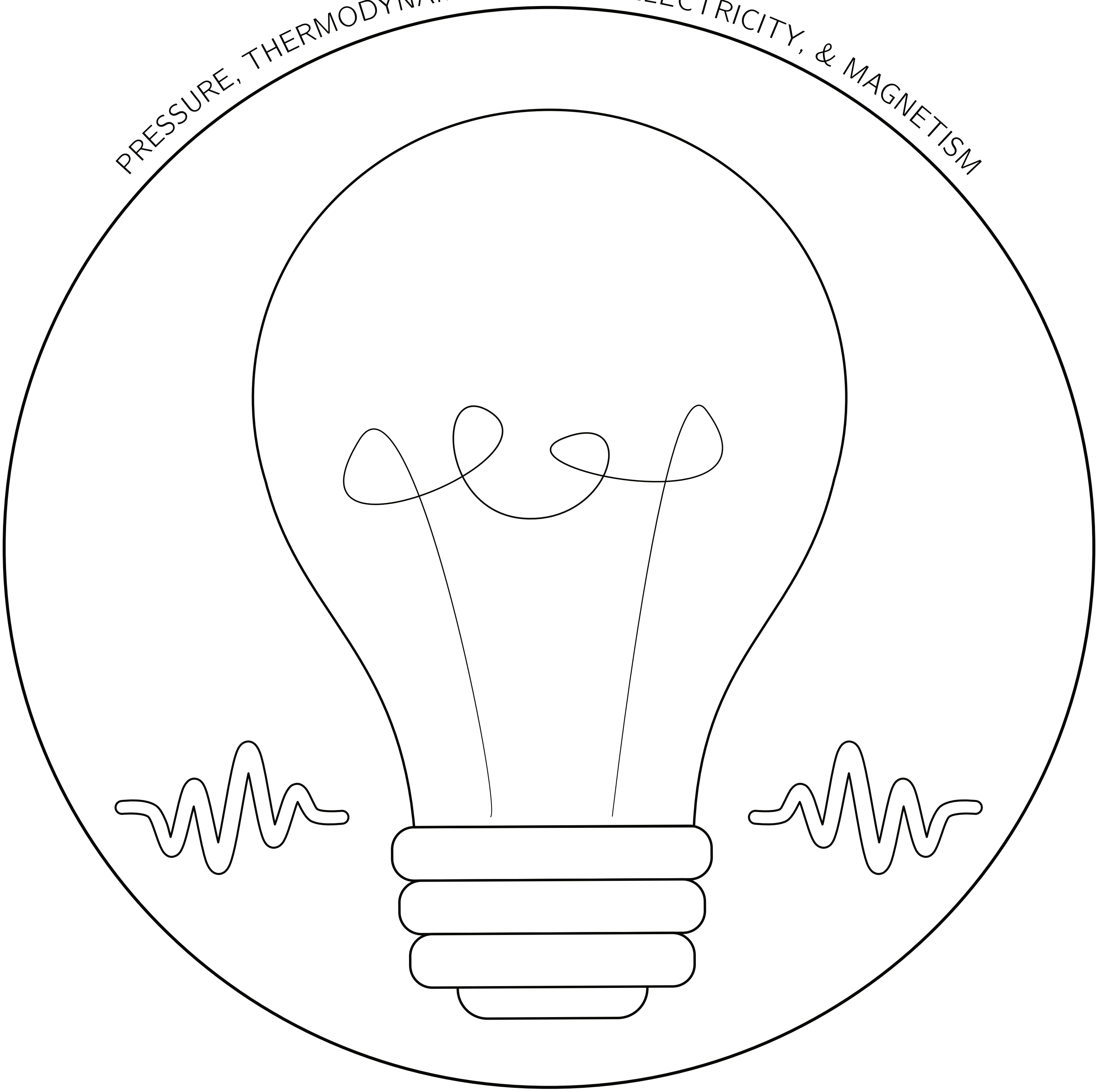
Physics 2

PRESSURE, THERMODYNAMICS, WAVES, ELECTRICITY, & MAGNETISM



SCIENCE MOM

Physics 2

Pressure, Thermodynamics, Waves, Electricity, & Magnetism

Lesson	Date	Topic	Pages
1	Wednesday, Jan 17	Introduction	5-7
2	Monday, Jan 22	What's the matter?	7-11
3	Wednesday, Jan 24	Elemental	12-15
4	Self-paced	Fun physics tricks	16-19
5	Monday, Jan 29	No such thing as cold	21-25
6	Wednesday, Jan 31	Heat transfer	26-29
7	Self-paced	Clay pot fridge	30-31
8	Monday, Feb 5	Heat capacity & phase changes	32-36
9	Wednesday, Feb 7	Laws of thermodynamics	37-40
10	Self-paced	Make your own ice cream	41-43
11	Monday, Feb 12	THERMODYNAMICS QUIZ SHOW	44-46
Unit 2 End Break			
12	Monday, Feb 19	Pressure & fluids	47-52
13	Wednesday, Feb 21	Going for a swim	53-57
14	Self-paced	Egg in a Bottle or Rising Water	58-59
15	Monday, Feb 26	Density & buoyancy	60-63
16	Wednesday, Feb 28	Ocean of air	64-67
17	Self-paced	Boat Float or Density Column	68-71
18	Monday, Mar 4	Fluids in motion	72-75
19	Wednesday, Mar 6	When push comes to shove	76-78
20	Self-paced	Ping pong tricks	79-80
21	Monday, Mar 11	PRESSURE QUIZ SHOW	81-83
Unit 3 End Break			
22	Monday, Mar 18	What's a wave?	
23	Wednesday, Mar 20	Sound	
24	Self-paced	DIY Chladni plate	
25	Monday, Mar 25	Earthquakes	
26	Wednesday, Mar 27	Light 1	
27	Self-paced	Water Xylophone	
28	Monday, Apr 1	Light 2	
29	Wednesday April 3	WAVES QUIZ SHOW	

Lesson	Date	Topic	Pages
Apr 8-12 · SPRING BREAK			
32	Monday, Apr 15	Electromagnetism 1	
33	Wednesday, Apr 17	Electromagnetism 2	
34	Self-paced	Make a magnet with a battery	
35	Monday, Apr 22	Electromagnetism 3	
36	Wednesday, Apr 24	Electromagnetism 4	
37	Self-paced	Paper flashlight	
38	Monday, Apr 29	Electromagnetism 5	
39	Wednesday, May 1	Nuclear	
40	Self-paced	Review or homopolar motor	
41	Monday, May 6	The weird world of quantum	
42	Wednesday, May 8	Final Quiz Show	

SUPPLY LIST:

Fun Physics Tricks
