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 handling skulls, especially if skin is cut due to sharp edges.

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. Encourage participants to wash or sanitise hands after handling skulls.

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)

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 2024-02-04 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-02-15 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).

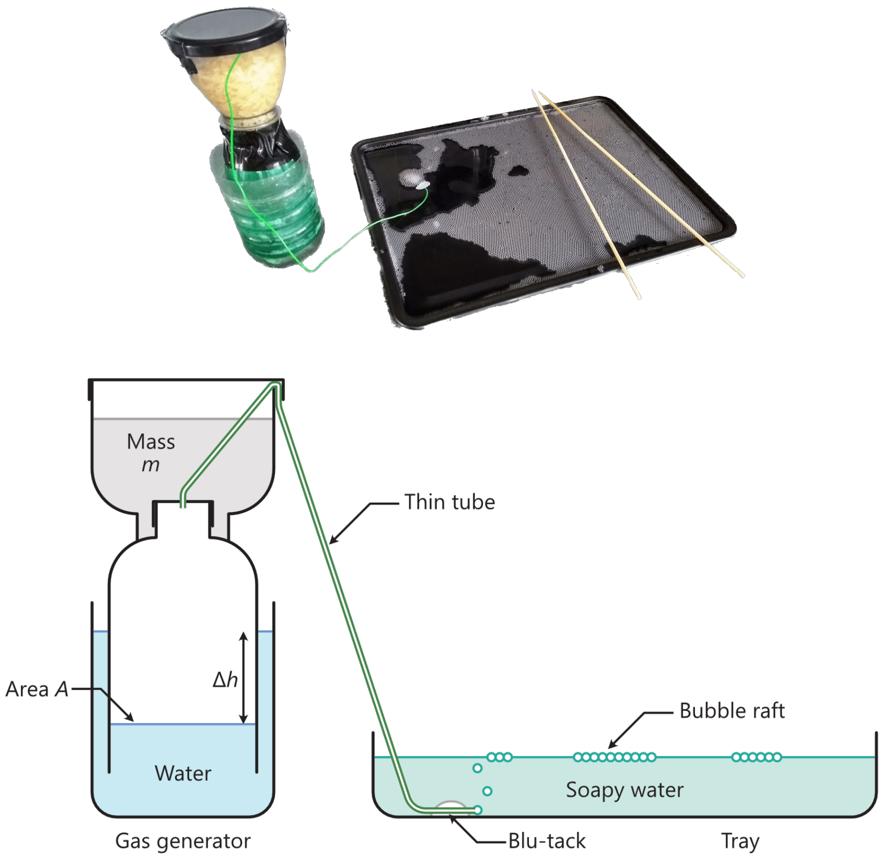


Fig 1: the setup for the experiment.

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 $\Delta p = \rho_w g \Delta h = m_{\text{gas}}$*)*
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).

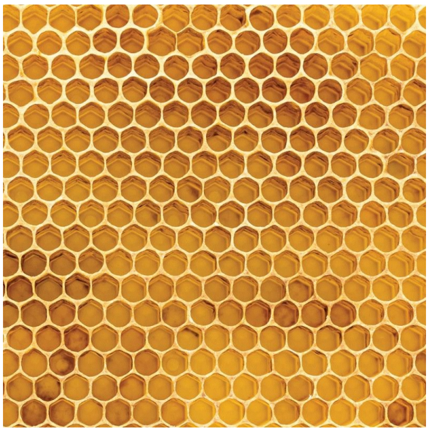
The experiment uses a single layer of bubbles: if they stick around near the tube for too long, they can start forming a double layer, so waft them away from the tube with a skewer.

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.



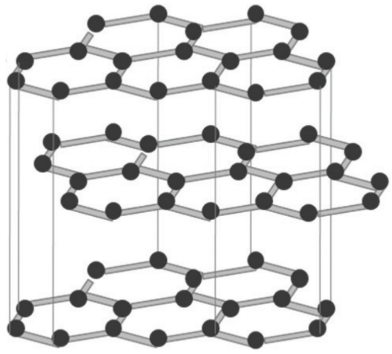


Fig 2: naturally-occurring hexagonal close-packed structures: honeycomb and graphite. The bubble raft is most similar to graphene – a single sheet of graphite.

