down the hill we also need to consider their rotational motion. The jars have linear kinetic energy due to the movement of their centre of mass and rotational kinetic energy from their rotation.

Does a roundabout just start spinning on its own without any pushing? Sixth form students should be familiar with F=ma, can introduce them to G=I x angular acceleration. G is the torque, the equivalent of force for rotational motion, students may have come across this before in the context of pivots. I is the moment of inertia. This is the equivalent of mass for rotational motion and is a measure of how easy it is to rotate an object. For linear motion, a larger mass makes it harder to move something. Here, a larger moment of inertia makes it harder to spin something. The difference between mass and I is that I is related to both mass and the distribution of the mass. Referring back to the roundabout, is it easier to make it spin fast if a person is sat in the middle or at the edge? (You can also try to connect this to the 'Spinning Chair' experiment if it is also out.) The larger the mass of an object, the harder it is to move and the larger the moment of inertia the harder it is to get the object to rotate. Additionally, the further away this mass is from the axis of rotation, the harder it is to move and the higher the moment of inertia. Link the two equations together and explain that we can treat angular motion is a very similar way to linear motion.

When different masses of the same shape are dropped and fall through the air they hit the ground at the same time. The larger the mass of the object the the larger the force due to gravity, but also a larger force is required to move it. Can think about how easy/hard it is to pick things off the ground that weigh different amounts. Can also relate back to F=ma. In this case F=mg, so a=g. Acceleration is constant. Now instead of just thinking about F=ma, need to think about G=I*angular acceleration. The torque, G is proportional to mass. Moment of inertia is also proportional to mass, but with different prefactors depending on the distribution of mass within the object. The means that accelerations for the empty jar and the jar of jam are different because the distribution of mass is different.

As rotating need to think about moment of inertia. The jar of jam has a larger mass than the empty jar and it also has a larger moment of inertia. However, because the jam is distributed uniformly throughout the jar, the mass increases by a larger fraction than the moment of inertia compared to the empty jar. The empty jar has almost all of its mass concentrated in a very thin layer of glass a long way from the axis of rotation whereas the one full of jam has a lot of mass quite close to the middle. Objects with more mass closer to the axis of rotation are easier to rotate than objects with more mass closer to the edges of the object. This means that relatively speaking gravity finds it easier to rotate the jam jar. This means that the jam jar travels faster down the slope. If instead we compared an empty jam jar made of glass and an empty jam jar of the same shape but made of lead, the jars would reach the bottom of the slope at the same time. The important point isn't that the jam jar has extra mass but the fact that the extra jam mass is distributed throughout the jar.

(could be worth mentioning, to reinforce the idea that total mass is irrelevant, that if there were no friction the jars would all slide (not roll!) down the hill in the same amount of time).

Next try the jar of jam vs the jar of water. The jar of water wins, why? What's the difference between the water and the jam? Answer: Jam is sticky, but water isn't. Because of this the jam is stuck to the outside of the jar and rotates with the jar when it rolls down the slope. The water however, isn't 'stuck' to the side of the jar so only sloshes slightly as the jar rolls. This costs less energy, so more energy goes into the linear kinetic energy of the jar down the slope. Overall energy must be conserved and both jars start with the same energy. (Neglecting the difference in mass between water and jam). So the water jar travels faster and wins the race.

The interesting case of the half-full jar and the jam jar can now be the ultimate race. The jam jar has the extra weight, but the half-full water jar doesn't have to spin as much, so you can get the kids to bet on which will win. This one is actually quite close, so you'll have to see which wins on the day!

In conclusion for linear motion the distribution of mass is irrelevant, only the total, whereas for rotational motion it's not just the mass that matters, its position is important as well.

An energy argument

What force is it that causes something to spin in the first place? (Friction acts at the point of contact of the jars). All of the problems can be explained by considering the energy of the jars. When the objects were dropped before, gravitational potential energy was converted into kinetic energy, but with spinning added, we need to incorporate a new energy term for the rotation of jam about the centre of the jar - rotational kinetic energy. The amount of rotational energy that you need to put in depends on where the mass is, so the empty jar has the worst distribution of mass and rolls slowest. For the full jar of water the water isn't rotating so the rotational energy is only for the glass, meaning it can roll quicker.

We can write the rotational kinetic energy down in an equation similar to the linear kinetic energy: LKE = (½)mv^2 RKE = (½)Iw^2 w is how quickly the jar is spinning. I is called the moment of inertia, and increases as mass gets further away from the centre, so more energy will be required. Actual definition is sum of mass * (distance from rotation axis)^2. E.g. figure skating: if a skater brings their arms in they've reduced their MOI but to keep the same rotational energy the same they spin faster"). Can demo this in the playground - several people stand at the edge of a roundabout spinning fairly slowly and walk in to the middle. The roundabout should speed up and if they walk back out it should get slower again.

The wikipedia page on 'moment of inertia' has more information and a nice gif animation of (front to back) a solid cylinder, cylindrical shell, ball and spherical shell racing down a slope.
http://en.wikipedia.org/wiki/Moment_of_inertia#Scalar_moment_of_inertia_...

Risk Assessment

Hazard: Rolling objects

Description: The objects rolling into people, and tripping them up.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Make sure the base of the slope is not heading towards a gangway or towards people's legs. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Jam jars

Description: The objects bouncing off things and breaking, then possibly making sharp objects as a result which can cause cuts.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Put something soft at the base and as much as you can around the sides of the slope (particularly near the base) to catch the objects. Consider wrapping the jars in sellotape. In case of breakage, close experiment until broken glass and spilled water is cleared up. Call a first aider in the event of an injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Liquid in jars

Description: Slip hazard from spilled water if jars break.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Keep children away from any spillages and dispose of safely and quickly. Put something soft at the base and as much as you can around the sides of the slope (particulary near the base) to catch the objects. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Objects on surfaces

Description: Jars falling off the bench and hitting people, or breaking and making sharp pieces of glass which can cause cuts.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Do the experiment on the ground. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-26 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2015-01-22 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-20 - Benjamin Akrill (bja32@alumni.cam.ac.uk), **Check 2**: 2018-01-20 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-29 - Benjamin Akrill (bja32@alumni.cam.ac.uk), **Check 2**: 2018-02-09 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2019-01-02 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-05 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-25 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Holly Smith (hs606@cam.ac.uk)

Check 1: 2022-02-09 - Sophie Miocevich (srm81@cam.ac.uk), **Check 2**: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk)

Check 1: 2023-01-18 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2023-01-19 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-12-23 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-01-06 - Lucy Bland (lb831@cam.ac.uk)

Seeing Sound

Use an oscilloscope and slinky spring to see how sound travels - Find out what sound is, the difference between low and high sounds, and loud and quiet sounds, and learn about sounds we can't hear

Last initially checked on 2024-01-06 by Lucy Bland (lb831@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Electricity needed**
- Box in which is mounted a signal generator and audio amplifier, with cables.
- Loudspeaker
- Oscilloscope
- Microphone + battery box
- Concertina, recorder, etc.
- Antiseptic wipes (to clean the recorder)
- Slinky spring

Experiment Explanation

Overview

Seeing Sound uses a signal generator and loudspeaker to make sounds, as well as various musical instruments. There is a microphone and oscilloscope to 'see' the sound, to allow kids to learn about what sound waves are and some of their properties. If the oscilloscope isn't working, or is too complicated to figure out, a reasonable alternative is to download a free mobile app instead. If doing this, keep your phone in your possession at all times.

Possible activities: - Explaining what sound is, and how you can hear things, using the signal generator and loudspeaker. - Looking at your voice on the oscilloscope when you say different words and vowels etc. - Comparing the voices of different people looking at pitch and volume. - Looking at how simple musical instruments work.

Other things to talk about: - How sound travels through the air. - How the oscilloscope displays a sound wave. - How people lose their upper hearing range and application to mosquito alarms. - That many animals can hear ultrasound just like children can hear things adults can't e.g. dog whistles and bat squeaks.

Tips for demonstrating: - Get the whole family to talk into the microphone so that you can look at the different pitches and volumes of their voices. - Get the children to try different vowel sounds, low sounds, and high sounds etc. - There's a lot which can be done in this experiment; you don't have to do it all, and you don't have to follow the order below…

Basic Procedure and Explanation

- Start by explaining how we can hear things. Ask the children if they know anything about waves - water waves, sound waves etc.
- When sound travels through the air, it is in the form of a wave, a little bit like the waves that you get on the surface of water (although longitudinal compression wave rather than transverse).
- Use the slinky to show how longitudinal waves travel. Normally we can't see these waves in the air, but our ears can pick them up. It's like people jostling all the way across a room.
- Using the signal generator and amplifier, get the loudspeaker oscillating at 10-20 Hz and get the kids to notice this. If they are careful they can touch the speaker gently to feel it move.
- Then turn up the frequency so you can hear it (make the connection between the wobbling and the sound) and can still feel it 50-80Hz. Get them to feel the air above the speaker they should be able to feel it moving. Say that the air wobbles above the speaker, and then wobbles all the way to their ear (you could use the slinky to demonstrate this - a picture of an ear and loudspeaker may help here too) and your ear hears the wobbles as sound.
- Turn up the frequency again, and get the kids to make the connection between speed of vibration and pitch.
- See what they highest they and their accompanying adults (and you!) can hear - should be just below 20 kHz for us and them, can easily be around 15 kHz for (proper) adults. If they seem to have superhuman hearing and claim to hear e.g. 30 kHz, secretly turn it off and see if they can still hear it!
- Explain that you can't see sound, because the air is transparent and it's moving too fast anyway. Then introduce the microphone and oscilloscope and look at the sound from the loudspeaker. (If the oscilloscope isn't working well, there are free mobile phone apps make a reasonable alternative if your battery can hold out. The following explanations still hold though the output isn't always as clean!) The children can also make some simple noises into the microphone. Vowels are good for this. Explain that each sound has its own particular shape - saying the alphabet can prove invaluable here. A long vowel sound should create a quite stable wave on the 'scope.
- Ask the child to sing a quiet note and a loud note, and see that the picture drawn gets taller with volume.
- Get child to sing a long note moving from a high note to a low note (dads may be useful here for very deep notes), and show that the wiggles on the screen get further apart the lower the note, and closer together the higher you go. This is a measure of increasing frequency - when things vibrate faster, we get a higher note (e.g. car accelerating).
- They can also feel their larynx vibrate when they talk - easier with lower sounds.
- Now for the musical instruments! Let them try to make different notes with recorder and concertina, and with the big pan pipes from the resonance experiment. Look at how different pitches, different volumes, and different timbres (types of note) appear on the oscilloscope. Ask if they play any instruments and explain how that creates vibrations.

Other things to talk about

- Introduce the idea of wavelength with long wavelengths corresponding to low frequencies and vice versa.
- A couple of features of the oscilloscope can be explained. You can explain that the microphone converts the air wobbling into an electrical wobble which makes the dot on the screen wobble up and down (you can show this by turning the freq very low on the oscilloscope and you should be able to see the dot going up and down). Speed the dot up again a bit and kids can normally work out that fast wobbles make short wavelengths on the screen, and from stuff earlier they should be able to work out that high pitch makes short wavelengths too.
- You can go into more detail of the biology of hearing, or use this point to encourage them to go onto the biology experiments afterwards!
- You can think about why the ear and loudspeaker are the shapes they are, and why these are quite similar. This is also quite like an amphitheatre.

Science Background for Demonstrators

Sound is a longitudinal (compression and rarefaction) wave through the air. The signal generator produces an oscillating electrical signal, made bigger by the amplifier; the loudspeaker contains a coil of wire which acts as an electromagnet, so that the speaker cone oscillates at the same rate as the signal. We hear because the sound wave makes our eardrums vibrate: the vibration is passed on through a series of bones which amplify its magnitude to the cochlea, where tiny hairs inside the fluid-filled tube pass a signal through the auditary nerve to the brain when they resonate with the vibrations. (The action of these hairs is complex, and only recently becoming understood.)

The microphone is capacitative, so needs a battery and resistor (in the little box) to produce a voltage signal for the ’scope.

Recorders (and suchlike) produce standing waves of air in the tube. The concertina is a free reed instrument: air is blown past a tongue of metal, which vibrates at a rate determined by its length and mass, in such a way that the air going past is caused to vibrate too.

Risk Assessment

Hazard: Heavy Objects

Description: The oscilloscope is heavy and could be dropped or knocked off table, possibly injuring children.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Keep oscilloscope away from edges of table, or keep in the opened box if convenient. In the event that the oscilloscope falls, switch it off. Clear up broken glass.

Call first aider in case of injury. Close experiment if necessary.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Recorder mouthpiece

Description: Spread of infection via recorder mouthpiece.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Clean mouthpiece of recorder with antiseptic wipes between uses. (During COVID, maybe worth not doing this part)

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Amplifier

Description: The amplifier can be quite loud, so there is the possibility of auditory damage.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Take care not to have amplifier on too loud.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Oscilloscopes (electrical)

Description: Electrical hazard.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: See electrical parts RA.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-02 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Aaron Barker (arb78@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-16 - Jachym Sykora (js973@cam.ac.uk)

Check 1: 2014-01-25 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-02-15 - Brett Abram (ba305@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-22 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-01-30 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-01-13 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2019-01-02 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-13 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-02 - Lucy Hart (ljfh2@cam.ac.uk), **Check 2**: 2021-01-03 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2022-02-09 - Joshan Parmar (jp862@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-01-18 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2023-01-19 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-01-06 - Lucy Bland (lb831@cam.ac.uk) , **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Seismometer

A seismometer and lots of explanation - Find out about the structure of the earth, and how we have found it out despite only digging down 0.2% of its depth.

Last initially checked on 2024-01-31 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-01 by Margaret Johncock (mllyj2@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Geology

Active (Experiment has working equipment at the time of last update, and is available for events.)

CHaOS+ (More complex explanations suitable for older children are available)

Equipment Needed

- **Electricity needed**
- In this box there should be:
  - Lego Seismometer (including magnets, weight, coil, spring and lego structure)
  - aux cord
  - micro-USB to USB cord
  - seispy converter
- 4/5 tennis balls (under development)
- One magnet in labelled sealed box (under development)

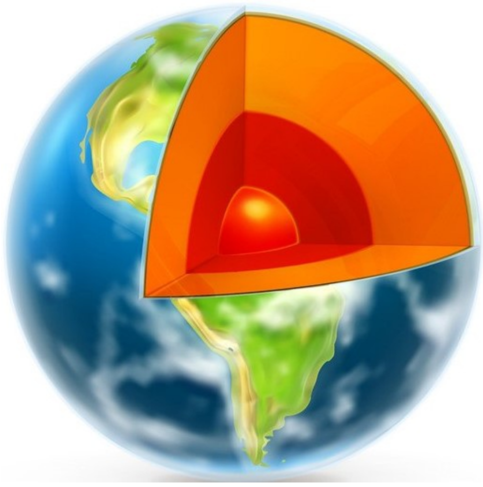
Experiment Explanation

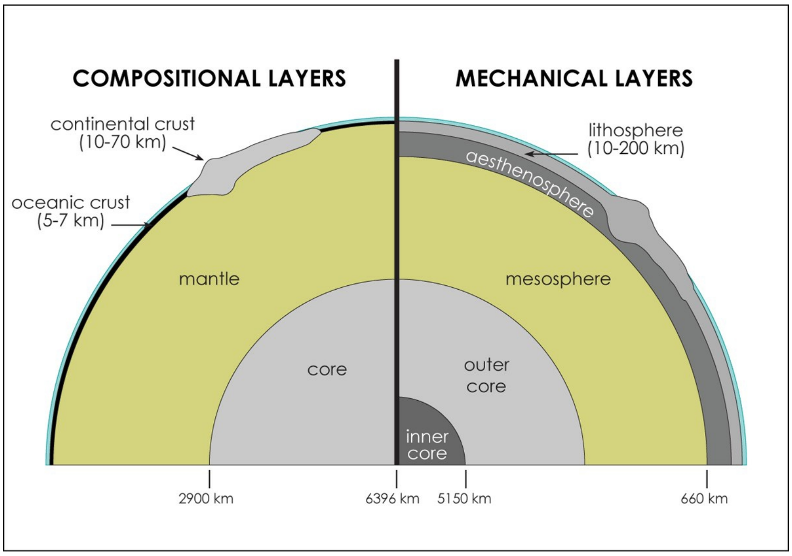
The following are some suggested talking points for the seismometer experiment. You do not need to do all of them, but there should be enough here for an interested person. A lot of it is not directly related to the seismometer, but the larger field of seismology. Drawing diagrams and asking questions is a good way to keep it interactive. Keep the seismometer set up and refer to and use it throughout the experiment.

For when we have a tennis ball with magnet: Start off by using the tennis balls to discuss how we might work out what is inside something without just opening it. Get participants to experiment with the tennis balls; e.g. shake, compare weights, test with the magnet in the box, to think about what might be inside them. Then start discussions about what kind of techniques we can use to see inside the earth.

Otherwise - rely on drawn diagrams.

What is the earth's structure? (figures 1 and 2)





There are two dominant classification schemes:

• Crust, mantle, outer core, inner core are the popular terms. The boundaries between these are defined by chemical compositional changes, i.e. the rock type changes from one side to the other. The crust/mantle boundary is called the 'moho boundary'.

• You can also describe the crust and mantle by the lithosphere (which covers the crust and upper part of the mantle) and the asthenosphere, which is everything deeper up to the outer core (mesosphere is sometimes also included). The lithosphere and asthenosphere are different in elasticity. Across the boundary, the temperature increases, making rock more ductile and less rigid (A famous example of the importance of this transition is the failure of the titanic: In the icy temperatures, the metal hull became brittle and was subject to a brittle failure).

The earth structure classifications are therefore chemical and physical respectively.

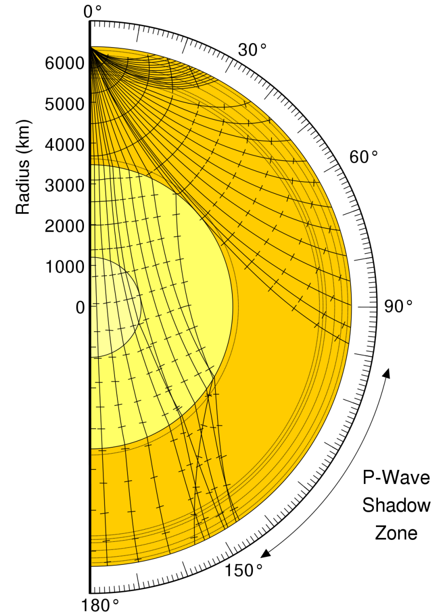
How do we know what the earth's structure is?