- Bottle with narrow neck
- Drawing supplies and paper
- Empty aluminum can
- Balloon
- Coin
- Glass cup or jar
- Teabags (the style with a tag and string attached)
- Matches or a lighter

Clay Pot Fridge
- 2 small clay pots
- 2 larger clay pots
- 2 metal lids or aluminum pie tins to cover the pots
- Enough sand to fill the space between the clay pots
- 2 small towels
- thermometer
- water

Homemade Ice Cream
- Ingredients for ice cream
- Ice
- Rock salt
- Oven mitts or towels
- Either 2 metal cans of different sizes and duct tape OR ziplock bags of different sizes

Boat Float
- Aluminum foil
- A sink or container that can be filled with water
- Coins
- Rice
- Tape
- Liquid measuring cup
- Scissors

Density Column
- 2 tall clear cups or cylindrical containers
- Sugar and water OR various liquids such as vegetable oil, and corn syrup
- Measuring cup
- Food coloring
- Spoon

Egg in a Bottle
- 2-3 hardboiled eggs (medium size)
- Bottle with an opening slightly smaller than the egg
- Small birthday candles or matches
- Matches or lighter

Rising Water:
- Dish or pie plate
- Water
- Candle that can stand upright
- A transparent jar, glass or bottle
- Food coloring (optional)
- Matches or lighter

Ping pong ball launch
- Blow dryer
- Ping pong ball
- Paper towel or toilet paper tube

Ball on a string
- Tape or glue gun
- Faucet or hose
- Ping pong ball
- String

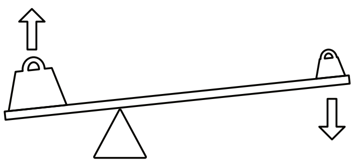
Remaining supply list and science standards to come here in later versions of the notes.

PHYSICS - THE FUNDAMENTAL SCIENCE

Physics is a broad field of science dedicated to understanding matter, space, energy, and time. It has dozens of different areas of specialization!

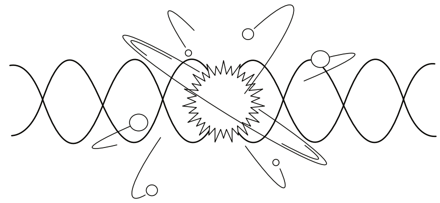
In our Physics 1 class we studied classical mechanics and had one bonus lesson on relativity (which is a pretty important concept in astrophysics). In Physics 2 we'll be covering a wide variety of topics!