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.

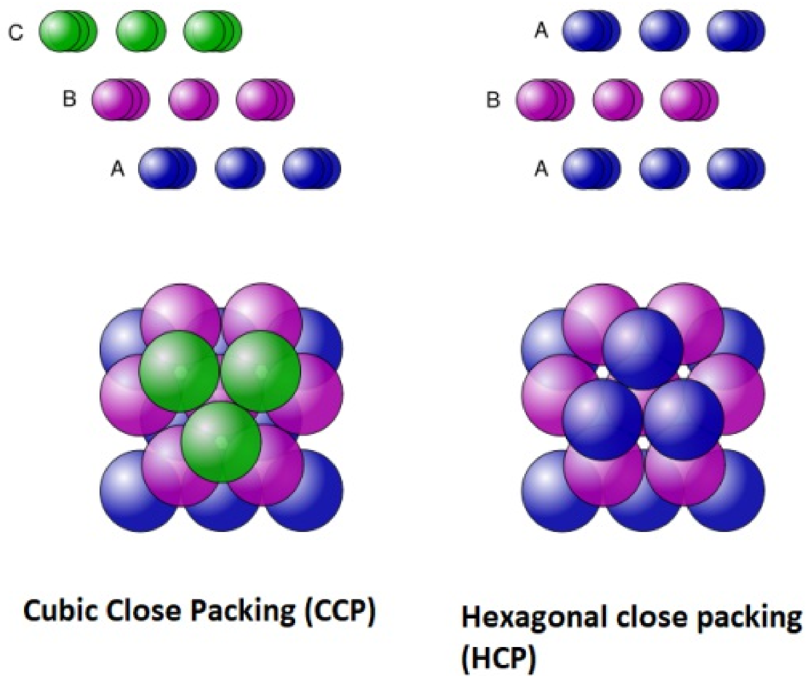


Fig 3 : 3D close-packed structures

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.

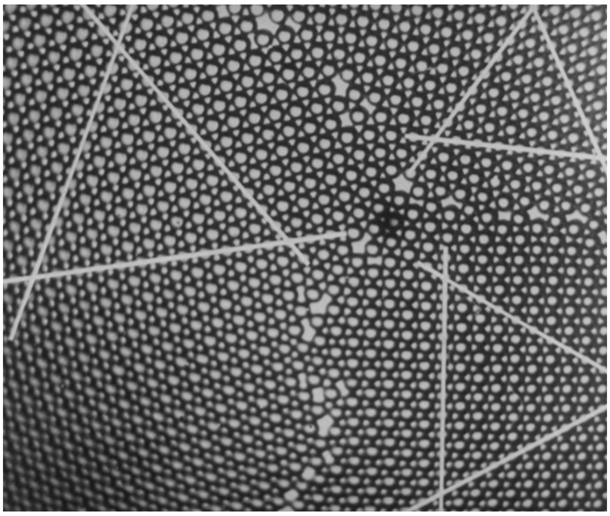


Fig 4: three grains, with the lattice orientations for each drawn. Note the defects on the grain boundaries. Screenshot from the Bragg video.

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**.