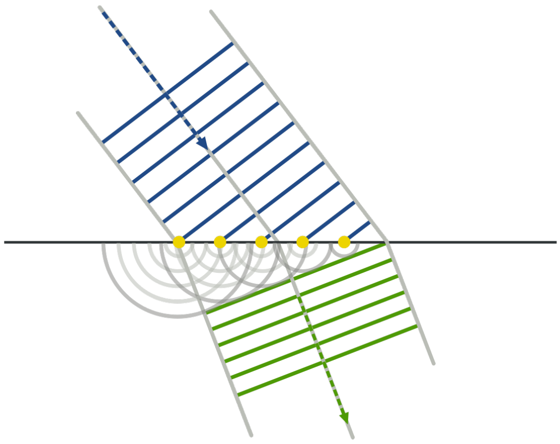
How far do you think we've drilled? Earth's radius is 6371km. We certainly haven't drilled down very far: Kola Superdeep Borehole in Russia continent went 12.3km. The earth's crust is ~8km deep in the ocean, and ~27km deep in the continents, so we haven't even reached the bottom. Why? Calculate what the pressure might be at 12.3km depth (continental crust density = 2.83* that of water, ocean crust even denser ~3.3*water). This is a hydrostatic pressure, so there is the same pressure pushing upwards. Quite hard to push down.

We don't have samples from very deep: ~400km. The peridotite in the 'Rocks and Fossils' experiment will be from a similar depth. This is only partly into the mantle! How do we have this if we haven't drilled down to it? 'Rocks and Fossils' has a rock cycle explanation.

The solution: Earthquakes!!! They naturally probe the earth for us. What is an earthquake? Earthquakes occur by 'elastic rebound'. Over time, tectonic processes (possible digression to plate tectonics here, much higher pressures at convergent plate boundaries) build energy. Once this overcomes friction, rupture occurs, and seismic waves radiate off. Deepest earthquakes are around 300km and occur almost exclusively at convergent plate boundaries. Why are none found deeper? Ans: refer back to discussion of ductile vs brittle, hot rock flows better and stresses are dissipated.

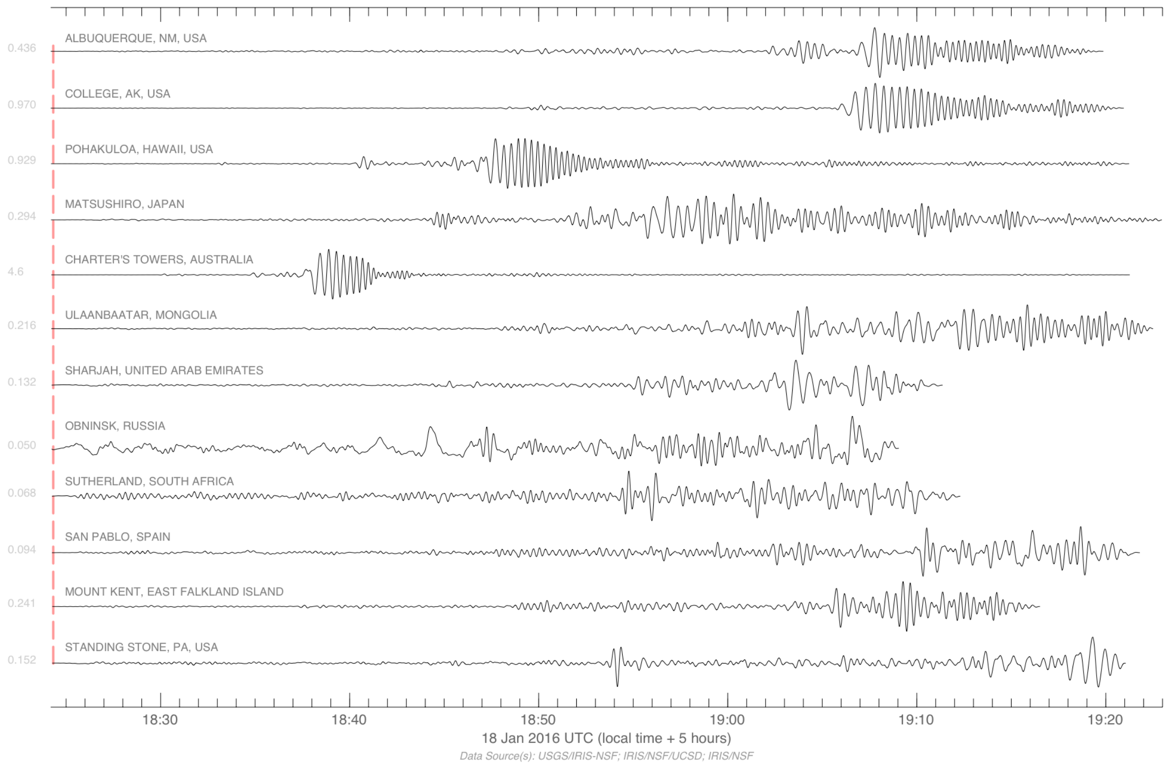
How do waves move through the earth? (figures 3 and 4)

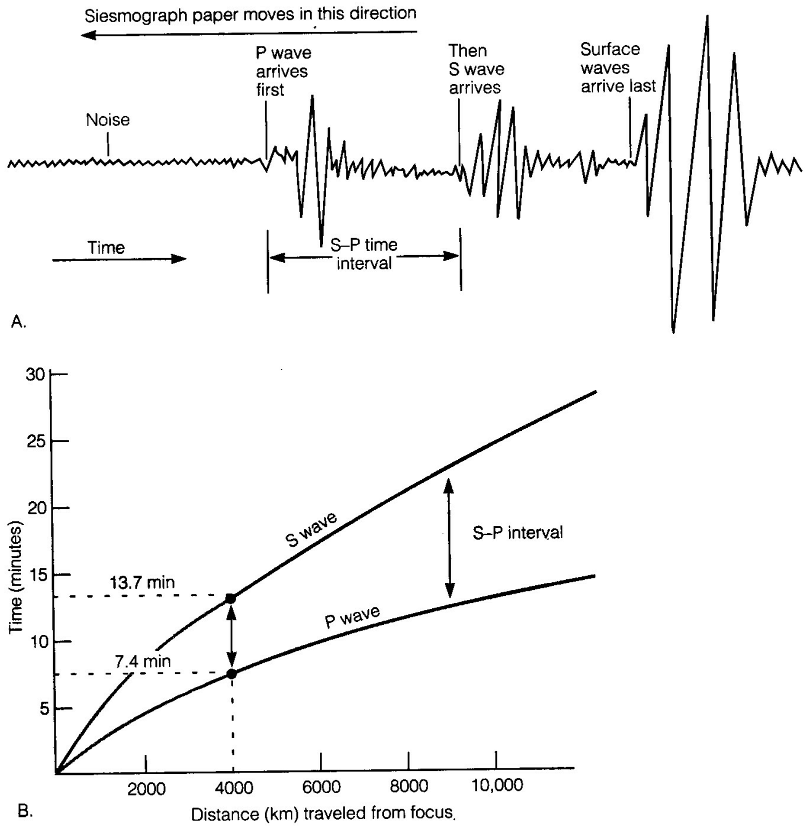




As we get deeper, waves get quicker (wave speed is a function of density and elastic moduli). Now for a diffraction explanation, maybe huygens wave principle? As they get deeper, waves get slower, and they curve! So waves emitted initially away from the surface come back.

Arrival Times (figures 5 and 6)

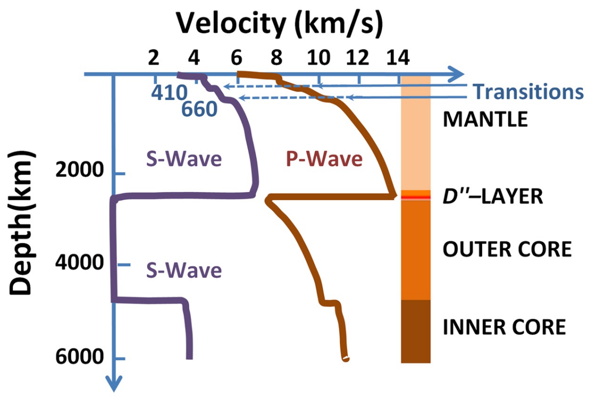




We use different arrival times to figure out where an earthquake originated, called the hypocentre (you may have heard of the epicentre: that is the point on the earth's surface above the earthquake's origin). Can you figure out roughly how fast they are going on the seismogram above (assuming direct travel…)? Hawaii → Albuquerque ~5000km. Therefore wave speed is O(10km/s). This is not too far wrong (see figure 6 below). Why is this not right? We haven't considered the different paths of the waves, varying speeds etc.

There are different types of wave, P is longitudinal, S is transverse. P is faster. Finally, there are surface waves which appear at the boundaries, such as earth's surface. Why can't we separate the different wave types on our seismogram? Use the speed result above.

Evidence for Earth's Structure (figure 7)



Now for structure. Waves are reflected and transmitted at surfaces (maybe relate to 'Waves at Boundaries' experiment if that's out). The reflected bits return to earth's surface, so we can figure out where the major changes in earth's structure are. These are due to basically anywhere the structure dramatically changes. E.g. Crust/Mantle Lithosphere/asthenosphere, core/mantle, core/inner core. See above diagram for shadow zones.

Iron inner core: At the temperature and pressure we predict for the earth's core, an iron composition would replicate the wave speeds we observe. Iron is abundant in the solar system due to its high binding energy We have samples of iron meteorites from proto-planets which we think have a similar specified structure to the earth. We need a magnetic element to generate the earth's magnetic field

Liquid Outer Core: No s-waves pass through this region. Transverse waves can't pass through fluids. (NB: the mantle is not therefore molten as lots of people seem to think. It does flow, but on much longer timescales, so to an earthquake, it appears solid) The earth's magnetic field needs a flowing magnetic material. A-level physicists will probably have heard of faraday's law.

Solid Inner Core: The sharp wave speed change here us not likely possible in a purely fluid region. There is a small amount of evidence for inner core s-waves, generated at the inner core/outer core boundary. They have small amplitudes, so we're not sure we trust the observations yet.

Transition Zones: Generally due to solid-state phase transitions, and therefore their height is temperature sensitive [related by the Clausius-Claypeyron relation]. The low velocity zone between lithosphere and asthenosphere may be due to some degree of melt.

Appendix

It would be good to see whether geophysics is possible to explain without all the jargon.

Possible ideas:

P waves → sound or pressure waves

S waves → transverse waves

Asthenosphere → weak solid layer

Lithosphere → strong but brittle solid layer

Risk Assessment

Hazard: Jumping

Description: Whilst jumping a child may injure themselves

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Do not ask them to jump if the floor seems dangerous or they do not seem steady on their feet. Avoid doing this activity near to steps / uneven floors. In case of injury call a first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Lego parts / tennis ball fillings

Description: Small parts can be swallowed or choked on.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep the seismometer in one piece. If small children are watching, no touching. Keep careful watch on tennis ball fillings and don't allow very small children to open the tennis balls.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Sharp seisometer parts

Description: Some parts are sharp or could trap fingers.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: If small children are watching, no touching. Warn children of any sharp or trappy parts. Demonstrator be aware of risk and be careful of sharp parts.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Filled tennis balls

Description: Tennis balls could be thrown which may cause minor injury.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Be aware of what children are doing with tennis balls and restrict their use if necessary.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Magnet in seismometer, and to test tennis ball innards

Description: Small, choking hazard. Risk of trapping fingers. Could affect pacemakers etc.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Keep magnet in the seismometer assembly or a labelled, sealed box at all times. Do not allow magnet to leave experiment area. Warning sign regarding presence of magnet.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Risk Assessment Check History

Check 1: 2020-02-05 - Sophie Miocevich (srm81@cam.ac.uk), **Check 2**: 2020-02-06 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-21 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-22 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2022-02-09 - Sophie Miocevich (srm81@cam.ac.uk), **Check 2**: 2022-02-09 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-02-15 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-18 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-01-31 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-01 - Margaret Johncock (mllyj2@cam.ac.uk)

Skeleton and bones

Meet Boris, the friendly CHaOS skeleton. - Boris is a friendly life-sized plastic skeleton- come and say hello!

Last initially checked on 2024-02-08 by John Leung (cfl35@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- **This experiment can take place outdoors**
- Full size articulated skeleton called Boris.
- Collection of individual bones
- Foetal skull to show differences to the adult skull
- Artificial hip replacement

Experiment Explanation

Working with the skeleton can be an art. I usually don't have a formal "speech" but have lots of little topics and let them mess around with the bones filling in as appropriate.

Some things to talk about:

- Fitting individual bones to where they are on skeleton. What is skeleton for?

1. Upright - Ask them to imagine what we would be like without a skeleton
2. Movement - muscles pulling on bones, joints
3. Protection - skull-brain, ribcage-heart and lungs, vertebral column-spinal cord

- Ask them to guess where certain bones go. Easy ones are skull, hand and foot. Harder ones are pelvis, spine, collar bone etc.

- Feeling bones on themselves - collarbone, kneecap, shoulder blade moving, jaw moving out

- Why we have 2 bones in forearm

- How many bones in fingers/hand/body (3, 27, 206)? Often good to get them to guess how many bones there are in the hand and then explain why each finger has 3 bones etc.

- Where are smallest and largest bones?

- If all else fails, get the little kids to make up the arm from the individual bones

SKULL: - Ask them obvious things like where the eyes are to get them orientated. - Ask them why there are no ears or nose. -

Describe what the skull is for. I like to use the "helmet" protecting the squishy brain analogy. - Explain how must have holes so all the nerves can reach the brain - like phone cables. - Show them some of the holes - optic chiasma, foramen magnum etc. - Talk about jaw and how it hinges.

FOETAL SKULL:

Foetus = not fully formed - several bone plates coming together. Point to fontanelles. - Why? Needs to be able to change shape - fit through birth canal - Small brain compared to adults thus need rapid growth in 1st year - Growth almost complete at about 6yrs (vs chimp = 3yr) - gives time for learning thus different capabilities of humans (intellect, sybolism, abstract thought, complex tool use, complex social behaviours etc) - Adults often ask about the 'squidgy bit' on their child's head when they were born - you could talk about the anterior fontanelle and how it can be used clinically to assess the level of hydration of the child. - N.B. Boris is male and his pelvis won't allow you to birth this skull!

JOINTS:

- Explain how even without joints we couldn't move.
- Different types of joints:

1. Ball and socket - get them to put one together (hip is best). Show how it allows movement in all directions. Get them to move their arms in all directions
2. Hinge - get them to put one together (elbow is best). Ask them to move their elbows and knees. Point out how birds are weird as their knees bend the other way.

HIP REPLACEMENT - This is one of my favourite bits to talk about! - I usually start by getting them to guess what it is. Some will get it instantly, others will come up with odd suggestions ("A gun!"). You can tell them that it is used to replace a part of the body and get them to look at the skeleton and see if they can think where it might fit. Let them hold it and move it around at different angles etc. If all else fails I usually hold up a spare femur and the hip replacement next to each other in front of me until someone realises! - Talk about why you might need to have a hip replaced - arthritis, fractured neck of femur results in death of the head of the femur due to the poor blood supply so it must be replaced as it will not heal (many of them will know of people like grandparents who have had such replacements). - They often ask about why the ball is so much smaller than the head of the femur, explain that we've only got half of it and there would be a replacement socket too (if you've talked about arthritis in the reasons for needing a replacement you could get them to think that you need to replace both damaged surfaces with new smooth ones). - Then I often start pretending to be a materials scientist and briefly get them to think about what properties you'd want a replacement joint to have - e.g. ask them why it isn't made out of wood! Get them to work out that it needs to be strong, light, non-toxic and unreactive (not go rusty!). I assume ours is made out of titanium, newer and more expensive ones I believe are made from titanium (the head) and then some sort of ceramic which is much lighter. If they want more details about materials I tend to then have to send them off to ask a physicist/real materials scientist!

Risk Assessment

Hazard: Protruding parts

Description: Poking injury from protruding parts.

Affected People: Anyone touching Boris

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Make sure children do not go too near protruding parts; use tape or sugru (kind of like blue-tack but it sets, can often be found in Boris' box or toolbox) to cover up the more dangerous parts of the skeleton. Call first aider if necessary.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Bones

Description: Finger trap between bones (e.g. ribs, and joints).

Affected People: Anyone touching Boris

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Make sure children do not put fingers between bones, and ensure that skeleton is in a stable position when they do touch it. Call first aider if necessary.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Boris

Description: Skeleton can be unstable and may fall on children/demonstrator (this includes the possibility of things falling off of Boris).

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Keep a careful eye on the skeleton, and stay near it to be in a position where you can stop it from falling on anyone. Do not leave the experiment unsupervised. Consider tying skeleton to a chair if demonstrator is not able to be close to the skeleton throughout. In case of accident, call a first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Hip bone

Description: Hip joint is heavy and could cause damage if used as a weapon.

Affected People: Children

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Do not let children hold the hip joint if you do not trust the group to be sensible. Call first aider if necessary.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Psychological aspect of experiment

Description: People may not like psychological aspect of this experiment. Could faint or feel faint.

Affected People: Visitors

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Be aware that a small percentage of people may feel uneasy or unwell when talking about skeleton and organs. Stop if someone looks unwell/ goes pale. Fresh air/sugar/lying down all help recover or avoid injury. Call first aider if necessary.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Heavy Box + Boris

Description: Boris' coffin and Boris himself are quite heavy - could cause back injuries for people attempting to carry these.

Affected People: Demonstrators

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Don't carry the box by yourself - usually need at least two people. Use standard heavy box lifting procedures (i.e. bend knees, not back!). Take care to hold the box by the light grey lower handles instead of the lid. Boris himself may be light enough to carry, but only do so if confident and comfortable (and necessary). It is difficult to keep Boris' limbs under control when single-handedly carrying him, so best not to do so particularly in crowded areas. Always watch where you're going with either the box or Boris. Also watch for things falling off Boris!