CLASSICAL MECHANICS



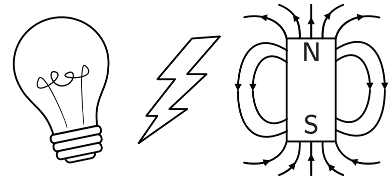
- [x] The study of how everyday objects move and behave

QUANTUM MECHANICS



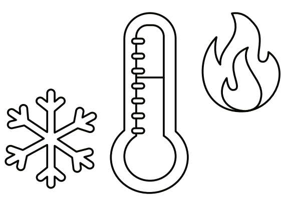
- [ ] The study of how very small particles behave

ELECTROMAGNETISM



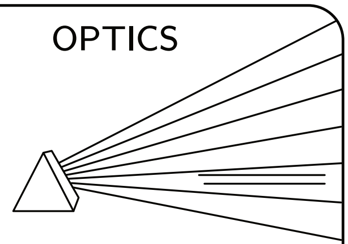
- [ ] The study of electric and magnetic fields

THERMODYNAMICS



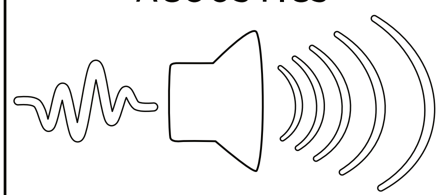
- [ ] The study of heat, energy, and entropy

OPTICS



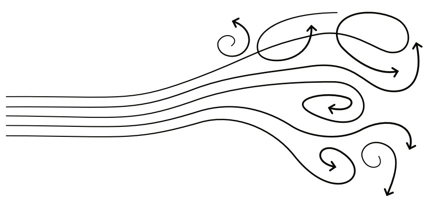
- [ ] The study of the behavior and properties of light

ACOUSTICS



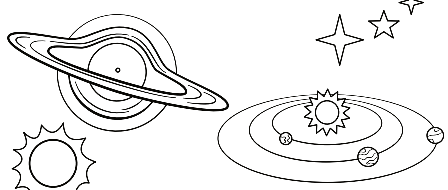
- [ ] The study of mechanical waves such as sound

FLUID DYNAMICS



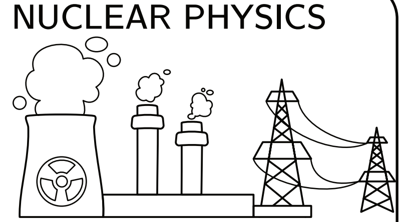
- [ ] The study of the flow of liquids and gases

ASTROPHYSICS



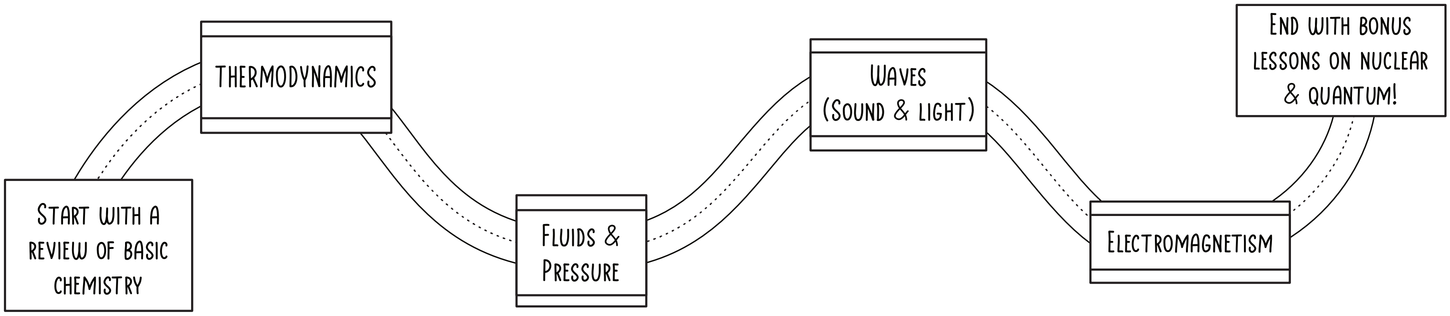
- [x] Physics in outer space! How stars, black holes, and solar systems work

NUCLEAR PHYSICS



- [ ] The study of atomic nuclei and the generation of nuclear energy

Physics 2 Road Map:



Why Physics?

WHAT DO YOU WANT FROM THIS CLASS?

Before we start, think about your **why**. Why study physics? What are your goals for this class?

Make a note or two about why you are taking this class. What do you hope to learn or experience?