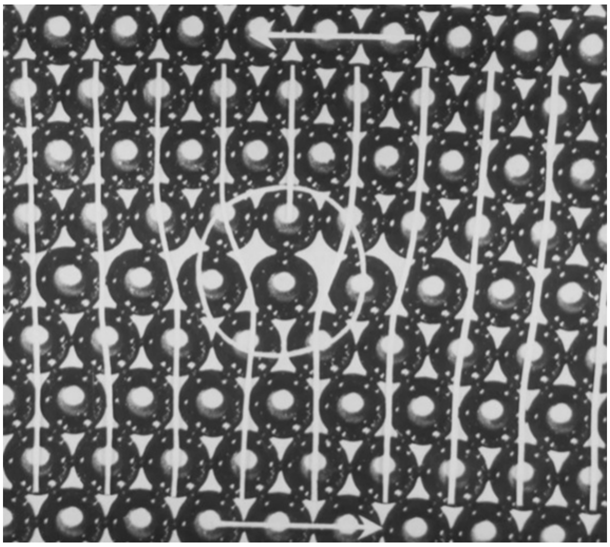


Fig 5: Dislocation within a bubble 'crystal'. Note how there is an extra column of bubbles on the top compared to the bottom. This dislocation has a Burgers vector of 1 bubble diameter to the left, and will move to the left to relieve the applied stress. Screenshot from the Bragg video.

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!

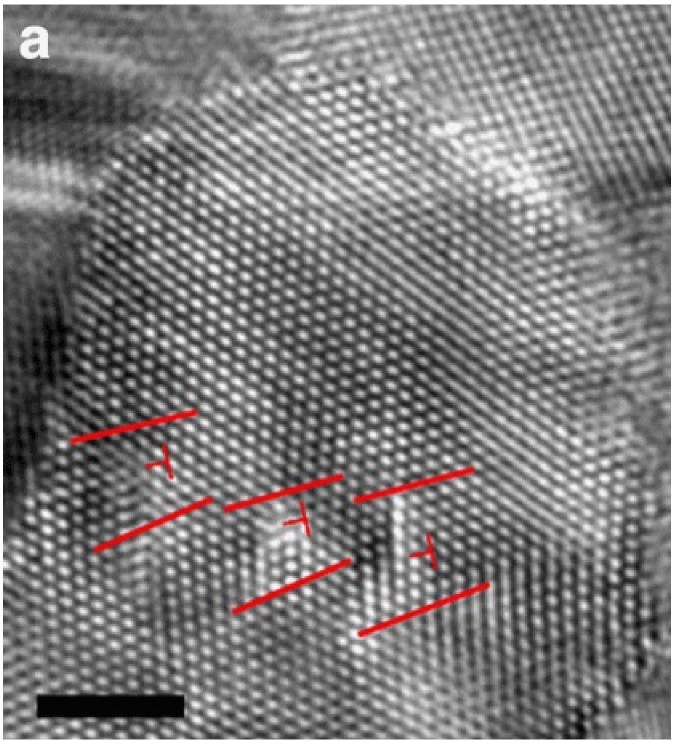


Fig 6: Electron microscope image of real grain boundaries and dislocations (marked in red) in a crystal of platinum. Scale bar is 2 nm (that is 0.000000002 m!) From Wang et al. (2014).

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. Use a sign to indicate the presence of soap. 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: 2024-02-04 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-02-15 - 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

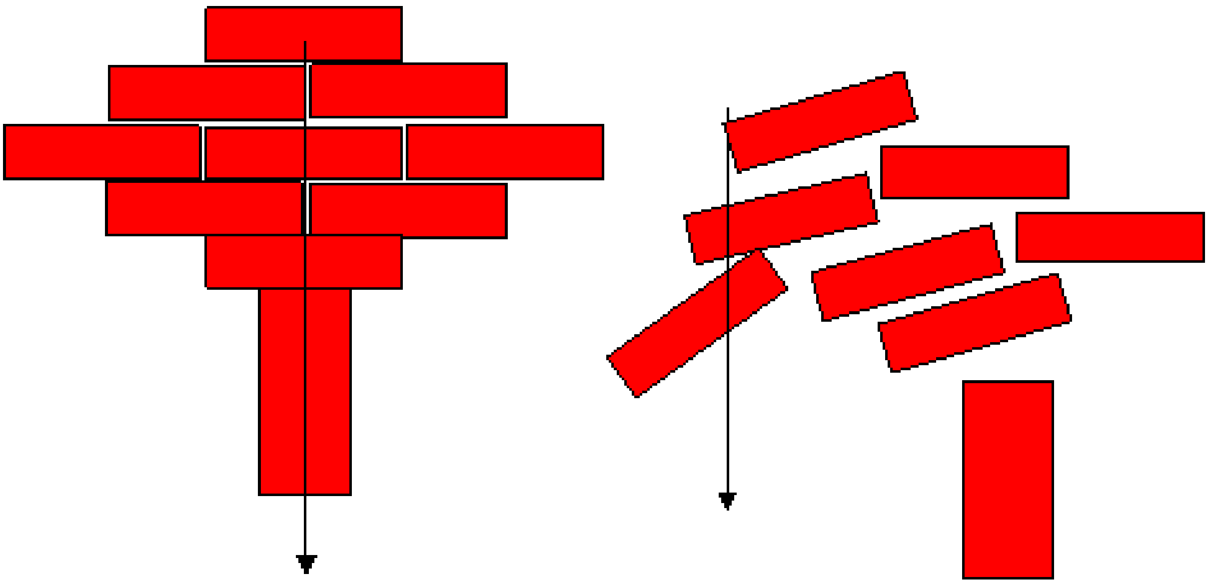
Active (Experiment has working equipment at the time of last update, and is available for events.)