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2012-01-11 - Elizabeth Mooney (erm40@cam.ac.uk), **Check 2**: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk)

Check 1: 2013-02-02 - Alex Davies (ad578@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-21 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-26 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-10 - Alisha Burman (arb95@cam.ac.uk), **Check 2**: 2015-02-12 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-01-21 - Natalie Cree (nc434@cam.ac.uk)

Check 1: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-12 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-27 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2018-01-13 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-01-03 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-18 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-02-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-22 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2023-01-22 - Emily Wolfenden (elw74@cam.ac.uk)

Check 1: 2024-02-08 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Slug Bubbles

Does a tube of water drain more slowly with a bung in the top? - Does the diameter effect how fast water drains from a sealed tube? Watch the bubbles produced and see which is fastest.

Last initially checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk) and double-checked on 2024-02-15 by Lachlan Rooney (lgmr2@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- 3 tubes of different diameters but similar lengths held vertically on a board.
- Frame
- Experiment Box
- Bolts
- Plugs that fit the tubes
- A small pile of straws - “small pile of straws” may mean “1 straw” - can find some more in air streams / stores if necessary.
- A jug for filling tubes.
- A couple of differently sized funnels for filling tubes.

Experiment Explanation

This experiment uses perspex tubes which are clamped to a board, and can be filled with water. When the bung at the bottom of a tube is pulled out, it empties. If there is a bung in the top, it empties much more slowly, as the air has to get in the bottom (a ‘slug bubble’).

What to do.

Put a bung in the bottom of a tube. Fill it up with water using funnel and jug. Kids really want to help fill them up, and this is a good way of getting them involved. Ask what they think will happen when the bung is removed: does the water rush out, drip out slowly, stay in etc.? Ask if they think it’ll come out fast enough to get their shoes wet. Then ask if they’re willing to test their hypothesis in reality, or take a few steps back and remember where their shoes were at the time (I normally look at the parents for confirmation of feet wetting next!) Count down and remove the plug. SPLASH :-) What happened? Water rushed out etc…

Why? Gravity pulled the water towards the ground and when the water came out of the tube, and air replaced it from the top. (Notice the subtle hint for the next stage.) Get it filled it up again, but this time put a bung in the top as well. WARNING: Make sure you hold the bottom bung on when you put the top bung in as water is not particularly compressible, and you can easily force the bottom bung out by pushing the top one in. Now ask them what’ll happen. Then demonstrate - you can ask one of them to remove it this time :-) Did they see the bubble go up the tube? Get them to try to explain what was going on. My explanation is just that for water to come out of the tube, air has to get in, as there can’t be nothing in the tube (vacuum) as the high air pressure around will not allow it. However, it did not all stay in there because the hole at the bottom was nice and large allowing air and water to swap. You can see the air going in - it goes up the middle in the form of a big bubble, called a 'slug bubble'. The water flows out down the sides.

Next we have a race... Fill up all the tubes, put bungs in both ends, and recruit some help to get it started. (You will probably have to loosen off the bungs in the bigger ones, as they are quite difficult to remove. Which one is going to empty fastest? Why? See what each spectator thinks - often people have different views. They can be encouraged to argue it both ways: perhaps the big tube will empty faster, as there is more space at the bottom, perhaps it will empty more slowly, as there is mor water to come out, or perhaps these effects will cancel out and they will empty at the same speed.

Ready, steady, Go!

The biggest one empties fastest. Why did it do that? A smaller hole at the end means that there is even less space for the water to swap over, so it comes out much slower. The more space there is for the air and water to squeeze past one another, the faster it can come out.

If you like, you can then move onto some straws, saying that straws are exactly the same, but they have even smaller holes at the bottom. Straw under water, thumb on the top. Remove from water, remove thumb. A straw has such a small hole that the surface tension of the water cannot be broken.

An interesting addition [Stolen from the Independent (2/8/06)] Poke a hole in the side of a cup, cover the hole, fill with water, uncover the hole: water comes out Repeat, only this time drop the cup at the same time as uncovering the hole: water stays in, so you can talk about gravity acting on water and the cup, and things falling at the same speed etc. Probably not a tremendously exciting addition, but maybe something to talk about with very interested people, or something... [Plastic cups tend to shatter when dropped on concrete, and are a pain to make holes in, so maybe paper would be better.]

Another point of interest (stolen from a demonstrator at CBS) is if you take out the top bung slightly from the small tube as well as the bottom one you can slowly stop the water (by gradually putting it back in) and this will allow you the same 'floaty' water as with the straw. Disturbing the bottom with a piece of grass allows an air bubble to form and causes it to stop floating. You make a hole in the surface to allow an air bubble to form.

One final nice thing to mention... This experiment in particular can be used to demonstrate the "scientific process", where you make a hypothesis, test it, then modify your theory to explain what you saw. Then you can tell the kids that they're real scientists now.

Risk Assessment

Hazard: Board

Description: The board could fall if not properly mounted.

Affected People: All, particularly small children

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Ensure that the board is properly bolted to the frame. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Water

Description: Slip hazard due to spilt water.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Use the box to catch the water. Clean up excessive spillage. Do the experiment outside if appropriate. Check also that the box is placed on a suitable surface that won't mind getting wet (e.g. not an expensive antique wooden chair). In case of injury, call a first aider.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-02-15 - Brett Abram (ba305@cam.ac.uk)

Check 1: 2015-01-04 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-22 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2018-01-20 - Matthew Le Maitre (msl54@cam.ac.uk), **Check 2**: 2018-01-20 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-02 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-18 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-19 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-09 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-17 - Jessica Trevelyan (jet81@cam.ac.uk)

Check 1: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk), **Check 2**: 2024-02-15 - Lachlan Rooney (lgmr2@cam.ac.uk)

Sounds from an oven shelf

Get very strange sounds from an oven shelf.

Last initially checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk) and double-checked on 2024-02-15 by Arian Pourabadey (asfp2cam.ac.uk)

Tags

Busking

Floating

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- Oven Shelf
- String
- Something to hit the shelf with (your finger nails will do!)
- You could also use a slinky instead of an oven shelf
- In this case a plastic cup works as an amplifier

Experiment Explanation

Get very strange sounds from an oven shelf. Hang it from two pieces of string, wrap string around your fingers, put your fingers in your ears, hit the oven shelf. It will sound like big ben!

Why does it happen?

First of all we have to understand that sound is all about vibrations. When somebody speaks, their voice box vibrates, and this makes the air around it vibrate. These vibrations carry information about what someone has just said. When these vibrations reach your ear, they make your eardrum vibrate and this is processed by your brain as sound. The amount of energy (or the volume of the sound) that manages to make the journey from voice box to ear depends on what the sound is travelling through and what kind of sound it is.

In the case of speaking to a friend or when you listen to the oven shelf, the vibrations must travel through air. Air is really sloppy, fluid and not very stiff. Water is quite similar - if you put your hand in water and slowly move it around, the water feels very soft and fluidic. However, if you slap the water then it suddenly feels very hard and stiff. This is because the water doesn’t have time to get out of the way so it has to form waves. Although it is not quite so obvious, this is the same for air. If you move something through it very quickly, the air feels stiffer and it’s much harder to move through it, so high frequency vibrations will transfer more energy into the air.

The ability of sound to reach someone’s ear also depends on the ability of the air next to the ear drum to vibrate. In the same way as a high frequency (pitch) vibration can transfer more energy to the air from the oven shelf because it has less time to get out of the way, a high frequency sound will transfer more energy from the air to your eardrum so the sound is loud. Low frequency sounds vibrate the air much more slowly, and so the air seems relatively more sloppy and doesn't transfer energy so well so they sound much quieter. So both low and high frequency sounds are produced by the oven shelf but it's only the high frequencies that vibrate the air by your ear drum much so the shelf sounds tinny and high pitched.

In order to hear the low frequencies, you need to create a stiff connection between the oven shelf and your ears. The string wrapped around your fingers provides this connection. The string is taut and stiff and can transmit both high and low frequencies. When you add the high and low frequencies together, the oven shelf suddenly sounds like a gong.

What about in the real world?

This is why your voice sounds different to everyone else and when you hear it recorded. Everyone else just hears you though the air, but you hear yourself through the bones in your skull as well, so different pitches will reach your ears than other people's.

For more see: http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/the-secret-sounds-of-the-oven-shelf/

Extra information In case someone of a more mathematical background is asking, it's the impedance mismatch between the shelf and the air that filters out the low sounds (acting as a high pass filter). We could get those sounds to the air better if we passed them through a series of media with different impedances instead of a big jump. The string has an impedance much closer to that of the shelf (being a solid and all) so there is less of a mismatch and better transmission.

One of the most familiar forms of impedance matching from school is the use of special gels with ultrasound scanning to ensure that more of the sound passes into the body rather than being reflected from the skin.

In fact, there are even more everyday occurrences. Some instruments such as acoustic guitars have a "soundboard" - essentially the front face of the instrument - and air cavity, connected to the strings via a bridge. The structure of this system amplifies the vibrations, particularly low frequencies, not by adding any energy (as in an electric guitar, which use electromagnets to sense the vibrations), but by a kind of impedance matching. If I understand correctly, the larger area of the soundboard, as well as the ability of the air in the cavity to resonate, are key to this.

Why labour this? Well, you can get the same oven-shelf effect from a slinky, and the listener can excite the vibrations by nodding their head. The extra cool part is that rather than sounding like a boring old gong or clock tower, the complex pulses reverberating up and down sound like a Star Wars laser battle.

If you listen very carefully without the strings you can hear the low laser battle sounds. But, if you put a plastic cup in the top of the slinky, it couples to its vibrations and the cup is able to act like a soundboard of a guitar and everyone can hear the effect without the need for string!

Risk Assessment

Hazard: Fingers

Description: If fingers are pushed into ears with long nails/too far it could cause some minor damage.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Encourage children to put their knuckles, not their fingers, in their ears.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Head

Description: Head banging - with the slinky version, over-vigorous nodding not in a clear space may cause someone to bang their head.

Affected People: Public

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Make sure the participants have sufficient space to take part.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2012-01-02 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-14 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-01-21 - Holly Davis (hd308@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-07 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2017-02-01 - Matthew Le Maitre (msl54@cam.ac.uk), **Check 2**: 2017-02-01 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-20 - Matthew Le Maitre (msl54@cam.ac.uk), **Check 2**: 2018-01-20 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-02 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-02 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2020-01-04 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-17 - Sian Boughton (seb216@cam.ac.uk), **Check 2**: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-23 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-01-28 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-01-18 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2023-01-19 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk), **Check 2**: Arian Pourabadey (asfp2@cam.ac.uk)

Spaghetti Loading

This experiment uses uncooked spaghetti to explore elastic buckling of vertical columns and 3-point bending of horizontal beams.

Last initially checked on 2024-01-30 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Margaret Johncock (mllyj2@cam.ac.uk)

Tags

Materials Science

Standard (A standard CHaOS experiment, useable for all hands-on events.)

CHaOS+ (More complex explanations suitable for older children are available)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- 1 pack of spaghetti (will need replacing periodically)
- 2 wooden blocks to hang spaghetti across
- 9 steel nuts
- 1 pack of elastic bands
- 1 tray to catch spaghetti fragments
- 1 hollow cylindrical beam (pending)
- 1 small I-beam (pending)
- Photos of the Pantheon/Acropolis, crushed concrete column, and wooden roof beams.

Experiment Explanation

This demonstration uses a spaghetti model to demonstrate elastic buckling and 3-point bending. I personally like to put it into the context of building a house out of equal-sized wooden logs. You can start by discussing use of spaghetti as a building material, because the more materials science we put into this experiment, the less likely it is that the engineering coordinators will try and claim it. Spaghetti would not make a good building material because it goes soft when wet. It is also quite brittle so may not fare well in heavy wind. Some people may suggest that it is weak, but large bundles of spaghetti are probably surprisingly strong.

Axial Loading:

How will we hold the ceiling up? Most students will say using a wall or pillar. Try to guide them towards pillars/columns since this is what you're actually going to be talking about. The job of a column is to keep the ceiling up. Hold up an intact piece of spaghetti by the palms of your hands, as this will enable you to load it under compression and demonstrate buckling. Buckling is bad as it allows the ceiling to move downwards, which could warp it and cause it to fail.

Push your hands together gently with your palms flat to demonstrate elastic buckling in the spaghetti. It is elastic because removing the force allows the spaghetti to return to its original shape. Ask the students how we can make the column stiffer i.e. resist buckling.

$$\sigma_{EB} = \frac{c\pi^2 E}{4(L/R)^2}$$

The above expression tells us that a smaller stress (force) is required to cause buckling if the aspect ratio, the ratio of the column length to its radius is larger. The column can be made stiffer in two ways: by making it shorter, or by making it wider. This can be demonstrated by giving the students pieces of spaghetti of different lengths and getting them to feel how much force it takes to make them buckle. Shorter pieces should be much more difficult to buckle.

The problem with making it shorter is that it has to span the distance between the floor and ceiling in order to hold up the ceiling. So the column length isn't easily customisable.

If you don't explain the aspect ratio thing to students, most of them will probably say that adding more logs to the column will make it stiffer. By adding more logs you make the column wider which also decreases the aspect ratio, thus making the column more resistant to buckling.

By this logic, we want an infinitely thick column. There are a couple of problems with this. Firstly, the wider the column, the more space it takes up. So we want an optimal thickness which will hold the ceiling up without using too much space. The other problem is that if the buckling stress is too high, the column will instead fail by crushing. A crushed column cannot bear any weight, but a column which is buckling still can provided it doesn't break. Therefore, it is better for a column to buckle slightly than break, and short fat columns may not be desirable.

3-Point Bending:

In the context of house-building, I claim that roof beams are loaded under a 3-point bend. To be honest, I have no idea if this is the case. So if someone has a better way to put it into context then let me know.

First, ask the student if you can make stronger roof beams by laying them out individually or bundling them up. Hopefully they will say bundling up. There are two reasons why bundling them up is better. Firstly, The more logs you have in the roof beam, the more weight they can bear since the weight is shared between the logs. Laying them out side by side means that you can't fit as many logs along the length of the ceiling that if you bundle them up, and make use of the vertical space.

Secondly, by bundling them up, you increase the second moment of area of the roof section. This makes the beam stiffer under a 3-point bend, and it can therefore take more weight without flexing. The equation for 3-point bending is shown below:

$$y = \frac{Fx}{48EI}(3L^3 - 4x^2)$$

Place a piece of spaghetti so that it is resting horizontally on top of the two wooden blocks. To make this part more interesting (if that's even possible), you can ask the students to take bets on how many of the steel nuts it will take (threaded onto the centre of the spaghetti beam) to break it. Usually, two or three is enough. After this, take a bundle of 5 pieces of spaghetti, and wrap an elastic band around one end to hold it all together. Ask the students whether it will take more or less weight to break the bundle (they should say more) and then ask how many nuts they want you to put on. Even with all 9 of the provided nuts, the bundle will not break. But you can show that however many they select, the bundle doesn't flex that much. **note:** it is difficult to demonstrate the effect of bundling vs. loose because loose spaghetti tends to bundle up when threaded through the nuts.

When bending the spaghetti bundle, the bottom surface ends up under tension while the top surface gets put under compression. Just like many materials, spaghetti is much stronger under compression than tension. This discrepancy is especially pronounced in concrete, which is extremely strong in compression and weak in tension, hence they are used for support columns rather than cables. You can show this using spaghetti by loading it in compression (trying to crush a piece between your fingers by pressing across its diameter) and then in tension (by pulling from opposite ends). Students should find that it is impossible to crush the spaghetti, but quite easy to pull it apart. If anyone does manage to crush the spaghetti, send them my way as I may have a job for them.

What this means is that the piece of spaghetti at the bottom of the bundle, which is under the most tension, will fail first. This is followed by the rest of the bundle as the stress is redistributed. The bundle fails in a 'chain reaction' as the fracture propagates from the bottom to the top surface of the bundle, with each piece of spaghetti breaking in sequence. This failure happens very suddenly and catastrophically. Macroscopically, there are no early warning signs as the failure of one log in the bundle leads to the instant failure of the entire bundle. Spaghetti is also brittle, meaning it will fail suddenly without plastic deformation. Therefore, this is something we want to try and avoid.

Hollow sections and I-beams (CHaOS+)

Hopefully by now someone has acquired a hollow beam and an I-beam. While these won't be loaded or broken in the demonstration, it is interesting to discuss how engineers can save on materials without sacrificing much strength.

Hollowing out a beam will decrease its mass significantly, with a less than proportionate loss in strength. This is because the larger the second moment of area of a beam (effectively a measure of the distribution of mass away from the central axis of the beam), the greater the 'beam stiffness' which is a product of second moment of area and young's modulus. A hollow beam will be much stiffer than a solid beam of the same mass.

Solid Beam

$$I = \frac{wh^3}{12}$$

Hollow Beam

$$I = \frac{wh^3 - w_{in}h_{in}^3}{12}$$

An I-shaped beam is used by engineers because it can achieve a similar strength to a beam with a solid cross section but requires less material to make and is also lighter. Some manufacturers even go as far as to cut holes in the stem of the 'I'. The further away material is from the central axis of the beam, the more it contributes to the stiffness of the beam. This is why cross sections with a greater second moment of area give stiffer beams. The beam is an 'I' rather than an 'H' because this orientation of the beam provides the most resistance to elastic deformation when the beam is under a vertical load, which it usually is in service.

Risk Assessment

Hazard: Uncooked spaghetti

Description: Public

Affected People: Sharp ends from spaghetti fracture scratching or stabbing people.

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Clear spaghetti debris from table throughout the experiment. Instruct kids to throw away spaghetti pieces as the experiment progresses rather than at the end. Also make sure fractured pieces are not held near the face. Do the experiment in a tray.

Call a first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Slippy spaghetti

Description: All

Affected People: Spaghetti debris on the floor could be "slippery" if stepped on.

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Clear spaghetti debris as much as you can throughout the experiment. As above, do the experiment in a tray to try to contain most of the shards.

Call a first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Spaghetti shards

Description: All

Affected People: Loose pieces of spaghetti flying into eyes when bent and fractured.