MAKE A PLAN

You'll learn more about physics in this course if you are actively engaged in the learning. There are 3 great tools for this: using the notes, doing the practice problems, and completing the hands-on activities.

Consider each of these and make a plan for how to best adapt them to your circumstances and preferences. Be specific with each plan! Describe when and where you'll do coursework. Think about what you'll do if interruptions or other commitments come up.

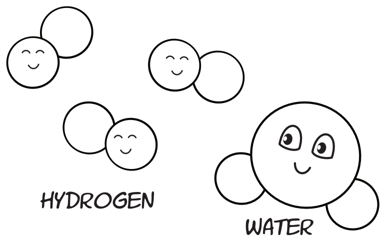
My plan for watching the lessons and using the notes:

My plan for doing the practice problems:

My plan for completing the labs or hands-on activities:

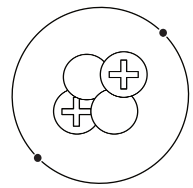
Unit 1: the chemistry you need for physics!

MOLECULE



The smallest fundamental unit of a substance, often formed by two or more atoms

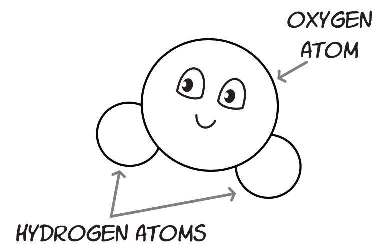
ATOM



One atom of helium

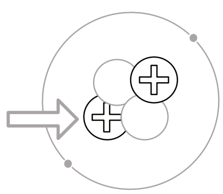
The smallest unit of an element

COMPOUND



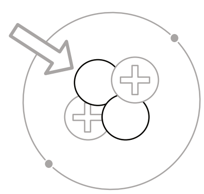
A molecule or substance made of two or more elements bonded together

PROTON



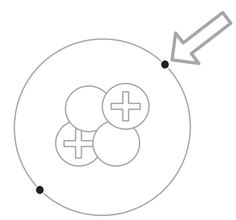
Positively charged particle in the nucleus of an atom

NEUTRON



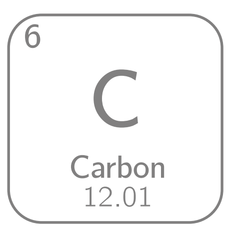
A particle with no charge in the nucleus of an atom

ELECTRON



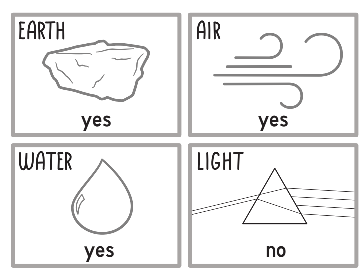
A negatively charged particle that orbits the nucleus of an atom

ELEMENT



A substance that cannot be broken down by chemical reactions

MATTER



Material that takes up space and can be weighed (it has mass)

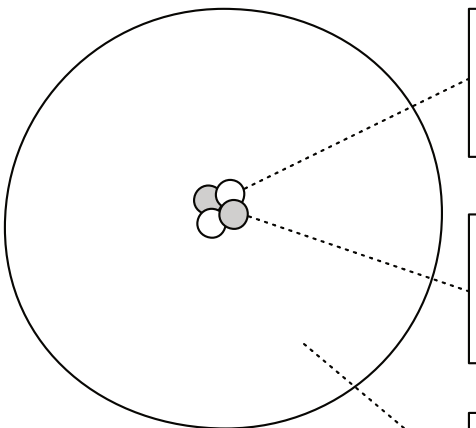
WHAT'S THE MATTER?

FILL IN THE BLANKS:

nucleus *neutrons* *properties* *sharing* *atoms* *bond* *protons*

Atoms are the smallest units of matter that retain the physical properties of an element. They contain a nucleus which has positively charged protons and neutrally charged neutrons. Negatively charged electrons surround the nucleus. Two or more atoms can bond together by sharing or transferring electrons.

THE PARTS OF AN ATOM:



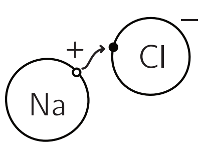
+ charge
PROTONS – positive charge and a mass of about 1 atomic mass unit. Located in the nucleus.

no charge
NEUTRONS – no charge and a mass of about 1 atomic mass unit. Located in the nucleus.

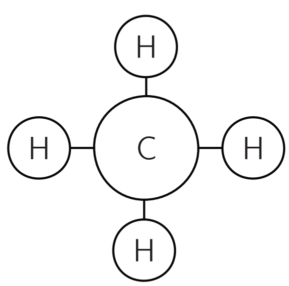
– charge
ELECTRONS – negative charge and almost no mass. Super tiny! Located in a cloud around the nucleus.