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!

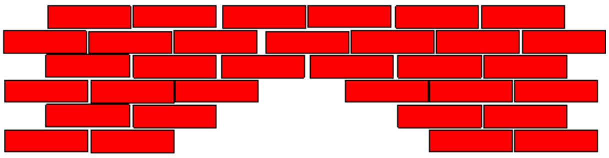
Note: some of the pictures in the box are arch bridges that go with the arch bridge experiment (which doesn't have its own box). Try not to confuse the two - the forces aren't the same in each.

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)

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. Wipe down the ear cups and headband with disinfecting wipes between sessions.

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)

Electrical Parts

Read before demonstrating any experiment that uses mains electricity

Last initially checked on 2024-07-09 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-07-10 by Timothy Wong (chw55@cam.ac.uk)

Tags

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

Other

Requires Electricity

Equipment Needed

Mains (240 V) power supply.

Experiment Explanation

Some experiments require electricity from a mains power (240 V) supply. Read this RA along with the experiment RA before demonstrating.

Risk Assessment

Hazard: Faulty/loose wiring and equipment

Description: Risk of fire or electrocution. This risk applies only to mains voltage equipment that plugs into the 240V mains supply; any part of an experiment that comes into direct contact with the public will use a power supply with a safe low voltage output.

Affected People: All

Before Mitigation: Likelihood: 3, Severity: 5, Overall: 15

Mitigation: DEMONSTRATOR must visually inspect all electrical equipment before using it. Please look for loose cables, bare wires or anything else suspicious. If you spot faults then please do not use that equipment, and report it to a committee member.

DEMONSTRATOR to ensure that there is a PA test sticker dated within the last two years on any mains voltage equipment, or that the equipment was purchased within the last two years (should be marked with the date of purchase if there is not a PA test sticker). If the equipment was PA tested or purchased more than a year ago, DEMONSTRATOR to check that there is a sticker to show that the equipment has been formally visually inspected within the last year.

DEMONSTRATOR to ensure that electrical equipment is not placed next to or under flammable materials (eg. under a jumper).

COMMITTEE to ensure that all mains voltage equipment is PA tested every two years, or if possible, annually. Newly purchased (unaltered) equipment need not be tested immediately, but should be tested, at the latest, within two years of purchase, and then every two years thereafter. If newly purchased equipment is not marked with a PA test sticker, it should be marked with the date of purchase. Electrical equipment that has been modified in any way should be PA tested before first use

COMMITTEE to ensure that, if equipment has not been PA tested within the past year, it is formally visually inspected by a committee member approved by the committee to carry out such checks, and marked with the date of inspection

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

Hazard: Water getting in contact with the equipment

Description: Risk of electrocution

Affected People: All

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

Mitigation: DEMONSTRATOR must think about the danger of water coming into contact with the equipment. Ensure electrical equipment is not near water, or on the ground in a place where water might pour in event of a nearby experiment breaking. If outdoors, DEMONSTRATOR to keep cables off ground and away from damp, especially if using the venue the next day as well (dew settles).