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Forewarn students and when bending spaghetti, bend away from self and away from others.

In case of injury call first aider.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Masses

Description: Public

Affected People: Masses falling onto feet or fingers.

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Set-up on table to avoid toes. Have 'drop zone', no fingers under masses. Use light masses (10-50g) to avoid heavy masses hurting fingers.

Call a first aider in event of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Spaghetti

Description: Public

Affected People: Transfer of bacteria if students try to eat spaghetti that others have touched.

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Instruct students to not eat the spaghetti. Use different strands for each student, and for each group.

In case of contact, advise parents to take children to GP if illness develops.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2018-01-18 - Laura Wells (lbw28@cam.ac.uk), **Check 2**: 2018-02-06 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-08-11 - Yaron Bernstein (yb258@cam.ac.uk), **Check 2**: 2018-08-11 - Matthew Le Maitre (msl54@cam.ac.uk)

Check 1: 2019-01-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2019-01-27 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2020-01-18 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-09 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-19 - Toni Renz (ir331@cam.ac.uk), **Check 2**: 2023-01-19 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-01-30 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Margaret Johncock (mllyj2@cam.ac.uk)

CHaOS SCIENCE ROADSHOW

Spinny Chair

Use a freely spinning chair, some masses and a bicycle wheel to see some unintuitive physics.

Last initially checked on 2024-01-04 by Andrew Marriott (asm206@cam.ac.uk) and double-checked on 2024-01-04 by Lucy Bland (lb831@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- Spinny chair *(Heavy - be careful when lifting)*
- Masses - 2 small and 2 large (bags of rice covered in gaffer tape)
- Bicycle wheel with handles, with spokes covered in cardboard to minimise finger trap risks

Experiment Explanation

Overview

By using a spinning chair, weird effects due to conservation of angular momentum can be felt.

Set up

Try to make sure the chair is level, there is more than a metre of clear space around it in all directions, and the floor is something that won't graze anyone who lands on it (e.g. carpet).

Find somewhere convenient to keep the bits of kit so that people don't trip over them.

If you're unsure that you've got the screws in correctly, check with a committee member.

Things to demonstrate:

Demonstrate the effect of the masses by starting the child spinning on the chair with the masses close to their body and then asking them to extend their arms (make sure you do it this way round as otherwise they can pull their arms in and start spinning too fast).

With the child on the ground, start the wheel spinning and then hand it to the child vertically. Ask them to rotate the wheel so that it's horizontal. They will feel a force in the opposite direction. Ask what they think might happen if they were on the chair.

With the child on the chair, start the wheel spinning vertically and ask them to rotate it to the horizontal. They will start to spin. Ask them if they notice anything about the direction the wheel is spinning vs the way they spin.

Ask the child to try the experiment with their feet on the floor. The chair will no longer spin. Ask them if they can say why.

Show the child the difference in the bicycle wheel's behaviour if you let it dangle freely from the string when it's not spinning vs when it's spinning. Hold the wheel by one handle with the axis pointing from you to the child - ask them to gently waggle the end up and down, it's heavy but doable.

Start the wheel spinning and repeat - they will find it less controllable.

Things to be aware of:

Smaller children may not be able to lift the masses. In this case, it's probably enough for them to just hold their arms and legs out. Smaller children may also not be able to lift the wheel/ their arms may be too short. Either ask their adult to do it and explain what they feel to their child or sit on the chair yourself to demonstrate the effects (this can be tricky if you make yourself dizzy).

If you're at a school, make sure you let different kids in the group have a go and get them to explain what they notice to each other. There is some potential for slipping off the chair and landing badly. Get people to sit well back on the chair - that way they have good contact with the seat, and they can easily adjust their centre of gyration by leaning forwards. Small children need to be lifted onto the chair. Only use moderate speeds when spinning the chair.

Only continue for as long as the child is remaining engaged/ understanding what you're saying. If you get to the section on precession and feel like the child isn't following anymore, you can just demonstrate it to them as a cool effect, rather than trying to explain it.

Explanation

My general tip here would be don't get too technical. A lot of the point of this demonstration is to try and get the kids to notice the weird effects and predict what might happen because of them. In general, young kids will not understand vector addition and will quickly get bored if you mention it.

The masses

The approach here is age dependent. For younger children who might find moments of inertia and angular momentum a bit complicated, you can ask them to look at how quickly the bags move if you're spinning at a constant rate with arms out, and compare it with their speed with arms in. It might be helpful here to talk about a runner going round a racetrack - does the runner on the inside or the outside track travel further? If they both complete a lap in the same time, who's running faster?

So when your arms are out, the bags will travel faster than when your arms are in (for the same rate of rotation). This means that when you pull the bags in, they'll now be moving "too quickly" for the rate at which you're spinning - and so they'll start to "overtake" you and your arms naturally pull on them to slow them down, speeding you up in the process! The reverse explains why you slow down again when you put your arms out. You can also fit in Newton's first law here, to explain why the bags don't slow down until you pull on them. You will probably need to do a lot of acting out holding the bags and demonstrating the direction of forces.

For older children, you can introduce the idea of angular momentum (or spinniness). Explain that angular momentum depends on two factors. First, the rate at which a system is spinning and second, the distribution of mass within the system (i.e. the moment of inertia). The further away the mass is from the axis of rotation, the larger the moment of inertia is. Next you need to introduce the idea that the angular momentum of a system is a fixed quantity (in a closed system but the distinction doesn't matter here). This is a strange idea but it can be related to spinning on roundabouts. Ask the child what they would do on a roundabout in order to speed up (lean in) and slow down (lean out). When they lean in they are moving their mass closer to the axis and so decreasing the moment of inertia. To compensate for this reduction in the moment of inertia, the rate of spinning must increase, hence they speed up.

In a similar way, when they start with the masses close to their chest, they are in effect 'leaning in' and the system has a small moment of inertia, meaning a high rate of spin. When they move the bags away, it's like they're leaning out and they increase the moment of inertia and so spin more slowly.

The wheel and the chair

Ask the child what you have to do to make the wheel start spinning. Hopefully they will say you need to push it/ apply a force. When the child rotates the wheel from the vertical to a horizontal plane, they are changing the axis about which it spins. In the same way that starting an object spinning about an axis requires the application of a force, so does changing the axis about which the object is rotating (in the same way as it requires a force both to start moving and to change your direction of motion). This means that the child must be applying a force to the wheel's axis in order to rotate it. By Newton's Third Law, the axis of the wheel is causing an equal and opposite force on the child, which is why they experience a force. (If they're older you can try and explain the difference between a force and a couple here but it's not necessary).

When the child is on the chair, rotating the wheel causes them to start to spin. This is because the force on the child gets transmitted to the seat of the chair, causing a torque which makes the seat spin.

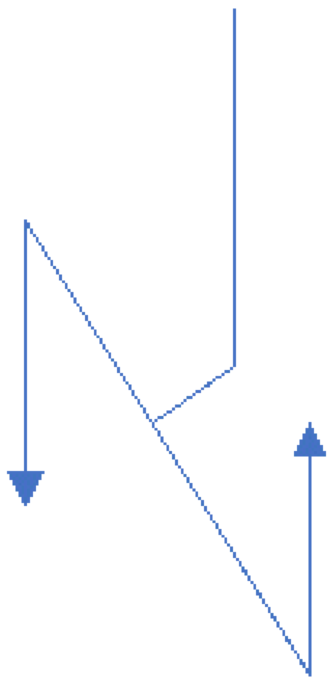
When it comes to the relative directions of the spin, they should notice that they rotate in the opposite direction to the wheel. Here you can link back to the idea of angular momentum. Explain that the total angular momentum of a system doesn't change. Initially, the child and the stool were a system with no angular momentum. Then they got the wheel and rotated it so that it lay horizontally. This means that the wheel has some angular momentum oriented along the z axis. In order for the whole system to still have 0 net angular momentum, the child and the stool must rotate in the opposite direction to the wheel so that their angular momentum points in the opposite direction.

When the child's feet are on the floor the force is transferred through their feet to the Earth rather than to the chair (this is technically a lie but one I can live with telling children). The Earth has essentially infinite mass and so the force has no visible effect on its motion. (You can draw a comparison with what happens when they jump- when they land they exert a downwards force on the Earth but that doesn't make the Earth actually move 'downwards' as it's so much more massive than they are).

Precession

(By this stage you may have already lost a few of the younger kids so it's a judgement call as to whether you try and explain the precession or just demonstrate it as a cool effect and mention that you can find similar things in your smartphone to let it know which direction is which).

A fairly intuitive explanation of why the wheel doesn't fall over is as follows. Consider the direction of the acceleration of two points on the extreme sides of the wheel, due to gravity. Assuming the axis of the wheel tips by some small angle theta, the motion is as drawn below:



Looking at it like this, the wheel should clearly continue to fall over. However, this fails to take into account the fact that all the points on the wheel are rotating around the wheel's axis and so, half a cycle later, the points shown will be on the opposite side of the wheel. Things that have already started moving in a given direction have a tendency to keep moving in that direction (cf Newton's First Law) and so the point of the left-hand side will now be moving up and the point on the right down. This creates a rotation in the opposite direction to that caused by gravity, returning the wheel to its original upright position and preventing it from falling over.

(This can also be used as a very hand waving explanation to nutation – the slower the wheel rotates, the longer it takes for the wheel to complete half a rotation and so the further it will fall before the direction of motion reverses again – why nutation is clearer when a top is spinning more slowly)

This also (kind of) explains why the wheel is harder to push down once it's spinning. By pushing down on the wheel, the child is effectively trying to do what gravity was doing in the above. Thus, their push will be opposed by the wheel while it's spinning for the same reasons that gravity was.

You can also do a 'proof by impossibility'. First, go back to the fact that, for an object to rotate about a given axis, there must have been some force applied to cause that rotation. In the case of the wheel it's obvious; you have to push tangentially on the wheel. Now ask what force makes the wheel rotate round so that it falls over. The answer to this is that gravity causes a torque that makes the wheel rotate about an axis in the x-y plane. Now, consider the case where the wheel was spinning, and it did somehow fall down. It would have to be spinning about the z axis. However, the only force acting on the system was gravity and we already decided that causes a rotation about an axis in the x-y plane. Thus, there are no forces in our system that would cause the wheel to have a rotation about the z axis and, if there are no such forces, there can be no way that the system ends up in this state.

Risk Assessment

Hazard: Chair

Description: Falling off chair.

Affected People: Anyone on the chair

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Demonstrator must maintain control of the chair and should not allow it to spin at speeds at which there is a significant risk of the child falling off. Starting children with arms tucked in and moving them out to slow down is a good way to ensure this. Make sure that the chair is placed on a flat floor, or grass which is sufficiently flat to ensure stability, with no corners or edges to fall against. If there is an area of flat grass or carpeted or wooden floor, this should ideally be used, though carpet introduces the possibility of grazing - warn the users of the wheel of this. Avoid placing the weights, and other hard objects on the floor haphazardly near the chair, which could injure children if they fall off. Sit well back on the chair to ensure good contact with the seat and allow easy adjustment of the centre of gyration by leaning forwards. Similarly avoid dizziness in both yourself and children by not spinning too fast or for too long.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Chair instability (possible incorrect assembly)

Description: Chair could fall with a child on it, causing injuries to visitors.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Stop children/ members of public getting too violent - do not allow them to spin too fast. Ensure chair is on flat ground. Tell children to step off if it is spinning too fast. Stop the chair if it gets out of control. Make sure other children stand away from the chair whilst it is spinning. Use chair with stable base. Small children need to be lifted onto the chair by an accompanying adult to avoid pushing it over.

Demonstrator to ensure the chair is correctly assembled (all parts are labelled). If unsure, ask an experienced member of committee to help.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Children on chair

Description: Hitting someone while spinning

Affected People: All around the chair

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Keep viewers back, possibly by marking an area with hazard tape. Encourage people not to spin too fast and to stay aware of their surroundings when spinning.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hzard: Chair and bags of rice

Description: Heavy chair and bags of rice can be dangerous in transport.

Affected People: Demonstrator

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: The person carrying the equipment should be strong enough to do so, or get someone to help carry it. Use standard manual handling techniques.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Bike wheel

Description: Rotating bicycle wheel could hurt fingers.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Bicycle wheel is covered in stiff plastic to stop fingers being inserted between spokes. Be ready to help child with rotating wheel if it gets out of control.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Bicycle wheel

Description: Bicycle wheel is fairly heavy, and could damage people if dropped.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Demonstrator should assess the size/strength of a child before getting them to hold the gyroscope. If the child cannot hold it comfortably in both hands, with arms horizontal and the wheel easily not touching them then they are too small and/or weak (remember they will have to hold it for a while, and not drop it when it feels like it's fighting them). The demonstrator ought to be ready to take the wheel back if required or help support the wheel by the other handle, and take some time to practice and get a feel for how it moves before demonstrating it to the public (it's not hard to do, but it's difficult to think of why people might drop it if you've not had a play yourself).

Ensure that people (particularly smaller children) don't have the string around their wrist whilst holding the wheel so that it doesn't sprain/damage the wrist if dropped. Possibly best to wrap it around one of the handles while holding it so it doesn't flail about and hit someone. Another dropping risk comes from dangling it on the end of a piece of string. This is a good bit of the demo to do, but make sure that the string is both well tied, and not frayed, before doing this. Only do this part of the experiment if the demonstrator is comfortable lifting the wheel.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-14 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-01-23 - Vamsee Bheemireddy (vrb23@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-22 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-12-29 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2017-02-01 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-13 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2018-01-29 - Lucy Hart (ljfh2@cam.ac.uk)

Check 1: 2019-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-01-09 - Grace Exley (gae23@cam.ac.uk)

Check 1: 2020-01-19 - Daniel Cropper (djc96@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-12 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-12 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2022-01-09 - Sophie Miocevich (srm81@cam.ac.uk), **Check 2**: 2022-02-09 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-01-20 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-29 - John Leung (cfl35@cam.ac.uk)

Check 1: 2024-01-04 - Andrew Marriott (asm206@cam.ac.uk), **Check 2**: 2024-01-06 - Lucy Bland (lb831@cam.ac.uk)

Surface Tension

Exploring surface tension through floating paperclips and racing boats - nan

Last initially checked on 2024-01-30 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- Bowl or tray of water
- Paperclips
- Plastic fork or paperclip sized pieces of kitchen paper
- Paper
- Scissors
- Washing up liquid and some toothpicks or a pipette
- Rubber bands or balloon (as an analogy for surface tension).

Experiment Explanation

Overview

Showing that surface tension can support paperclips, but can be broken down by washing up liquid (surfactant) - this can be used to make 'boats' move across the water. This works well when demonstrated with psychedelic milk where you can see patterns forming with food colouring in milk due to flows driven by variations in surface tension.

What can you show with it?

Paperclips lowered gently onto the surface of water can float.

Pieces of paper floating on the surface will move away rapidly when surface tension is reduced by adding washing up liquid.

Other things to talk about

Washing up liquid breaks down the surface tension of grease on pans, allowing it to be easily removed from the pan. This is related to how insects like mosquitos and water striders can stand on relatively still water.

What makes an object float or sink?

Tips for demonstrating

Alternatively, I found that the water needs to be REALLY clean to float the paperclips (as do the paperclips), so it can be easier done separately in a cup that was easy to wash. This also means the paperclip can be left floating while playing with boats.

Use a generous amount of washing up liquid to reduce the surface tension.

Basic Procedure and Explanation

'Will a paperclip float or sink when dropped in water?'

Get the children to drop a paperclip into the water from a sensible height (>5cm) to show that paperclips usually sink. You can also usefully talk about what makes things float or sink - ask about common objects e.g. apples (apple bobbing at Halloween), boats, etc.

'What about if I put the paperclip in gently?'

Now lower a paperclip in gently by placing it on one side of another paperclip bent at 90 degrees. This leaves the paperclip floating on the surface of the water.

This may require a bit of practice beforehand and if this doesn't work then try lowering it with the paperclip at the end of a plastic fork or above a small piece of kitchen paper, which will eventually sink into the water.

Now get the children to look closely at the paperclip. They should be able to see that the paperclip is pushing down the 'skin' of the water.

Without the paperclip, the surface of the water in a large container is nearly flat. This is because all the water molecules are strongly attracted to other water molecules, but not to air. Therefore the water molecules try to make the surface (the interface between the water and air) as small as possible.

The paperclip pushes down on the water. This is balanced by the surface tension of the water which acts outwards in all directions on the surface. The children should be able to see that the surface of the water rises directly next to the paperclip and this gives the upward force needed to balance the weight.

'What about pieces of paper?'

Get the children to cut up some small (about 4cmX4cm) bits of paper to make the boats. *They can do this while you rinse out the tray at the beginning of the experiment.*

Get them to place the pieces of paper on the surface of the water - gently, so as not to sink the paperclip!

Using the pipette, or a toothpick dipped in washing up liquid, put some washing up liquid into the water. Try to do this gently so that you don't get accused of making ripples. Also, try to put the washing up liquid between some pieces of paper so that they move apart in different directions.

The paper pieces should move away fairly quickly, and the paperclip should sink. This also works well when it is done as a race between two people starting at the same end of the tray. You may find that the boats stop moving after a while even as more washing up liquid is added.

What is happening here?

By adding the washing up liquid, the surface tension is reduced. Thinking about rubber bands or balloon, a stretched rubber band will ping away when cut (the tension in the band is reduced, but the tension at the ends remains). Reducing the surface tension in the water makes the water ping away, carrying the paper with it. The paperclip sinks because the surface tension is reduced so much that it can no longer be supported. The paper boats still float as they are less dense than the (now slightly soapy) water. The boats eventually stop moving as the washing up liquid has now spread evenly across the surface, reducing the surface tension evenly across the surface.

What happens if we add soap to the floating paperclip?

You might want to remind them that the surface tension is keeping the paperclip 'floating'". Smart kids say that the paperclip would whizz. REALLY smart kids say that the paperclip would sink. You can make a big deal of the fact that they are making a prediction based on previous observations in relation to a hypothesis and then testing it, just like 'real' scientists.

The paperclip sometimes whizzed a little bit before it sank, but not much.

Get the kids to put soap in with their fingers, and have towels available for cleanup.