TYPES OF CHEMICAL BONDS

Electrons transferred from one atom to another

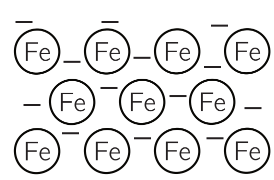


Makes + and – ions!

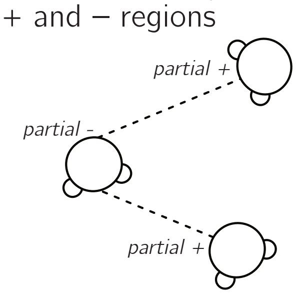


Share electrons between atoms

Electrons are shared between all atoms in an "electron sea"



Weak attraction between partially + and – regions



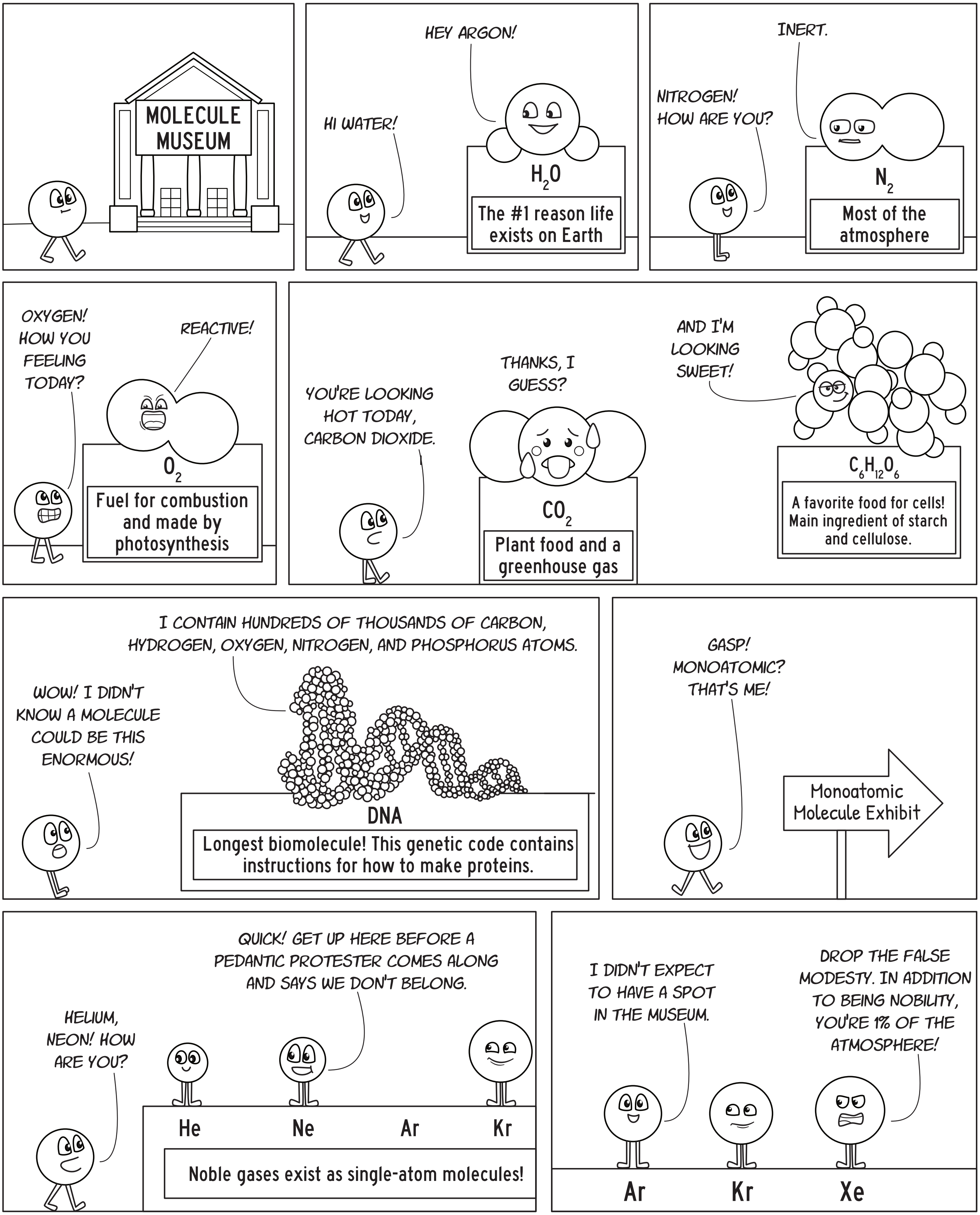
IONIC

COVALENT

METALLIC

HYDROGEN

Famous Molecules



Practice Problems – What's the Matter?