DEMONSTRATOR please make sure that you know the location of the electric wall socket where the equipment is plugged in.

VENUE SAFETY OFFICER should locate and make known the location of the cut-off switch for the room, if there is one.

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

Hazard: Trip hazard on cables

Description: Risk of injury or pulling things over

Affected People: All

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

Mitigation: Ensure all cables are safely taped down, take extra care in areas where people might be walking. If possible, keep cables behind experiments.

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

Risk Assessment Check History

Check 1: 2023-02-19 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-19 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-07-09 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-07-10 - Timothy Wong (chw55@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

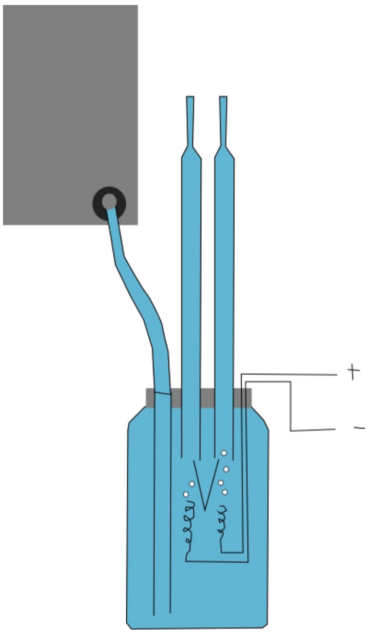
Water is H_2O and, if you apply enough energy (needed to break bonds), it can be split into its constituent parts (there should be some models).

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 a small amount of chlorine gas is theoretically possible if tap water is put in the electrolysis chamber by mistake.

Affected People: All

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

Mitigation: Only put saturated magnesium sulfate solution into the electrolysing chamber, as these ions will not decompose before the H_2O. As an extra precaution, use deionised water (chloride ions have been removed) instead of tap water everywhere else in the apparatus. Experiment must only be set up and operated by a trained demonstrator familiar with the apparatus and the solutions 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. Demonstrator should use ear defenders as hearing protection, 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 electric shock hazard from mains electricity due to presence of high ionic strength solution (magnesium sulfate solution conducts electricity better).

Affected People: All

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

Mitigation: Only low voltage from the power supply can come near the liquids under normal operation. 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). Affix to a stable support structure in the venue using bungee cord. 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)

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 inside area becomes wet, locate a mop and dry the area. If on grass, do not demonstrate if the ground becomes too muddy and slippery.

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, causing a choking hazard.

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)

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: 2, Severity: 3, Overall: 6

Mitigation: Ask all participants in the hand-washing activity (if doing) to ensure they do not 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 on hand when demonstrating (but put back in Safety for storage between demonstrating days). 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: Some people might be allergic to lemon juice or bicarbonate of soda.

Affected People: Public

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

Mitigation: Put up a sign warning of potential allergens in the reagents. If participant(s) are allergic, they should stand well back and not touch anything. Do not leave kids alone with the experiment.

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

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: The lemon juice and bicarbonate of soda are food-safe, but they still should not be eaten as they might be out of date and will not have been refrigerated.

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 to seek medical attention if they start to feel ill.

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)

Outdoors

Read before doing any experiment outside -

Last initially checked on 2024-07-09 by Peter Methley (pm631@cam.ac.uk) and double-checked on 2024-07-09 by Timothy Wong (chw55@cam.ac.uk)

Tags

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

Other

Outside

Equipment Needed

An outside area

Experiment Explanation

Some experiments can be demonstrated outside. Read this RA along with the experiment RA before demonstrating outside.

Risk Assessment

Hazard: Hard and potentially uneven floor

Description: Risk of potentially enhanced injury if person falls over whilst engaging with experiment.