Some of the kids might think that you made a wave by putting your finger in the water but get them to test this by putting a soap-free finger in and actually trying to make a wave. Obviously, the boats didn't whizz.

Another demo of surface tension

We don't do this demo but I've seen it before and can easily grab the stuff. You'll need a see through glass, some coins and a ping pong ball. Fill the glass to the brim, float the ping pong ball on top. Gently lower coins successively in the glass, you should be able to get the water to rise above the rim. The surface bulges upwards in the middle, doing this also pulls the ping pong ball to the centre, I'm not sure why though but it demos how high it is in the middle. This is a surface tension effect, you could probably talk about bubbles too as that seems similar.

TW - I believe this demo should also work if you use fountain pen ink (or other easier to clean alternative ink) instead of washing up liquid. This should give a more visual but also more messy approach. You should also be able to dip the tails of the paper boats in the ink and briefly dry them instead of trying to add washing up liquid behind.

Risk Assessment

Hazard: Scissors

Description: Using scissors to cut out boats from card/paper – possibility of cuts.

Affected People: All, particularly small children

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Use safety scissors. Hand scissors to parents of small children. Supervise use at all times.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Water

Description: Slip hazard from spillages.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Clean up spills quickly. Ensure mopping materials are available.

In the event of an accident, call a first aider.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Surfactants

Description: Surfactants can be harmful if ingested.

Affected People: All, particularly small children who may try to ingest things

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Only use harmless surfactants; keep a track of where they are. Supervise the experiment well.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 1, Overall: 1

Hazard: Paperclips, toothpicks and other small objects

Description: Paperclips and toothpicks could be sharp (especially if broken). Also possible that a small child could eat one.

Affected People: Mainly small children

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Don't let children take paperclips away. Supervise use of all the objects in the experiment.

Don't use visibly broken and sharp paperclips.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Paper and wounds

Description: Child / Demonstrator could get paper cuts or wounds could already be present, which could subsequently become irritated by liquids uses.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Careful using paper and cutting it up.

Cover up any wounds (either received during experiment or preexisting).

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-14 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-02-13 - Nunu Tao (nmt26@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-25 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2016-01-17 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2017-01-30 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-27 - Hannah Thorne (hbt23@cam.ac.uk), **Check 2**: 2018-02-04 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-02-05 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2020-01-23 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-27 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2022-02-09 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-02-07 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-02-08 - Joshua Wu (jw2311@cam.ac.uk)

Check 1: 2024-01-30 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Suspension Bridge

A suspension bridge made from rope and wood that children can walk across. - Walk across our bridge, then find out what makes it stay up.

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-02-14 by Timothy Wong (chw55@cam.ac.uk).

Tags

Tour only (Experiment is only used on tour.)

Engineering

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- One suspension bridge (two supports, two ropes with clips to suspend deck, deck, two anchors; this should all be set up already, if not, ask a committee member)
- Selection of moveable weights (small children)
- 3-4 m of rope
- Weights on a hanger
- Rope tied into a knot to have three ends coming out in different directions (optional – for vector addition)

Experiment Explanation

Overview

A suspension bridge made from rope and wood that children can walk across!

Possible activities: 1. Children enjoy just walking over the bridge! 2. Have one child stand on the bridge and trace the forces down to the ground. Unclip the roadway to see what holds it up. Tension. 3. Put one kid on and see how much the bridge is bent. What if we add more children? 4. Why do we want the cable to sag? Use a seperate rope with a weight in the middle. Need to pull very hard to hold up the weight with the cable horizontal, but less hard if you let the rope sag.

Other things to talk about: 1. Real life suspension bridges 2. Why build suspension bridges? 3. How to build suspension bridges - sinking piers into water, digging to bedrock, anchoring cables, etc. 3. Material science - tension and compression and cracking.

Tips for demonstrating: Don't be fazed by the crowds - keep control and take time to ask questions and demonstrate the science. If children are beginning to run over the bridge or get overexcited, limit the number of children on the bridge to one at a time.

Basic procedure and explanation

Get children to walk over the bridge, then ask them questions. On a busy day you could stand blocking the entrance to the bridge until a group have listened to the science, then let them walk over.

What holds up the roadway? You can unclip it to show that it hangs from the sagging cables. suspension means hanging.

How does it work? Have one child stand in the middle of the bridge. He's pushing down on the roadway because he's heavy. What holds up the roadway? It's hanging from the sagging rope. Pushing and pulling forces - the rope is being pulled. Trace tension in rope over the piers and down into the ground. Get them to touch the various cables feel the different tensions. Ropes are anchored to the ground by the stakes so they have something to pull on. What would happen if we took out the stakes? Which way do the wooden piers get pushed (down into the ground).

Why do we have the rope sagging and not taught horizontal? Use a seperate rope with a weight in the middle. One child holds each end. Ask them to raise the weight into the air by pulling on the ends of the cable. Need to pull very hard to get the rope horizontal. Why? Because they're pulling sideways but they're trying to pull the weight upwards. So most of their pulling is wasted. Much easier if the rope is sagging.

Because the rope is sagging, we need these big wooden piers to hold it up. We don't want the whole roadway to sag though - cars would have to drive up to the top of the pier and down and up and down again - very silly! We want a flat roadway. So we hang the flat roadway from the sagging rope.

What about the roadway bending? Put one kid on and see how much the roadway is bent. Will the roadway be more or less bent if you add more kids all along the bridge? So the roadway doesn't bend if you spread out the load. Real suspension bridges don't bend as cars go across them! This is because the deck is usually either a beam or a truss, so can spread out the loads like when people stand all along our bendy roadway. If a train goes over the bridge then the engine is a very heavy load in one place so it will bend, so we don't tend to use suspension bridges for railways.

Other things to talk about

Real life suspension bridges. Severn Bridge. Clifton Bridge in Bristol. Menai and Conwy Suspension Bridges in Wales. Humber Bridge. Union Bridge (over River Tweed). Brooklyn Bridge in New York. Golden Gate Bridge at the entrance to San Francisco Bay.

Why build a suspension bridge rather than another type of bridge? Imagine building an arch bridge. Would need lots of bricks, which are heavy. Rope is very light and cheap, so easier to make longer bridges. Arch bridge would need lots of arches and more piers on the river bed, suspension bridge only needs two. Can be built high to allow ships to sail underneath.

Building them in real life. Steel cables not rope. Need to sig down through earth to bedrock to start building piers. May need to dig underwater using a pressurised diving chamber called a caisson - this was first done when building the Brooklyn Bridge in New York. Anchor cables by dropping a heavy lump of rock on them. May have two bits of rock with interlocking teeth and cable between.

Talk about tension and compression. Rope is good under tension, brick cracks under tension. Making steel rope - wind strands of iron into a small length, wind many of them together. Testing for strength!

Science background for demonstrators

'Why' suspension bridges are a good idea is to do with the stability of tension - no need to waste strength and weight resisting buckling, so can make lighter and hence longer spans. Resistance to buckling is mostly a geometric effect. We really need a good demo to communicate this. This is in contrast to the strength of materials in tension and compression - most do better in compression as cracks are such a big problem in tension.

'How' they work is a matter of vector addition of forces. When explaining on tour, I used a knot with three strands of rope coming from it. That was enough for a very basic feel for what is happening, but I would really like something with springs in it to demo the actual vector addition, explain resolving into components and so on (i have an idea using some peg-board and newton-meters to do this, but making the geometry of the vector addition clear will be a real challenge).

Pedestrian suspension bridges often place the deck under tension to resist bending.

Suspension bridges aren't used for trains because they can apply such concentrated force, requiring a more concentrated deck so that a suspension bridge is no longer an efficient solution.

Risk Assessment

Hazard: Ropes

Description: Trip hazard from ropes and, especially, stakes near the ground. (Falling onto a stake could cause a severe head injury.)

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: When PUTTING UP, mark the pegs and/or stakes with hazard tape, and, if they are in an exposed position, cover them with boxes. Cover stakes with a cut-open tennis ball to provide cushioning. Call a first aider in the event of an accident.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Falling parts of the bridge

Description: Injuries from parts of the bridge falling on someone walking over it, or near to it, should the bridge fall over.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: The bridge must be PUT UP under the supervision of someone suitably experienced. It must be put on level ground, and pegged down adequately (or tied to an adequately fixed object). The piers must be attached to the rope so that their tops can't slide. The DEMONSTRATOR must be aware that the bridge can fall sideways if pushed hard, or swung on. The bridge must be closed if it's fallen or partly fallen or about to fall. Call first aider/999 if required.

After Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Hazard: Bridge

Description: Falls to the ground from the bridge, possibly complicated by entanglement in the ropes.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: The bridge should not be PUT UP on a hard surface. Grass is preferable, or mats may be used. The DEMONSTRATOR must supervise children carefully while crossing, and be ready to catch very small children if the parent isn't.

Control how many children are on it at a time, and do not allow jumping, swinging or climbing on or off part way through.

Anyone tangled in the ropes may need to be untangled.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Piers

Description: Banging head on the crossbars of the piers.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: The crossbars should be covered with hazard tape when PUT UP, and more hazard tape tied on slightly below, to make them obvious.

Call first aider if required.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Separate rope and weight

Description: Trip hazard from the separate rope and weight used to explain the principle.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: The rope and weight should be put safely out of the way - e.g. under the bridge - when they aren't being used by the DEMONSTRATOR.

Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Finger trap

Description: Finger-trap between planks on the deck of the bridge, and in the karabiners.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: The bridge is designed to minimize this problem. The DEMONSTRATOR should keep children away from the underside while it's in use, and warn that karabiners can pinch during assembly.

Call first aider if required.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Risk Assessment Check History

Check 1: 2011-01-26 - Rosy Ansell (rosemary.a.r.hunt@gmail.com), **Check 2**: 2012-01-30 - Coryan Wilson-Shah (cw412@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-18 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk)

Check 1: 2015-02-01 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2015-02-12 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2016-01-02 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net)

Check 1: 2018-02-06 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2018-02-06 - Joanna Tumelty (jt574@cam.ac.uk)

Check 1: 2019-01-20 - Yaron Bernstein (yb258@cam.ac.uk), **Check 2**: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-01-26 - Oliver John (oaj24@cam.ac.uk), **Check 2**: 2020-01-27 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2020-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-09 - Lucy Hart (ljfh2@cam.ac.uk)

Check 1: 2021-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-09 - Lucy Hart (ljfh2@cam.ac.uk)

Check 1: 2022-02-06 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-01-14 - Jamie Barrett (jb2369@cam.ac.uk),**Check 2**: 2023-01-16 - Emma Crickmore (elc75@cam.ac.uk)

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk),**Check 2**: 2024-02-14 - Timothy Wong (chw55@cam.ac.uk)

Thinking Caps

A logical puzzle - Can you work out the colour of your own hat?

Last initially checked on 2024-02-19 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2023-02-19 by Lauren Mason (llm34@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Maths

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

This experiment can take place outdoors - Paper hats in 4 colours, with at least 5 in 2 different colours. Contact Josh (jlg70) for instructions on how to make paper hats, or just watch a youtube video. - Charts detailing possible configurations of hats for a couple of the problems.

Experiment Explanation

This demonstration involves getting visitors to solve problems using paper hats. Presented below are some ideas for problems, but feel free to come up with your own. This was developed for and used on mini-tour 2017 for CHaOS PLUS, but some of the ideas can be presented to our general audience. The following are presented roughly in order of ascending difficulty, but anything with a star is more difficult. Only do starred ones if you are very comfortable with the material.

I like to present this in the context of a jail, with me being a sadistic jailer forcing people to cooperate and solve puzzles to escape.

a. 2 people, 2 colours of hats. Put one hat on each person, and let them see the other person. Can they work out anything about the colour of their own hat: no, decisions were independent.

What if they can speak to each other: yes, just tell the other person their hat colour.

Suppose they guess one after the other, is there a way that at least one of them can be correct: yes, the first person just guesses the other person's colour.

*What if they guess at the same time, agreeing a strategy beforehand: Often people say guess randomly. this has a 75% chance of working. get them to work this out. What other strategy could they use, incorporating the information about the other person's hat? They could guess the same, which has a 50% win rate. They could guess differently, which has a 50% win rate. one person guesses the colour they see, the other person guesses the opposite of the colour they see has a 100% win rate, combining the above 2 strategies.

Note: The above strategy means that 100% of the time exactly one person gets the right answer. This is the best we can do - i.e. no strategy exists that works 100% of the time where sometimes both people get the right answer. The reason for this is that regardless of strategy the expected number of correct answers for each person is 1/2, so any strategy averages 1 correct answer between the 2. Thus if it ever exceeds 1 it must also sometimes fail.

*b) As in the last part above, but we have 3 people. This is easy, because 2 people just play the game and ignore the other person. So what if there are 3 potential colours of hats? In this case the strategy is harder, and you will need to teach a bit of modular arithmetic. A nice way to approach this is to rephrase the 2 hat strategy. One person was right when there were an even number of red hats, and the other right when there were an odd number. Instead of calling the hats red and blue, lets call them 1 and 0, and have one player assume that the hats add up to 0 and the other to 1. They can then determine the colour that their own hat needs to be for them to be correct. But wait, what if the sum of the hats is 2? Well, in order to make this work we are going to have to do a funny sort of math where 2=0. So what is 1+1 you ask? 0 they say. There are no other sums, since all numbers are 0 or 1, and they can probably do 0+0 and 1+0.

Now, for 3 hats, instead of calling them red and blue and green, call then 0 1 and 2 and do the same thing. Here we use a different sort of funny maths where 3=0. Get them to do all the sums in this maths (2+1 = 0 and 2+2 = 1). If one player assumes the sum is 0, another assumes it is 1 and the last assumes it is 2 then one of them has to be correct. the challenging part of this is trying to get kids to come up with most of it themselves. This should be possible with older kids (15+) but I haven't tried with young ones.

c. A line of n people, 2 possible colours of hats, one hat on each person. Each person can see all the hats of people in front of them in the line, none of the hats behind them. People guess one after the other, starting at the back of the line. They can agree on a strategy beforehand. Can we guarantee somebody gets it right: yes, person at back just says the colour they see on next person, next person says that colour.

How many can we guarantee: Half (rounding down), using the above stratergy.

What if there are 3 people, can we definitely get 2 right (half rounded up): yes, the person at the back says red if they see 2 of the same colour, blue if they see 2 different colours. This tells the next person if their hat is the same or different to the one they see. Then the person at the front knows if their hat is the same or different to what they just heard.

*In general, what is the best we can do: n-1, since the person at the back reports the parity of the number of red hats they see (red = even number for example), and then everyone can determine their hat from what they have heard before.

*d) As before, but the line goes infinitely far forward. What is the best you can do (will infinitely many people always get it wrong). It turns out that the answer is no, you can make sure that at most finitely many people get the answer wrong (if you assume the axiom of choice). When discussing strategy, divide all possible sequences of hats into equivalence classes based on whether 2 sequences are eventually the same, and then pick a representative from each class. All people answer as if they are in the representative of whatever class they are in. Since the sequence they are answering in and the sequence they are actually in differ only finitely many places, only finitely many people will be wrong.

e. Now we have 3 people and 2 possible colours of hats. The rules are as before, except at least one person has to get it right and nobody can get it wrong. Strategy can be discussed. What is the best we can do: 12.5%, since if nobody can get it wrong everyone must be right.

What if we allow passing: a simple strategy is to have one person guess, and the other 2 pass, giving a 50% win rate.

Can we do better than this? It turns out that there is a better strategy. Since each person who guesses is wrong/right 50% of the time, the only way we can do better is to have the correct answers spread out but have everybody be wrong at the same time. To do this, we use the following strategy - if you see 2 of the same colour hat say the opposite colour, otherwise pass. Thus exactly one person will be right 75% of the time, and 25% of the time everybody will be wrong. A table illustrating this should be included in the maths box.

Risk Assessment

Hazard: Hat corners

Description: Risk that children will poke their eyes with pointy hat corners.

Affected People: Children

Before Mitigation: Likelihood: 2 , Severity: 2, Overall: 4

Mitigation: 'Make sure that children handle hats as little as possible, and mostly just wear them. When they do handle them make sure you know who has them and whether they are being sensible. Call first aider in case of injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall:2

Hazard: Hats

Description: Risk that hats will fall on floor and children will slip on them.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Make sure you know where hats are at all times and that children are not running around in a way that could be dangerous if hats fall. Call a first aider in the event of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Paper

Description: Risk that children will cut themselves on paper edges.

Affected People: children

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Make sure that children handle hats as little as possible, and mostly just wear them. When they do handle them make sure you know who has them and whether they are being sensible. Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-01-16 - Thomas Webster (tw432@alumni.cam.ac.uk)

Check 1: 2019-01-01 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2019-02-04 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-01-07 - Matthew Le Maitre (msl54@cam.ac.uk), **Check 2**: 2020-01-27 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2020-12-12 - Yian Aaron Koh (yak23@cam.ac.uk), **Check 2**: 2021-01-22 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2022-02-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2022-02-09 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2023-02-15 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-16 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2024-02-19 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-19 - Lauren Mason (llm34@cam.ac.uk)

Trebuchets

Using a medieval inspired siege-weapon to launch bean bag bunnies - Fire projectiles across the room using our trebuchets! Can you work out how to make them go really far?

Last initially checked on 2024-01-09 by Jessica Trevelyan (jet81@cam.ac.uk) and double-checked on 2024-02-14 by Timothy Wong (chw55@cam.ac.uk).

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Engineering

Active (Experiment has working equipment at the time of last update, and is available for events.)

Equipment Needed

- **This experiment can take place outdoors**
- 2 x collapsible trebuchet
- Rice in balloons + gaffer tape
- (all in a big red box)
- Bolts (with wingnuts) to assemble trebuchet in plastic tub
- Release pins (also in plastic tub)
- Note for future: An artificial soft surface (e.g. piece of roll mat) would lower the wear rate of the weights, esp. on tarmac or dry mud. If they start leaking nuts during a session, repair with gaffer tape!

Experiment Explanation

The Challenge:

Split the group into two teams. This could be two groups of children at schools or a child and their parents at events. Each team gets a trebuchet. Compete to try and launch the projectile the furthest or to get it into a box if space is limited.

Optional challenge to beat the day's record.