1. What is the smallest unit of an element that retains the properties of that element?
   - A. A compound
   - B. An electron
   - C. A molecule
   - D. An atom

2. What is the center of an atom called?
   - A. Electron
   - B. Nucleus
   - C. Proton
   - D. Neutron

3. Which statement best describes the term molecule?
   - A. The smallest fundamental unit of a substance, often made of 2 or more atoms
   - B. The smallest particle of a chemical element
   - C. Something that cannot be broken down into simpler substances
   - D. Something that is always made of the same type of atom

4. Which particles are found in the nucleus of an atom?
   - A. Protons and Neutrons
   - B. Electrons and Protons
   - C. Neutrons and Electrons
   - D. Protons and Photons

5. What is the charge of an electron?
   - A. Positive
   - B. Negative
   - C. Neutral
   - D. Variable

6. All atoms of the same element contain the same number of:
   - A. Electrons
   - B. Protons
   - C. Neutrons
   - D. Ions

7. What is the charge of a neutron?
   - A. Positive
   - B. Negative
   - C. Neutral
   - D. Variable

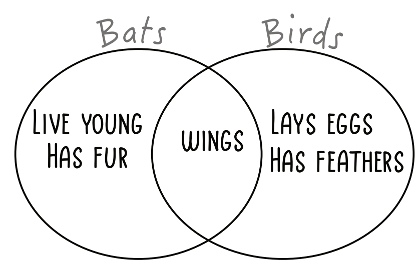
Practice Problems – What's the Matter?

8. How many hydrogen atoms are present in a molecule of glucose ($C_6H_{12}O_6$)?
   A. 6
   B. 12
   C. 18
   D. 24

9. Which type of chemical bond could be described as sharing of a sea of electrons amongst many positively charged ions?
   A. Ionic Bond
   B. Metallic Bond
   C. Covalent Bond
   D. Hydrogen Bond

10. Which of the following is not composed of atoms?
    A. Water
    B. Rock
    C. Sunlight
    D. Plastic

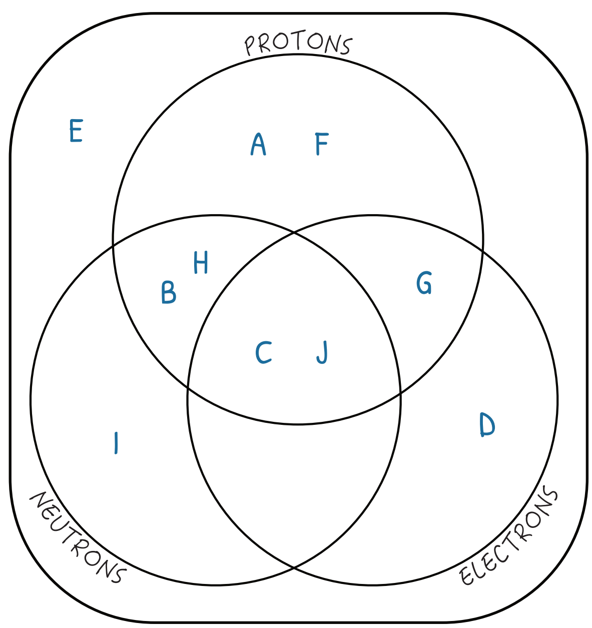
A VENN DIAGRAM USES OVERLAPPING SHAPES TO SHOW RELATIONSHIPS BETWEEN 2 OR MORE THINGS. SHARED CHARACTERISTICS ARE PLACED IN THE OVERLAPPING REGION:



11. Bonds between atoms primarily involve:
    A. Sharing or transferring protons
    B. Sharing or transferring neutrons.
    C. Sharing or transferring electrons.
    D. Sharing or transferring photons.

12. Which statement is more correct?
    A. An atom contains very little empty space.
    B. By volume, an atom is mostly empty space.