Affected People: All, particularly children

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

Mitigation: Ensure the experiment is set up on flat floor, away from potential trip hazards (e.g. steps) or drops (e.g. gutters). If experiment involves lots of motion (e.g. spinny chair), take extra care while supervising visitors, and do not leave the experiment unattended. If the experiment is to be held and carried around (e.g. floating experiments such as prism goggles) then demonstrator should ensure that the experiment is being done safely, avoiding e.g. accidentally walking into a gutter.

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

Hazard: Weather (Part I)

Description: Rain and/or ice could make the outside floor slippery. Wind could blow objects into people or push visitors off of relevant apparatus.

Affected People: All

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

Mitigation: >In the event of adverse weather, encourage children to behave sensibly and not run about. If the demonstrator or committee deem the weather to make the experiment too dangerous to operate, close the experiment (e.g. too windy or wet).

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

Hazard: Weather (Part II)

Description: Cold / hot weather causing adverse effects to visitors or demonstrators

Affected People: All

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

Mitigation: Demonstrators should be dressed appropriately for the weather. If hot, demonstrators should seek water from committee members. If cold, demonstrators should have sufficient layers. If very uncomfortable, demonstrators should be moved inside. Visitors should also be monitored, and offered e.g. water if severely affected by the weather.

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

Hazard: Crowds

Description: There may be a queue of people nearby, and people walking in and out of the area, posing a risk of being bumped into / invading experiment spaces.

Affected People: All (mainly visitors)

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

Mitigation: Experiments should be set up far enough away from each other such that there is minimal risk of visitors engaged in separate experiments from taking up required space from another experiment. Experiments should be set up away from the queues, and the way in/out of the building(s). If the experiment is to be held and carried around (e.g. floating experiments such as prism goggles) then demonstrator should be aware of their surroundings at all times, and ensure visitors do not accidentally hit other people potentially walking by.

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

Risk Assessment Check History

Check 1: 2023-02-19 - Emma Crickmore (elc75@cam.ac.uk), **Check 2**: 2023-02-19 - Asmita Niyogi (an637@cam.ac.uk)

Check 1: 2024-07-09 - Peter Methley (pm631@cam.ac.uk), **Check 2**: 2024-07-09 - 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 n-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 ⇔ 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)

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)

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. There should only be one knife in the box, and the demonstrator should know where it is at all times.

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, and possible allergens

Affected People: All

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

Mitigation: State reagents on a sign to highlight allergens. If participant(s) are allergic, they should stand well back and not touch anything.

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 boiling 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)

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. Wipe the ends of the pipes with some anti-bac wipes when they're done. If possible, only the demonstrator should use the pan 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

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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.

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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)

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)

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: Boris should be kept on his stand, and on stable, level ground. 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)

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)

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.

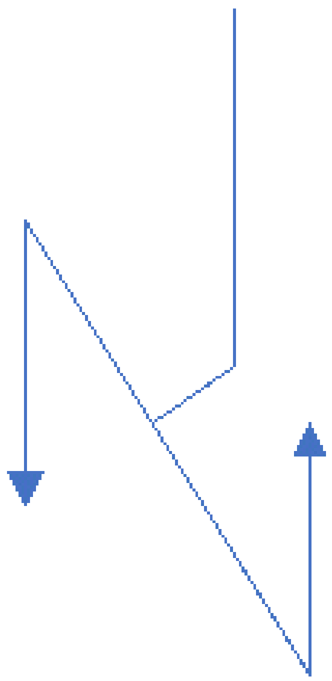
When it comes to the relative directions of the spin, they should notice that they rotate in the opposite direction to the wheel. Here you can link back to the idea of angular momentum. Explain that the total angular momentum of a system doesn't change. Initially, the child and the stool were a system 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)

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 - 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 sufficiently blunt before using. Instruct people to hold firing pin by the pipe-cleaner. Demonstrator to check no pipe-cleaner 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)

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.)

Outside

Physics

Equipment Needed

- **This experiment should 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 on a surface which can get slippery, keep a mop close to hand and cordon off the area. If done on grass, stop/relocate the experiment if the area becomes too muddy.

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)