Explanation:

The trebuchets can be modified in two main ways, the pivot position and and the angle of release.

The optimal pivot position seems to be the third or fourth hole from the weight (don't tell them this). With the weight close to the pivot, it cannot accelerate the arm fast enough. This can be explained via the analogy of opening a door via pushing it near the hinge, which is much harder than doing it normally. However, with the weight too far from the hinge, the acceleration of the arm is greater, but speed of the projectile end is small as it is now too close to the pivot. This time, the structure of the trebuchet also needs to be taken into account, as the weight hits the ground before completing the full swing. As it is not good at either end, the best position needs to optimise the balance between these two ideas.

The angle of release can be altered by the position of the spaghetti spoon launcher. The best launching angle should be 45 degrees, or a bit less accounting for air resistance. However, it will not necessarily fire at the same angle when the pivot position changes so this may also have to be adjusted.

If the projectiles have a string attached, this can act as a sling to launch them further. At the moment that the projectile leaves the trebuchet, it is swinging relative to the arm, so its relative speed adds up with the normal launch speed. Show them this after they have tried it normally.

Things to talk about:

- Levers: the more the distance to the pivot the less the force, but the greater the distance moved. It might be worth starting off with a brief explanation of how levers work using an arm.
- Why it's best to have the projectile far from pivot.
- Angle of release: 45 deg should always be best for range, neglecting wind. How can we control the angle? - the projectile is ejected from the trebuchet when centrifugal force overtakes any force the holder exerts on it. (Centrifugal force gets bigger as the arm accelerates through the swing.)
- Using a sling to get extra velocity.

(more suggestions welcome) Set up instructions: ———————— The spagetti spoon end should be on the same side of the base which has the small loop and the 2 prongs. Use the firing pins (narrow metal rods attached to brown pipe cleaners and strings) to connect the metal end of the looped rope to the ring under the spagetti spoon. The looped rope can be attached to the prongs to adjust the launch height. Fire the trebuchet by pulling out the firing pin with the string.

Risk Assessment

Hazard: Projectile-carrying arm

Description: Injury from projectile-carrying arm flying up and hitting audience member or demonstrator in the face. This is a bigger problem when the weight is far from the pivot, as the arm flies up with large force. Also has the potential to be especially nasty if pointy bits of spaghetti spoon hit someone in the eye.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Instruct kids and demonstrators to fire the trebuchet by standing to one side and pulling out the firing pin. Do not let them stand over it and put their face in the way. Safety goggles should be available for anyone who wants them. In the event of an accident, call a first aider.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Weights

Description: Injury due to weight dropping suddenly and hitting audience member or demonstrator.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Weight - has been made from nuts - no sharp edges and will deform on impact. Make sure small humans stand out of the way of the weight as it drops. Also don't let them be thrown/launched. Call first aider if required.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Projectile

Description: Could hit audience member or demonstrator and injure them.

Affected People: Mainly bypassers or observers

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Projectile - light rice bag, trebuchet designed to have limited range and velocity, and will not hurt on impact, even at high speeds. Make sure people do not stand in front of the trebuchets when firing - could indicate firing zone with some hazard tape. Avoid busy areas/thoroughfares. If the area happens to get busy mid-demonstration, either ask people to evacuate the 'smash zone' or wait until they have moved. Call first aider if required.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Firing pins

Description: Ends of rod and pipe cleaners could be sharp and cause injury.

Affected People: Anyone operating the trebuchets

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Ends of firing pins should be sanded down to remove any sharp edges. Demonstrator to check edges are suffiently blunt before using. Instruct people to hold firing pin by the pipecleaner. Demonstrator to check no pipecleaner ends are stick out. Call first aider if required.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Arm and support gap

Description: Trapping fingers between arm and support when the trebuchet is fired.

Affected People: Anyone operating the trebuchets

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: The supports are solid to reduce possibility of fingers being in way of arm. Given the launch position, it is highly unlikely that the person discharging the weapon will be at risk of this. Therefore, one must be aware of anyone else who may get in the way. Firing pins have string attached so trebuchet can be fired from a distance. Call first aider if required.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Spare projectiles

Description: Spare projectiles may act as a trip hazard on floor.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Ensure all spare projectiles are near to the experiment, and don't end up in walkways. Preferably keep them in the box when not in use. Call first aider if required.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-26 - Rosy Ansell (rosemary.a.r.hunt@gmail.com), **Check 2**: 2012-01-30 - Coryan Wilson-Shah (cw412@cam.ac.uk)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-18 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2014-01-23 - Vamsee Bheemireddy (vrb23@cam.ac.uk)

Check 1: 2015-02-01 - Benjamin Lai (bl337@cam.ac.uk), **Check 2**: 2015-02-12 - Richard "Miffles" Mifsud (rwm41@cam.ac.uk)

Check 1: 2015-12-16 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2016-01-02 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2017-01-22 - Robert Gayer (rg478@cam.ac.uk), **Check 2**: 2017-02-10 - Thomas Webster (tw432@alumni.cam.ac.uk)

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-02-06 - Joanna Tumelty (jt574@cam.ac.uk)

Check 1: 2019-01-20 - Yaron Bernstein (yb258@cam.ac.uk), **Check 2**: 2019-01-30 - Helen Gildersleeves (hcg31@cam.ac.uk)

Check 1: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-05 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-06 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Lauren Mason (llm34@cam.ac.uk)

Check 1: 2023-02-12 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-13 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-01-09 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2024-02-14 - Timothy Wong (chw55@cam.ac.uk)

UV (Fluorescence)

Looking at how materials fluoresce in UV light. - The world looks different when it's lit by UV… see how you can use this type of light to make clothes look extra-bright, find out whether banknotes are real or fake, and revive dead glowsticks.

Last initially checked on 2024-02-04 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Darkroom needed**
- **Electricity needed**
- Short blue box containing:
- UV LED lamp
- White paper
- Washing powder tablets
- Glowsticks
- Highlighters
- Sun cream
- Board covered with glow in the dark paint
- Also useful:
- Banknotes, driving license (anything with UV security markings)

Experiment Explanation

In a nutshell..

Show kids that there's more to light than the colours that they can see- and how this can explain why some ordinary things glow in "black light"

How to set up the equipment

This is best set up on the floor so that you don't look directly at the bulb. Put the lead and switches of the box towards you, with the flat side of the box towards your audience. The experiment is better in a dark corner/ in a dedicated dark room area. See the Risk Assessment for more details, but do thing about avoiding trailing wires in the dark! Also, there should be a power lead for the light box with this kit- please don't pack it with the main box of extension cables! There's lots of extra things in the box- if you keep them in the empty blue box when you're not using them it's easier to find them in the dark/ helps people avoid tripping over them!

What does the box do?

Turn over the box **with both lights switched off**, and show the kids the two bulbs. One is for "ordinary/normal" white light. The other bulb is a UV bulb- a kind of light human eyes can't see. There is a switch for each on the back. Turn it back over as soon as you're done with this to avoid UV directly into people's eyes.

See Risk Assessment for more details, but briefly: this particular UV light is pretty safe- it's not that far into the UV, so isn't as energetic/ dangerous as some other sources. You should hopefully spot that it gives off weak visible light too. It's also fairly weak - but *don't use it while it is facing up* just in case!!

What is light/ UV light?

The light most of us are really familiar with is white light. But that's actually a mixture of different colours. Most of the time we can't tell that, but sometimes we can see these colours split up, like in a rainbow.

Do you know the colours of the rainbow? Ask them to tell you! [Red -> Orange -> Yellow -> Green -> Blue -> Indigo -> Violet (basically purple!)]

It turns out that there are more kinds of light than our eyes can see. Some kinds of light are "redder" than red is - we call that kind of light "infra-red" (there's another CHaOS experiment about this- check it out!). You might have seen images from cameras that can detect this kind of light, perhaps watching animals at night on TV, or police chase criminals with helicopters. At the other end of the rainbow there are other kinds of light that we can't see. These are more blue/ more purple than violet, and we call this kind of light "ultra violet".

It's weird to think that there's kinds of light we can't see, but not all kinds of eyes detect the same light. For example, some people can't tell red and green apart, which is called "colour blindness". Another example: some insects, such as bees, can see UV light. Some types of flowers have extra patterns in UV, so this helps them find the nectar in the middle of a flower! (How cool is that?!)

But what about wavelength/ spectra?

Add this extra level of detail with caution: it can be too much detail to take in if they've never thought about UV/ IR before, and you can overwhelm them. You can come back to this later on once you'rve showed them some of the cool things that glow!

EM Spectrum: we call all the kinds of light (including UV, IR, visible) "electromagnetic radiation". One way of understanding this is to say that all these kinds of light have different sizes of wavelength. There's some charts in the box that you can point at when you explain this. Start with the rainbow: Red light waves are wider/longer than blue light waves. Following on from that, infra-red has longer waves than red light; UV has a shorter waves than blue. If you go further outside that you can see microwaves (that you can cook with) and radio waves (which can hold information. like music). These have a longer wavelength, much longer than infra-red. If you go the other way you get to X-rays- these have smaller waves than UV!

Energy: Another way of viewing the light is as a stream of particles. We call them photons. They are like small balls travelling at the speed of light. And photons of different colours have different energy. Blue photons have more energy then red ones and ultra-violet ones have even more energy. This if why UV can cause damage to your skin. (You can use analogy with a light and heavy ball. The heavier has more energy and can harm you more if thrown upon you.) It causes damage to the cells (which can cause cancer if it goues really bad). When you get sun burned you have absorbed too much of UV. So wear suncream to prevent this! (And X-rays have even more energy and do not stop on your skin - they can go through your body so you can use them to see what is inside. But they are also more harmful and that is why it is used as little as possible.)

Some things glow if you put them under UV light

Put an object from the box under the UV light. Boring old white paper works- though pretty patterns on driving licenses/ credit cards/ banknotes are a good start if you have them! Either way, this first item should glow! Here's a way of explaining this…

1. Turn on the UV light
2. Place a (fluorescent) object underneath it - it should glow.
3. What's happening? How can we see glowing if we can't see UV?
4. It's fluorescence! (Use this word! Here's a simple explanation- let us know if you have an alternative!)

The object absorbs or takes in light that we can't see- UV light. The object can then change the light from UV to a kind we can see. The energy in the UV light is being converted into a different visible form, and things that do this are called fluorescent.

Wikipedia has a more precise explanation, but it depends on understanding lots of other technical words! *"Fluorescence is the emission of light by a substance that has absorbed light or other electromagnetic radiation. It is a form of luminescence. In most cases, the emitted light has a longer wavelength, and therefore lower energy, than the absorbed radiation."* (From http://en.wikipedia.org/wiki/Fluoresce)

Where are UV lights used in everyday life?

In shops, to check if money is fake! (See markings on banknotes)

Ask if they've ever seen notes being checked in shops. You can ask parents if they have a five pound note you can borrow briefly. If you look at the note, there are all kinds of features visible to the eye (metal strip, watermark etc.) but if you put the note under the UV light, you can see extra information, like the value of the note. This is useful in preventing forgery because printing with UV sensitive ink is difficult and expensive. Again, the UV gives the special inks energy so they give out light. Don't forget to give the fiver back

In discos, to make white things look super bright!

You might have seen this!

Fluorescent objects in the box Highlighters: - Fairly boring in white light, but spectacular under UV. Draw on white paper or non-fluorescent card, on even a smiley face on the back of your hand!

Glowsticks: - Show them glow sticks in the UV - which will glow. Glow sticks get their energy from a chemical reaction rather than UV, if you give them energy from UV they will still glow though

Tonic water: - This is probably the brightest fluorescence in the box, so I usually leave it until last. It's quinine that's causing the glow- this compound is more famous for helping to kill malaria parasites when it was added to tonic water. In the past it was in much higher doses than it is now.

Glow in the dark board: - There is also a board coated with the phosphorescent paint - put it under the UV light for 10 seconds (or more - doesn't do any harm), then turn the light off and let them see how the board carries on glowing. Turn the light back on and invite them to put their hands on the board. Make sure they keep their hands in the same place for at least 10 seconds, and see if they can guess what the board will look like after they take their hands away - the effect will be most long-lasting if you turn the UV light off at almost the same time as they take their hands off the board. Some parents may want to take photos!

For more info on tonic water visit: http://en.wikipedia.org/wiki/Tonic_water

Washing powder: - Residual powder makes your clothes look whiter by helping balance out the yellower colours of sad old white clothes. **This gets everywhere, need to replace blocks!!**

Phosphorescent things in the box (glow in the dark stars): - Phosphorescence is very like fluorescence a chemical in the paint absorbs energy from the UV light, but instead of releasing it again in miliseconds, it releases it slowly over minutes.

Glow in the dark paint: tube (not presently available) - Apparently this stains, so don't open the tube! (There is some phosphorescent paint, this does the same thing as fluorescent dyes but releases the energy much more slowly -> glow in the dark stars etc. NB: this should be well wrapped in plastic (whilst being non-toxic it is very staining) - you can often see it glowing through the container.)

Why is there sunscreen in the box?

- UV light from the sun (not this box, so it's safer than sunlight!) has lots of energy. This damages your skin (or cells, and ultimately, the DNA) when you absorb/ take in too much of this.
- If you use sun screen it can absorb the UV/ block it from reaching your skin, which reduces the damage the sunlight can do
- See this in action: spray a white sheet of paper with a bit of sunscreen. Predict what will happen (should look black). Try it under the light.
- Try drawing with the sunscreen- you can write hidden messages!
- Combine this with highlighter pens- you should be able to block fluorescence.
- Try not to use too much sunscreen -it's pretty expensive...

Bits of an old explanation- should all be in section above!

I start off trying to get the idea across, that UV is a colour, but you just can't see it..

What colours are there in a rainbow? -> ROYGBIV..

Have you thought that there might be some other colours that you can't see? If they are older ask them if they have heard of infra red, microwaves, radio waves, X-rays, UV -> they are all colours of light that your eye can't see

Mention that bees can see UV- they seem to get a kick out of this. Some flowers that look plain white to us literally have landing stripes on for bees.

Explain that the tube gives off UV and show them what happens when you put the paper in the UV. This is because when UV hits the paper it gives it some energy, which it can release as blue light…

Do you know what UV does to your skin? normally they don't

What happens to your skin if you stay out in the sun too long -> sunburn -> Due to UV Sun cream

What do you put on to stop you getting sunburnt? -> sun cream

What do you think it does to the UV? -> Stops it

What do you think will happen if we put sun cream on the paper? Quite often they work out that it won't glow

Get them to draw stuff on the paper with the suncream then put it in the UV light -> dark lines. Which I was impressed with the first time I tried it.

It's always more striking if you do the drawing-on-the-paper-with-suncream in the light (take them outside the darkroom) and then bring the paper in… in the darkroom it's harder to see how little difference the suncream makes to visible light. Which I (and lots of parents) think is really cool… sometimes I manage to convince the kids, too. If you've got a group working round the darkroom experiments it's worth being aware what they've already had demonstrated to them, as if they've seen, say, polarised light, they should (OK, might) have some idea about what (you want them to tell you) light is.

Fluorescent things

Get them to play with the highlighter pens (they are much more impressive on paper or cardboard that doesn't glow) Glow sticks get their energy from a chemical reaction rather than UV, if you give them energy from UV they will still glow though Paper money and driving licences (security marking)! Driving licences also have patterns only visible in UV.

Links to IR

This experiment often links well if placed near IR or demonstrated as a pair. You'll find the lights in IR can be too bright to see UV florescence. If separate demonstrations try and place slightly further apart or use the boxes as a screen otherwise switch them off as you move across.

Risk Assessment

Hazard: UV light

Description: Skin/eye damage.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Use UVA LED light, which is less harmful, so much less harmful light. Warn users not to look directly at it. Avoid prolonged skin exposure. Ensure that if hands are at short distances directly under the lamp (<0.5 m), they don't remain there for longer than 5-10 mins. Minimise time drawing directly under lamp. In the event of an accident, call a first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Electrical cables

Description: Trip hazard.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Place wires sensibly (not across middle of room), and put the UV light in a place it is not likely to get trodden on.

Tape down if necessary. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Washing powder

Description: Risk of ingestion of washing powder sample, or getting it into eyes.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Washing powder to be kept in a sealed clear plastic tube. Call first aider in event of injury, who may perform an eye wash if trained and confident to do so.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Sun cream

Description: Some people have an allergic reaction to sun cream. Avoid getting in eyes.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: If children want to put sun cream on their skin, first make sure that they've previously used sun cream without allergic reaction. Call first aider in event of injury, who may perform an eye wash if trained and confident to do so.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Glow stick chemicals

Description: Risk of ingestion of split glow stick - chemicals can cause irritation to skin and eyes and vomiting if ingested.

Affected People: Public

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Don't let children repeatedly play with and bend glowsticks. Make sure anyone in contact with the glow stick washes their hands immediately and clear up spillages before continuing. Call first aider in event of injury.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2012-01-02 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-03-13 - Anna Kalorkoti (anna.kalorkoti@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-21 - Holly Davis (hd308@cam.ac.uk), **Check 2**: 2014-01-21 - Chris Hardy (cjh206@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-07 - Tim Morgan Boyd (tmb58@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2017-01-17 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2016-01-30 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-27 - Hannah Thorne (hbt23@cam.ac.uk), **Check 2**: 2017-02-13 - Thomas Webster (tw432@alumni.cam.ac.uk)

Check 1: 2019-01-31 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-01 - Emma Vinen (Ev312@cam.ac.uk)

Check 1: 2020-01-15 - Beatrix Huissoon (beh37@cam.ac.uk), **Check 2**: 2020-01-16 - Jean Pichon (jp622@cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-22 - Holly Smith (hs606@cam.ac.uk)

Check 1: 2022-02-09 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-13 - Chiara Delpiano Cordeiro (cd796@cam.ac.uk)

Check 1: 2024-02-04 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk)

Vacuum Bazooka

Firing a projectile using a vacuum cleaner and a long tube. - Experiment with launching projectiles using the power of a vacuum cleaner.

Last initially checked on 2024-01-31 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **Electricity needed**
- Vacuum cleaner
- PVC Sections
- Joining Pieces
- Small projectile, wrapped in bubble wrap.
- (More projectiles can be made by screwing up paper and wrapping in duct tape, filling balloons with rice and putting in more balloons or using pipe insulation.)