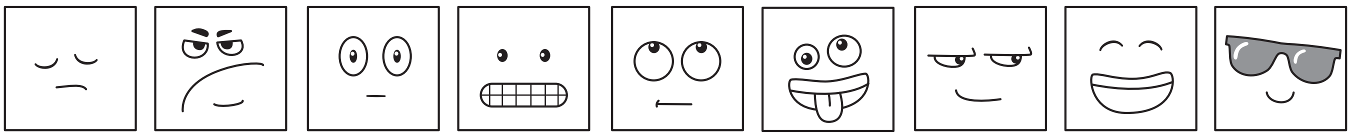
13. Place each letter in the appropriate part of the Venn diagram of protons, neutrons, and electrons.
    A. Has a positive charge
    B. Contributes significant mass to the atom
    C. Is a subatomic particle
    D. Orbits the nucleus
    E. Is a molecule
    F. Determines the atomic number
    G. Has a charge
    H. Is in the nucleus of an atom
    I. Has no charge
    J. Found in an oxygen atom



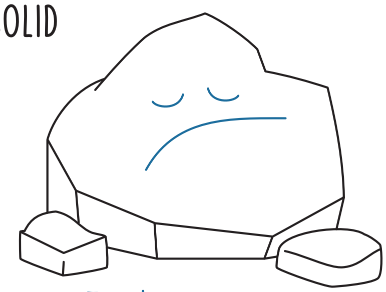
Elemental

Atoms and molecules can exist as different **states of matter**. The most commonly-encountered states are solid, liquid, and gas. But other states (such as plasma) exist as well. Substances that cannot be broken down further by chemical reactions are called **elements.**

Complete the cards below for each state of matter. Would you describe their shape and volume as fixed or flexible? On a scale of one (least energetic) to five (most energetic), how would you rate them for particle movement? Draw a face on each state of matter avatar.



SOLID

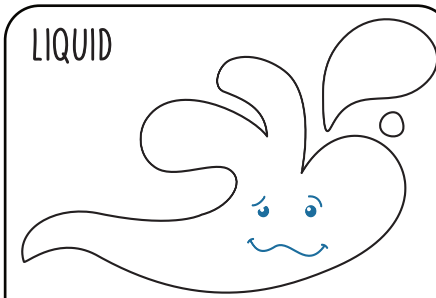


SHAPE: Fixed

VOLUME: Fixed

ENERGY LEVEL:

LIQUID

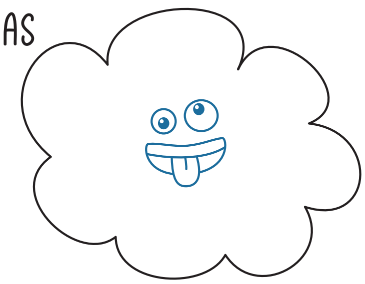


SHAPE: Flexible

VOLUME: Fixed

ENERGY LEVEL:

GAS



SHAPE: Flexible

VOLUME: Flexible

ENERGY LEVEL:

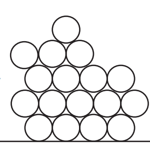
THE ENERGY OF MOVING PARTICLES IS CALLED KINETIC ENERGY.

The boxes below show the movement of the molecules in the same substance at different temperatures. Write the name of each state of matter and then draw lines to match them to their corresponding tag or label below.

Solid

Ex. Iron, wood, rubber, granite

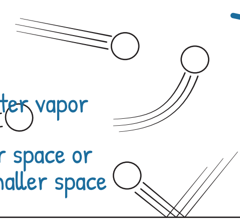
Can be in crystal structure (regular pattern) or not (amorphous)



Gas

Ex. Air, helium, steam or water vapor

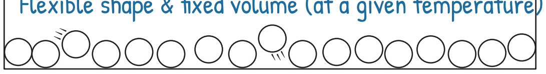
Can expand to occupy larger space or be compressed to occupy smaller space



Liquid

Ex. Water, rubbing alcohol, oil, lava

Flexible shape & fixed volume (at a given temperature)