Experiment Explanation

Fire a small, light projectile up to 10m using a Vacuum cleaner and a length of tubing. To fire a projectile place the piece of card over the end closest to the T bend and add the projectile from the other end.

The projectile is accelerated along the tubing by the pressure difference generated by the Vacuum cleaner and shoots out of the end of the tubing. We need the card to create a seal at that end, the card is too big to travel towards the vacuum but the air pressure holds it in place. When we add the projectile we fully seal the tube. The increased air pressure out side the tube pushes the projectile along, accelerating it towards the vacuum cleaner. When it reaches the T junction it continues going straight on, with enough force to knock off the piece of card and fire out. It keeps on going instead of being sucked back because it's gained momentum from the acceleration, and the brief force from the vacuum once it's passed isn't enough to stop it.

Another good intro to this experiment is through what is this (point at vacuum cleaner), what is it for, how does it clean... Eventually you'll make your way onto suction and then you can get people to feel the suction force from the ends of the tube, you'll notice that it's stronger closer to the split junction. If you seal an end using a piece of card it becomes stronger at the other end. This leads on to putting projectiles in with and without the end sealed. Without the seal it won't fire as there's not enough suction, but be careful, as soon as you seal the alternate end it'll fire out.

You may want to talk about why it's not sucked back into the tube, most of the projectiles would actually fit but don't go that way. One thing you could do is extend out of the front of the T bend, this will lead to projectiles being sucked back though which is a bit annoying but may help some groups. You can also talk about turning corners, in a car (most) people slow down to turn, this is because you need to change the direction in which the particles momentum is, this requires a force which we don't have. Similarly running round a corner and why in the 400m there are wide corners, wide corners means a more gradual change in momentum.

```
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
LOTS OF PARTICLES  /¯¯¯¯¯¯¯¯¯¯\
LOTS OF PARTICLES /------------\
LOTS OF PARTICLES|--------------| ———————————> Force
LOTS OF PARTICLES \------------/
LOTS OF PARTICLES  \__________/
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \/ air escapes here \/ \_\_\_\_\_\_\_\_\_\_
```

There are more particle collisions on the left hand side of the ball than the right due to the vacuum cleaner reducing the pressure on the Right hand side.

Particle Theory

A good way to start (I think, depends on the age group) is often good to ask what the surroundings are made of, solids liquids gases etc, and introduce the idea of particles (kids, even young ones may have heard of atoms or molecules). You can talk about how particles behave in each state of matter, and then start to focus on the air around you. Many kids will know the names of the gases that make up the atmosphere, so that's a nice question to ask, then you can explain that you get lots of these gas particles zooming around, but that you can't normally feel them. Example, wind blowing you backwards. You can also explain that many, many particles bump into you each second, but because you're used to it you don't notice (and your body has evolved to deal with it, if they're old enough to know about evolution). Maybe make a comparison, such as a bag of flour (1 kg) on an area the size of a postage stamp (1 cm^2).

Projectiles

There are lots of things we can talk about in optimising how the bazooka fires. Swapping to a more powerful vacuum cleaner will increase the muzzle velocity and hence the distance travelled. Why? Because this increases the pressure difference created in the tube. What about swapping the piece of card for a better seal? Well this would be good for increasing the pressure difference but it depends on how easily the projectile can knock it off when it fires out, we lose some energy (and hence speed/distance) by knocking it off. My theory is that this is probably worse. What about changing the angle you hold it at? If they've seen the trebuchets experiment or know some mechanics they may have some ideas about a slightly upwards angle being good for distance. However with the vacuum bazooka we have gravity also playing a roll. Firing directly downwards will obviously increase the muzzle velocity and I doubt firing directly upwards will work. You could do the maths and figure out the optimum yourself before demonstrating and write it here. Projectile weight is another variable, this one should also interact with the above. Demonstrating outside you'll find the crosswind probably means slightly weightier projectiles get blown about less hence fly further. With less wind the lighter the better, unless you're firing downwards from a vantage point. These should be tested on the bazooka and see what happens.

Also see the Vacuums experiment which can be paired with this one.

Risk Assessment

Hazard: Projectile

Description: People being hit, and potentially injured, by the projectile and/or PVC tube. Also possible damage to surroundings.

Affected People: Mainly persons not part of the experiment

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Demonstrator should maintain control of the direction the bazooka is firing in. If not holding the firing tube the demonstrator should have the projectile, end stop or both in his/her possession at all times to prevent bazooka being fired by anyone else. Bazooka should be sited to allow it to be fired along the room into a wall or (ideally) curtain, such that people who are not involved in the experiment cannot accidentally walk through the area, and so that those that are participating can be excluded from the firing area during firing. Projectile should be composed principally of light-weight packing material or similar (such as bubble wrap). It may be desirable to weight the front end with blu-tack or similar to encourage predictable flight but this should be done with consideration for the total resulting weight. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Electrical parts

Description: See electrical parts RA.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Follow electrical parts RA. In the event of an accident, call a first aider.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Hazard: Electrical cables

Description: Trip hazard.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Place wires sensibly (not across middle of room). Tape down if necessary. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Risk Assessment Check History

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-02-14 - Nunu Tao (nmt26@cam.ac.uk), **Check 2**: 2014-02-16 - Benjamin Lai (bl337@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-25 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-03 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2017-01-15 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2017-02-02 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-04 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2018-02-04 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-02-03 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2020-01-18 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2020-01-19 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-04 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2021-01-19 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2022-01-23 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-01-30 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-02-17 - John Leung (cfl35@cam.ac.uk), **Check 2**: 2023-02-18 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-01-31 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk)

Vortices

Make smoke rings and see how they form - Experiments with smoke rings and tornado formation.

Last initially checked on 2024-02-04 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- **Darkroom needed**
- **Electricity needed**
- 2 Vortex cannons + spares
- Polystyrene Cups
- Power supply for the smoke generator
- Smoke generator
- 2 Water bottles, food dye and vortex tube connectors for bottles
- Canned smoke (for busking/floating)
-
- ———With Tom W bought for CBS 2021———-
- 4 more bottle connectors
- An airzooka
- 25 silicone bracelets

Experiment Explanation

Overview:

This experiment exhibits vortices, in particular in smoke rings. and vortices in water flowing between 2 bottles.

Basic procedure and explanation:

CARE: Check fire alarm status of the venue - machine shouldn't produce very hot smoke so heat sensor shouldn't be affected however smoke detectors will be. Consider isolating alarms and the risk of doing so in that venue. Alternatively demonstrate outside. In the event that the alarm goes off, switch off power and follow standard fire procedure (as per venue RA). Open windows and doors to ventilate area.

This experiment is about smoke rings, but, to understand why they happen, it's best to start with something simple, like pouring water between two bottles. Have you ever noticed what water does when it goes down a plughole? Does it just go straight down? With any luck, your audience will have already noticed that it doesn't, but it's still useful to show them a simple vortex in action using the pair of bottles connected by a plastic connector. The water can't just go straight through (because air needs to go the other way), so it forms a vortex and thus air can go straight up through the middle. If you use a lot of water then you'll be able to see the air bubbles coming up followed by a jet of water.

One experiment you can do is compare two of these bottle setups. Add about 500ml of water to each bottle, the exact amount doesn't matter, however, you'll need the same in each to make it fair and if you add too much water then you'll struggle to get the vortex to form. I found 1L of water required a lot of swirling to get the vortex to form and people may think you're putting in energy to help it go down. You could always try and show this isn't the case by shaking one up and down to give it 'energy' but not help the flow. Then have a race as to which bottle will empty first, turn both bottles over and give one a swirl to encourage the vortex to form. The vortex should be noticeably faster. You may notice that the undisturbed bottle also forms a vortex eventually,

So far the cores of our vortices (whirlpools) have been roughly straight lines. It's possible to make a vortex the core of which bends back on itself in a circle. You can spin your hand in the air at this point - this demonstrates how awkward the thing is to describe without a real example! Fortunately, we have one - since air is a fluid, like water, we can make a ring of vortex in it. If we use smoke, we'll even be able to see it. This is what the smoke machine is for. Using the smoke machine plug in and hit the button, it has around 3 minute warm up time and high output so only switch it on for a couple of seconds. The vortex cannon should show some good smoke rings. You can also feel the force if you fire it at someone, try not to let people get carried away in a fight, this shows we can transmit force through the air. By stacking the polystyrene cups in a pyramid kids can try to knock them over from a set distance. See how far away this can be done, and note how slowly the ring moves. The smoke shows us this travelling. The sides of the hole in the vortex cannon slow down the smokey air near the sides more than that in the middle, and making a twisting movement all of the way round. This makes a ring of vortex - can you see how it's rotating?

Using a vortex like this we can transmit forces through a fluid over much longer distance than without. See how far you can knock down the cups from, do you think you could easily blow them over from this distance otherwise using just the air? Even if you had a hair drier or a fan to push lots of air it'd probably dissipate over the distance. The moving vortex ring carries the spinning fluid and like a wheel of a car lessens the friction and allows the inner fluid to travel long distances with little loss of mass and kinetic energy.

You can talk about how the smoke machine works. It pulls in the fluid from the tank and heats it causing it to vaporise and form a cloud. The fluid is a mixture of water and glycol or glycerine. You can then talk along the lines of phases of matter and the transition from liquid to gas. You can talk about why we can see the smoke but the normal gases in the air are transparent. This is because the sheer number of water droplets making up the smoke. Normally light is scattered slightly by gases in the air but because there's not that many molecules we can't really see it. The sheer number in the smoke means it's scattered a lot after only a short distance, hence why we can see it. It's a white colour as it scatters all wavelength equally. It's slightly grey because of some of the absorption from the other parts. (I think this is true at least.)

Other things to talk about:

Pipe smokers can make smoke rings, as can volcanos! You can also see air in water rings from dolphins and scuba divers.

Vortices in air occur in weather systems. Tornados are a particularly vivid example, but there are big, slow vortices as big as whole countries above us in the sky all of the time, determining the direction of the wind.

Eddy shedding and flag ripples are also interesting (apparently) but I don't know anything about them.

Test with another shaped opening by sticking a piece of card over the front of the airzooka, even if you try and do a square you'll find you either form nothing or still get a ring, this is the only stable solution. (If we break an airzooka it could be worth hot knifing it to form a permanent square zooka)

The ring is stable as air in the centre of the vortex is moving faster than the air at the edges, this causes a twisting motion. This shape is stable as fast air is at a lower pressure so in relation to the stationary air at higher pressure there's a force keeping it in a ring. When it slows the pressure difference decreases and the ring expands as the pressure in the ring increases.

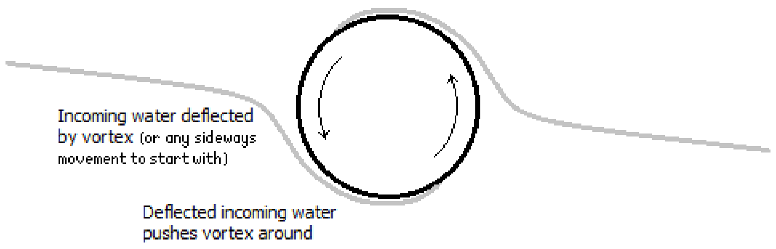
If you touch the ring it breaks as it's a big disruption to the stability.

You can attempt to get them to interfere and can see some repelling (not sure why it happens though) they can theoretically merge or destroy too but hard to do. The best way to get them to merge seems to be having two people stand next to each other and both fire forwards and slightly together at the same speed. You need the rings to meet along the same plane and spinning in the same direction to interfere constructively.

There's also no net movement of air, think about what this would do to the pressure, air just rotates around the vortex. The smoke is highlighting the forward flow: were we to fill the room with smoke and fire clean air vortices, we'd see reversed motion of smokey air. To try and demo this I have some silicone bracelets, if you imagine these are the smoke ring and then try and roll them along your wrist you'll see that the bracelet spins as it moves.

Apparently, you can generate smoke rings by shaking an incense stick. You can also do this at home with a coke bottle, a balloon (or small cardboard box) and an incense stick.

In future, we could add a simple plug hole demo to this. Just a waterproof slope with a plug installed and a bucket underneath. You should then be able to disprove some common myths about plugs always draining (counter)clockwise in the northern hemisphere by just doing it a few times. The direction is influenced by the initial angular momentum that gets imparted into the system



Risk Assessment

Hazard: Water

Description: Spilt water could be a slip hazard

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 3, Overall: 9

Mitigation: Clear up spills promptly. Make sure the bottles are firmly connected before inverting. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Water

Description: Spilt water could be dangerous if there is electrical equipment nearby.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 4, Overall: 12

Mitigation: Clear up spills promptly. Isolate electrical equipment from the mains if it may have been affected. Try not to spin the water bottles close to the smoke machine, for example. In the event of an accident call a first aider. Switch off power supply to any equipment causing injury. See electrical RA

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Cups

Description: Knocked over cups could be a trip hazard

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Pick up cups if scattered everywhere. Don't let people run around. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 4

Hazard: Canned smoke

Description: Canned smoke is flammable.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 5, Overall: 10

Mitigation: Ensure it's kept away from naked flames, do not allow the build-up of too much smoke in an unventilated area (e.g. the darkroom tent!). In case of fire, follow standard procedures for fire (see venue RA). Evacuate area, use fire extinguisher only if safe to do so, call fire brigade.

After Mitigation: Likelihood: 1, Severity: 5, Overall: 5

Hazard: Smoke machines

Description: Smoke machines are hot during operation and can cause burns if touched or may cause damage to other things.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 3, Overall: 12

Mitigation: Move using the yoke (hanging bracket) if necessary. Place on a heat resistant surface. Let it cool down periodically. If burns occur run under tepid water. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Hazard: Smoke

Description: Smoke/haze can cause irritation to the lungs and problems for asthmatics.

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 4, Overall: 16

Mitigation: Minimise time machine is on for. Use in a well-ventilated area. Swap demonstrators on the experiment if required and warn spectators. Avoid breathing in the fumes. Call a first aider in the case of an injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Smoke

Description: Excess smoke can affect visibility, increasing the likelihood of other accidents (falls, burns, etc.)

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Mitigation: Do not run the machine for extended periods of time. If smoke becomes too thick increase ventilation and cease demonstrating. Switch off power and call first aider in case of injury. In very poor visibility evacuate as if there were a fire (as per venue RA) opening windows and doors were possible to ventilate area.

After Mitigation: Likelihood: 1, Severity: 3, Overall: 3

Risk Assessment Check History

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2018-01-04 - Thomas Webster (tw432@alumni.cam.ac.uk), **Check 2**: 2018-02-04 - Benjamin Akrill

(bja32@alumni.cam.ac.uk)

Check 1: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2019-02-05 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2020-02-03 - Beatrix Huissoon (beh37@cam.ac.uk), **Check 2**: 2020-02-03 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk)

Check 1: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2021-01-20 - Polly Hooton (prh43@cam.ac.uk)

Check 1: 2022-02-09 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2023-01-12 - Jamie Barrett (jb2369@cam.ac.uk), **Check 2**: 2023-01-13 - Chiara Delpiano Cordeiro (cd796@cam.ac.uk)

Check 1: 2024-02-04 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)

Water rockets

Launching lemonade bottle water rockets with a foot pump. - Try not to get wet as you fire water-powered rockets into the air. Who can shoot it the highest?

Last initially checked on 2024-02-04 by Lauren Mason (llm34@cam.ac.uk) and double-checked on 2024-02-15 by Timothy Wong (chw55@cam.ac.uk). ## Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Physics

Equipment Needed

- **This experiment can take place outdoors**
- Pump.
- Bung with hole or with valve.
- Rope
- Launching base.
- A selection of lemonade (or other fizzy drink) bottles
- Lots of water in a large container.
- Preferably another bucket for filling the container.
- *The box also includes some of Dave's 'professional' water rockets, but we currently do not have the right pump for them and these bottles will hurt more if they hit people! For now, the 2L drinks bottles and the old launcher works better*

Experiment Explanation

Setup

Set up the rope running from the launch area to a higher point (raising the launch area, e.g. blocks, can keep the rope above head height) - run the rope through the tube attached to the bottle. Jam the bung in the bottle and get kids to pump until the rocket launches up the rope. Hopefully it should come back down to somewhere you can grab it. Keep people out of the area where the rope is so that they don't get hit by the rocket or walk into the rope!

As a further point - it can very occasionally be done without the guide rope pointing vertically upwards, or without a guide rope at all. This is suitable in large sports halls or outside only. Here care needs to be taken that a large enough area is cordoned off so that it does not hit anyone when it returns to Earth. If a guide rope is not being used, it can still be helpful to attach a rope to the rocket, in order to limit its range (such as to avoid hitting people) or to aid retrieval.

Explanation

Water rockets are great fun. Everyone wants a go, from 3 to 13 - and the teenagers and adults too, if they are brave enough to admit it. The does mean that you'll always have a queue and so an interactive discussion is difficult to achieve: on the upside, they'll be back for another try. I always try to remember the faces to keep a line of questioning going from launch to launch. I question them before every launch on a couple of points and while questioning I always keep their rocket in my hand, it keeps their attention and stops a rocket from flying up your ass.

As a first question I always ask: "So how do you think it works?" Which is always a good starter and that gives you your level. If it's not a terribly bad explanation, generally I don't try and correct it or improve it and I let them launch their rockets. Each time they come back a couple more questions maybe a little demo. They very rarely listen to the children ahead of them, which is kind of stupid, but there you go.

Then I suppose I start to refine their understanding of how it works and try and get them to experiment. Trying the bottle, full, empty; the bung in hard, or soft - you have to fiddle this one as it is difficult to control. Indeed you have to fiddle the empty bottle too, you want it to go about 5 feet and catch it, otherwise it can go almost as high as with water.

You've got a couple of lines of questioning. Pressure is always a good one. You can relate it to the pump. As a kid I could never pump up my bicycle tyres, because I didn't push the plunger very far. That sort of inspires me down this line. You can put your thumb over the valve and get them to push down on the plunger, the further they push down the harder it gets. When they let go the air may push it up a little. So that's your basis for explaining what pressure is, how you raise the pressure in the bottle and how it pushes the bung out. Don't use density.

Older kids and adults may talk about molecules. When your talking about molecules you can raise the concept of molecules inside the bottle hitting the inside of the bottle. I quote how fast an air molecule moves, about 500 ms-1, so even though it's light it packs a punch. I crush the bottle, put the bung in and then pump some air in. The bottle comes back to its original state, so the air molecules hitting the wall have pushed it back into shape. Then invite an assistant to squeeze the bottle, it's soft, but as you pump more air in it gets harder and harder, because those air molecules are pushing back at you. It's not a way people generally see the world so it's kind of a fun thing to do.

As part of fully explaining how it works you need the water there to push the rocket up. Every reaction has an opposite but equal reaction. I put the question: "when you lean on a wall and push on it, does it push you back?" All ages generally say no. So on to the demo, lean forward and get an assistant to push on your hand as your wall; "Now, I'm pushing against him and he's pushing against me and I'm going nowhere, what do you suppose happens if he's stops pushing against me." Your assistant stops pushing and you pretend to fly forward. "So if you're pushing against a wall, it must be pushing back."

The more water you've got in the bottle the harder the air pushes it down and the bottle up. So the more water the higher it goes. Sometimes getting them to imagine throwing a tennis ball versus a boulder can help.

Next is the energy. Where is the energy stored? This can lead on nicely to all sorts of questions about conservation of energy and what forms of energy are being converted from launch to launch. So the more air the higher it goes.

There seems to be a catch 22 situation. Of course it means there is an optimum and this is an important scientific concept in itself. Remember the heavier it is the lower it goes as well. This is all worth expanding on, especially with adults and at this point I may sweeten the pill by saying that on tour "we" settled down to try and work out what the optimum amount of water is, four sides of maths later we still hadn't solved it. The mathematics of how these bottles launch is more complicated than NASA rockets as the thrust changes over time.

The next bit is the bung. This is what really makes it go high or low. "If I push in the bung really hard will it go higher, lower, or not make a difference?"

I even ask the tots questions. I push some air into the bottle and say, "What are these?" Bubbles. "What's in a bubble?" Air, relate to blowing a balloon, what is in a blow? Indeed what's air?

These are just some of the themes I question on and there are plenty more so you shouldn't get bored. Remember, hold that bottle 'til you've got some science into, or out of, them!

Practicalities

Let them fill their bottles some way away, though you may want another bucket to make your own adjustments to the amount in the bottle. The area around the launch site gets very wet, so move on occasionally. Stay away from roads, people and roofs. Keep the queue back and make sure the rocket isn't angled towards their, or your, face. Bottles may get stuck in trees, that's half the fun.

If you're launching along a rope, you can engineer your setup so that most of the water goes back into the bucket on launch. This will save you some walking!

The more taut the rope is, the less friction the rocket will experience and the further it will go, so tie it to something strong and tie it tight!

Risk Assessment

Hazard: Bottle (projectile), epsecially if flown without rope

Description: Hitting people with the bottle

Affected People: All

Before Mitigation: Likelihood: 5, Severity: 3, Overall: 15

Mitigation: Keep people away from the rope (which the rocket travels on) by blocking off any area where the rope is below head height with chairs, hazard tape or similar. Make sure the person launching the rocket doesn't lean into its path (try to keep the pump as far away from the rocket as the hose will allow - we have lengthened the hose to make this job easier). Also locate the experiment sensibly, bearing in mind walkways that people will want to use in the venue, roads etc and wind direction.

If done without a guide rope, cordon off sufficiently large area to ensure it lands within it. Check prevalent wind direction as well by test firing the rocket before people come.

Wait until the surrounding area is fully clear before launching.

If using the rope to limit range, the areas in which the rocket might land (accounting for prevalent wind direction and lean of the launch stand) must still be cordoned off as there are two hazards - both from the rocket falling on someone and the trip hazard due to the rope.

It is the responsibility of the demonstrator to ensure that the area is clear and there is no chance of the rocket straying into the path of anyone.

After Mitigation: Likelihood: 2, Severity: 3, Overall: 6

Hazard: Bottle (pressurised)

Description: Bottle exploding; debris might cause small cuts or fall on people.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Mitigation: Check bottle for cracks and other damage before use. Any damaged bottles should be cut or marked to show they cannot be used if they cannot be disposed of immediately. Only use 2L "fizzy drink" bottles (Coke, Fanta, etc.) not bottles for still drinks which are not (always) suitable for pressurising. In the event of an accident call a first aider.

After Mitigation: Likelihood: 1, Severity: 2, Overall: 2

Hazard: Rope

Description: Walking into/tripping on the rope which the rocket travels on

Affected People: All

Before Mitigation: Likelihood: 4, Severity: 2, Overall: 8

Mitigation: Area is fenced off to prevent people from getting too near the bottle, ensuring people do not get too close to the rope as well. Keep rope ends tucked away and off the ground if possible.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Hazard: Water

Description: There is quite a lot of water involved, which presents a slip hazard.

Affected People: All

Before Mitigation: Likelihood: 5, Severity: 2, Overall: 10

Mitigation: Do the experiment outside on a surface that can take water. If done indoors or on a surface which can get slippery, keep a mop close to hand and cordon off the area.

Call a first aider in the case of an injury.

After Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Risk Assessment Check History

Check 1: 2011-12-30 - Mark Durkee (mark.durkee@cantab.net), **Check 2**: 2012-01-14 - Richard Ingham (richardingham@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-20 - Richard Hall (rjh216@cam.ac.uk)

Check 1: 2014-01-17 - Zephyr Penoyre (jp576@cam.ac.uk), **Check 2**: 2014-01-23 - Vamsee Bheemireddy (vrb23@cam.ac.uk)

Check 1: 2015-01-05 - Joseph Hooton (jh795@cam.ac.uk), **Check 2**: 2015-01-25 - Tom Comerford (tafc2@cam.ac.uk)

Check 1: 2016-01-04 - Andrei Ruskuc (ar720@cam.ac.uk), **Check 2**: 2016-01-17 - Frances Victoria Western (fvw22@cam.ac.uk)

Check 1: 2017-01-15 - Jared Jeyaretnam (jaj55@alumni.cam.ac.uk), **Check 2**: 2017-02-02 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2018-01-12 - Josh Garfinkel (jlg70@cam.ac.uk), **Check 2**: 2018-02-04 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-02-03 - Conor Cafolla (ctc43@cam.ac.uk), **Check 2**: 2019-02-05 - Josh Garfinkel (jlg70@cam.ac.uk)

Check 1: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk), **Check 2**: 2020-01-20 - Beatrix Huissoon (beh37@cam.ac.uk)

Check 1: 2021-01-02 - Lucy Hart (ljfh2@cam.ac.uk), **Check 2**: 2021-01-03 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-07 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-07 - Lucy Hart (ljfh2@cam.ac.uk)

Check 1: 2022-02-09 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2022-02-09 - Margaret Johncock (mllyj2@cam.ac.uk)

Check 1: 2023-01-12 - Andrew Sellek (ads79@cam.ac.uk), **Check 2**: 2023-02-18 - Peter Methley (pm631@cam.ac.uk)

Check 1: 2024-02-04 - Lauren Mason (llm34@cam.ac.uk), **Check 2**: 2024-02-15 - Timothy Wong (chw55@cam.ac.uk)

X-Rays

A collection of X-rays and other forms of medical diagnostic imagery. - Have you ever had an X-ray? Have you ever wondered how they work? Take a look at our collection of exciting X-rays and MRI scans, test your anatomical knowledge and diagnostic skills and find out about the physics behind the images.

Last initially checked on 2024-02-14 by Margaret Johncock (mllyj2@cam.ac.uk) and double-checked on 2024-02-15 by Asmita Niyogi (an637@cam.ac.uk)

Tags

Standard (A standard CHaOS experiment, useable for all hands-on events.)

Active (Experiment has working equipment at the time of last update, and is available for events.)

Medicine

Equipment Needed

- **Electricity needed**
- X-ray light box.
- Collection of X-rays and MRIs.
- Kettle lead with 'right-angled' end that fits.
- Torch.

Experiment Explanation

- General - What is it? Do they know when are they taken (when someone might have a fracture) and where? Asking whether they know anyone who's had one or had a plaster cast can be a good way to start.

How do X-rays work? You can talk about the production of X rays to older kids - it involves very high voltages across metal, releasing photons which travel along and get stopped by things which are dense and/or which have high molecular mass (this is why calcium shows up, and explains blood being somewhat radioopaque because of its iron content - you can see blood in the heart, and you can also visualise it on CT scans, which are just X-rays taken at loads of different levels and cunningly put together). The X-ray film starts white and becomes black where the photons hits it, therefore non-dense things, e.g. gas, look black on film and dense things, e.g. metal, stay looking white.

Smaller kids will appreciate something a bit like light which can go through softer things eg. skin but not harder things eg bone, metal implants. Likening it to a shadow can be useful. Of course then explaining a barium enema can be tricky, but you could describe it as "special liquid which can be seen on X rays".

Basically, you can go through the X-rays however you like and develop your own spiel. Here are some ideas:

- Ask lots of questions, get them to work out what everything is for themselves (our skeleton can help with this). If they're young it will probably take them half an hour to work out what they're looking at.
- What are bones for? (support, locomotion, protection - see Skeleton explanation)
- Skull X-ray - why do we have big spaces in our skull? (decrease weight)
- why do some of the teeth look different? (fillings - can talk about x-rays not passing through metal)
- Chest X-ray - identify the bones (ribs, clavicles, spine)
- Identify the organs (big spaces are air-filled lungs, the thing in the middle is the heart - they're always amazed by how low and central it is)
- But X-rays go through soft bits? What is the heart made of? How can we see it on the X-ray? Do bones have metal in them? (calcium - they usually know this or will get it with prompts about why you should drink milk to keep your bones strong)
- What is the heart full of? Does blood have metal in it then? (iron - they may not know this).
- Hand and foot X-rays - did they know they have so many bones in their foot/hand? Get them to feel the bones in their palm. Compare their hands to Boris if he's nearby.
- Angiograms/enemas - can talk about using contrast (dense liquids) to highlight structures we wouldn't normally be able to see.

MRI images

- First point - these images were donated by a committee member, so they are not anonymised as all the radiographs (which are teaching images) are. This is fine - you just might need to know as we have in the past had members of the public tell us off for using identifiable images, but it's ok as we do have full permission!
- Compare with X-rays e.g. can see soft tissues - when might this be useful?
- How does it work? The machine contains an extremely strong magnet. This makes all the water molecules in your body line up in the same direction they may have played with compasses in magnetic fields at school). The machine then fires radio waves at the body. This knocks all the little spinning water molecules slightly out of line, but a different amount out of line depending on the type of tissue it's in. When the radio wave is turned off, the molecules all flick back to where they were in the magnetic field, releasing energy in different amounts depending on how out of line they were earlier. This energy release is captured by sensors and turned into an image.

List of Radiographs (correct as of December 2020):

Human: 1. Gastrointestinal Tract- double contrast (gas and barium) 2. Gastrointestinal Tract 3. Chest 4. Hands 5. Pinned Femur 6. Dislocated Shoulder 9. Left foot 10. Spinal cord at shoulder level 11. Pelvic Fracture 12. Knee- displaced patella 13. Forearm 14. Skull 2 views- radiodense (bright white) tooth = filling 15: Dislocated Elbow 16: Angiogram Lung 3xMRI of spinal cord

New batch of Animal X-Rays from Queens Veterinary Schools Hospital - these have had patient/owner details cut out and could rip along cutting lines so try to avoid this! (Jennifer's X-rays folder): 1. Dog, fractured right femur, urinary catheter in place 2. Dog, plate used to repair fractured femur 3. Dog, plate has been used to repair the fractured femur, urinary catheter in place 4. Cat, normal cervical spine 5. Dog, normal spine of a dog 6. Dog, normal thorax of a dog 7. Dog, leg extended. normal pelvis 8. Cat, fractured left femur 9. Cat, fractured left femur 10. Cat, internal repair of a fractured femur 11. Cat, domestic shorthair, external fixator on the tibia, rushpin technique on the femur to allow repair without damage to the growth plates 12. Dog, cranial cruciate ligament rupture- soft tissue within the joint, tibia is mildly displaced cranially. Also evidence of osteoarthritis. 13. Dog, TPLO (Tibial Plateau Levelling Osteotomy) used to repair the cranial cruciate ligament rupture 14. Dog, normal stifle for comparison 15. Horse, lateromedial radiograph, front foot and hind foot. Can see the shoes, nails attaching the shoes, phalanges, navicular bone, proximal sesamoids and the start of the metacarpus/metatarsus. Radiopaque hairline marker helps assess the angles within the foot and possibly help diagnose laminitis

Other animal X-rays in this folder (blue stickers):

2. Male dog angiogram - can ask about what the most important organs are (can see these as those with greatest blood supply), contrast these with limbs which have far less blood supply - important in reducing heat loss, and possible because there are no major organs in limbs and most muscles are proximal (meaning the distal limbs are mainly bone and connective tissue, which require very little blood supply)

3. Arteries of the head (dog and sheep) - can ask about why the brain needs such a good blood supply - very important organ with high energy and oxygen demand (one of the few organs which cannot survive any period of hypoxia - neuron cell death begins 4-6 minutes after blood flow stops). It also has many different large arteries going into the brain, as if there was only one and it got damaged/blocked this would cause death as brain tissue cannot survive long without oxygen (about 2-3 minutes). As it is, only a small area of the brain will be damaged - this is what a stroke is - as the other arteries will continue to supply most of the brain.

- Following on for this, can ask why the nose also has high blood supply (esp. clear in sheep) - smell is a vital sense for survival in both sheep (prey) and dogs (predators) and requires energy and oxygen to allow adequate sensitivity for their needs. The nose is also important in cooling blood going to the brain and heating air breathed out through the nose which allows thermoregulation.

9. Dog intestine and pelvis lateral view - black areas in abdomen are gas build up in intestines which is normal

Other Animal X-Rays in black case:

For the exotic ones there's an information sheet which shows which X-ray is which and tells you about the animals. There are pictures of the animals which line up with the X-rays, which is good for young children as they enjoy matching them up. There should be: - Common marmoset - European rabbit - Joey kangaroo - Pumpkinseed sunfish - Frontsa cichlid (fish) - Green tree python - Western diamondback rattlesnake - Infant green iguana - Dwarf crocodile eggs - Veiled chameleon - Box turtle with eggs - Red-tailed hawk - Turkey vulture - Leaf Frog

Others: 1. Puppy angiograms x2 dorsoventral and lateral views - same interesting points as dog angiogram, also have epiphysis at joints. 3. Cat Barium Contrast study - shows the presence of megaoesophagus = dilation of the oesophagus which means that most food cannot get to the stomach (instead will be regurgitated, will see weight loss because of this), can feed animals in special chairs that sit them upright like a human so gravity can help food reach the stomach. 6. Bird skull 7. Puppy pelvis - shows left hip displacement and growth plates 8. Dog intestines barium contrast study - shows food in stomach and poo in rectum

Risk Assessment

Hazard: Light box

Description: Electrical hazard from light box.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: See electrical parts RA (attached)

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Light box (fluorescent tube)

Description: Flicker from the fluorescent tube in the light box has the potential to induce seizures in individuals with photosensitive epilepsy.

Affected People: All

Before Mitigation: Likelihood: 2, Severity: 4, Overall: 8

Mitigation: Discourage demonstrators with epilepsy from choosing this experiment, and the public from staring too closely at the light box for prolonged periods. If they complain of feeling unwell switch the box off and advise them not to look at it further. Switch off the light box if necessary.

Call a first aider in the event of injury.

After Mitigation: Likelihood: 1, Severity: 4, Overall: 4

Hazard: Light box (weight)

Description: Possible risk of light box falling off table onto people.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 2, Overall: 6

Mitigation: Ensure that the light box is not close to the edge of the table and is in a stable position.

Call first aider in case of injury.

After Mitigation: Likelihood: 2, Severity: 2, Overall: 4

Risk Assessment Check History

Check 1: 2012-01-11 - Elizabeth Mooney (erm40@cam.ac.uk), **Check 2**: 2012-01-23 - Ashley Smith (ashley.smith@cantab.net)

Check 1: 2013-01-08 - Ophelia Crawford (oc251@cam.ac.uk), **Check 2**: 2013-01-24 - Jaimie Oldham (jlo40@cam.ac.uk)

Check 1: 2014-01-21 - Catherine Bi (catherine.bi@cantab.net), **Check 2**: 2014-01-27 - Sharmila Walters (sw632@cam.ac.uk)

Check 1: 2015-01-10 - Alisha Burman (arb95@cam.ac.uk), **Check 2**: 2015-02-12 - Richard “Miffles” Mifsud (rwm41@cam.ac.uk)

Check 1: 2016-01-05 - Charlotte Attwood (ca402@cam.ac.uk), **Check 2**: 2016-02-07 - Charis Watkins (czrw2@cam.ac.uk)

Check 1: 2017-02-11 - Fiona Coventry (fiona.coventry@cantab.net), **Check 2**: 2017-02-12 - Andrew Sellek (ads79@cam.ac.uk)

Check 1: 2018-01-27 - Matt Worssam (mdw47@cam.ac.uk), **Check 2**: 2018-02-07 - Benjamin Akrill (bja32@alumni.cam.ac.uk)

Check 1: 2019-01-13 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2019-01-25 - Matt Worssam (mdw47@cam.ac.uk)

Check 1: 2019-12-23 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2020-01-10 - Esmae Jemima Woods (ejw89@cam.ac.uk)

Check 1: 2021-01-18 - Polly Hooton (prh43@cam.ac.uk), **Check 2**: 2021-01-20 - Conor Cafolla (ctc43@cam.ac.uk)

Check 1: 2022-02-09 - Grace Exley (gae23@cam.ac.uk), **Check 2**: 2022-02-09 - Maggie Goulden (mcg58@cam.ac.uk)

Check 1: 2023-01-22 - Jessica Trevelyan (jet81@cam.ac.uk), **Check 2**: 2023-01-22 - Jamie Barrett (jb2369@cam.ac.uk)

Check 1: 2024-02-14 - Margaret Johncock (mllyj2@cam.ac.uk), **Check 2**: 2024-02-15 - Asmita Niyogi (an637@cam.ac.uk)