Particles slide past each other but are still close together

Particles move quickly and are often very far apart from each other

Particles vibrate in place and have low kinetic energy

THE PERIODIC TABLE OF ELEMENTS

1 **H** Hydrogen																	2 **He** Helium
3 **Li** Lithium	4 **Be** Beryllium											5 **B** Boron	6 **C** Carbon	7 **N** Nitrogen	8 **O** Oxygen	9 **F** Fluorine	10 **Ne** Neon
11 **Na** Sodium	12 **Mg** Magnesium											13 **Al** Aluminum	14 **Si** Silicon	15 **P** Phosphorus	16 **S** Sulfur	17 **Cl** Chlorine	18 **Ar** Argon
19 **K** Potassium	20 **Ca** Calcium	21 **Sc** Scandium	22 **Ti** Titanium	23 **V** Vanadium	24 **Cr** Chromium	25 **Mn** Manganese	26 **Fe** Iron	27 **Co** Cobalt	28 **Ni** Nickel	29 **Cu** Copper	30 **Zn** Zinc	31 **Ga** Gallium	32 **Ge** Germanium	33 **As** Arsenic	34 **Se** Selenium	35 **Br** Bromine	36 **Kr** Krypton
37 **Rb** Rubidium	38 **Sr** Strontium	39 **Y** Yttrium	40 **Zr** Zirconium	41 **Nb** Niobium	42 **Mo** Molybdenum	43 **Tc** Technetium	44 **Ru** Ruthenium	45 **Rh** Rhodium	46 **Pd** Palladium	47 **Ag** Silver	48 **Cd** Cadmium	49 **In** Indium	50 **Sn** Tin	51 **Sb** Antimony	52 **Te** Tellurium	53 **I** Iodine	54 **Xe** Xenon
55 **Cs** Caesium	56 **Ba** Barium		72 **Hf** Hafnium	73 **Ta** Tantalum	74 **W** Tungsten	75 **Re** Rhenium	76 **Os** Osmium	77 **Ir** Iridium	78 **Pt** Platinum	79 **Au** Gold	80 **Hg** Mercury	81 **Tl** Thallium	82 **Pb** Lead	83 **Bi** Bismuth	84 **Po** Polonium	85 **At** Astatine	86 **Rn** Radon
87 **Fr** Francium	88 **Ra** Radium		104 **Rf** Rutherfordium	105 **Db** Dubnium	106 **Sg** Seaborgium	107 **Bh** Bohrium	108 **Hs** Hassium	109 **Mt** Meitnerium	110 **Ds** Darmstadtium	111 **Rg** Roentgenium	112 **Cn** Copernicium	113 **Nh** Nihonium	114 **Fl** Flerovium	115 **Mc** Moscovium	116 **Lv** Livermorium	117 **Ts** Tennessine	118 **Og** Oganesson

57 **La** Lanthanum	58 **Ce** Cerium	59 **Pr** Praseodymium	60 **Nd** Neodymium	61 **Pm** Promethium	62 **Sm** Samarium	63 **Eu** Europium	64 **Gd** Gadolinium	65 **Tb** Terbium	66 **Dy** Dysprosium	67 **Ho** Holmium	68 **Er** Erbium	69 **Tm** Thulium	70 **Yb** Ytterbium	71 **Lu** Lutetium
89 **Ac** Actinium	90 **Th** Thorium	91 **Pa** Protactinium	92 **U** Uranium	93 **Np** Neptunium	94 **Pu** Plutonium	95 **Am** Americium	96 **Cm** Curium	97 **Bk** Berkelium	98 **Cf** Californium	99 **Es** Einsteinium	100 **Fm** Fermium	101 **Md** Mendelevium	102 **No** Nobelium	103 **Lr** Lawrencium

MATCH EACH ELEMENT SYMBOL WITH THE CORRESPONDING NAME AND FACT:

7 N	**Carbon** - Forms strong covalent bonds with many other elements and with itself. The primary element in biomolecules and living organisms.
17 Cl	**Hydrogen** - The lightest and most abundant element in the universe. The Sun, Jupiter, and Saturn are all mostly made of hydrogen.
6 C	**Nitrogen** - 78% of the atmosphere is nitrogen gas (N_2). This element is also an essential ingredient of proteins and DNA.
1 H	**Chlorine** - Widely used to purify water and as a cleaning agent. In pure form, it is toxic and highly reactive.
8 O	**Oxygen** - Approximately 21% of the atmosphere is made from this element. It is reactive and forms many compounds with other elements.
94 Pu	**Iron** - This magnetic element is abundant in the Earth's crust and essential for many animals because of it's role in transporting oxygen in the blood.
26 Fe	**Plutonium** - Highly radioactive. Used in nuclear reactors and weapons.

Practice Problems – Elemental

1. Which best defines an element?
   A. A pure substance containing only one type of atom
   B. Two or more atoms bonded together
   C. An atom with one or more electrons removed
   D. The smallest unit of matter

2. Which is not considered an element?
   A. Salt
   B. Hydrogen
   C. Oxygen
   D. Aluminum

3. What is the smallest unit of an element that retains the properties of that element?
   A. Atom
   B. Molecule
   C. Compound
   D. Mixture

4. Which element is represented by the symbol 'Fe' on the periodic table?
   A. Fermium
   B. Lead
   C. Fluorine
   D. Iron

5. The process of a liquid turning into a gas can be called:
   A. Vaporization
   B. Melting
   C. Condensation
   D. All of the above

6. A volcano erupts and lava flows down a hillside. After a few weeks, the lava flow has become solid rock. What phase change describes this change?
   A. Boiling
   B. Condensation
   C. Freezing
   D. Melting

7. How many elements are in a water molecule?
   A. One
   B. Two
   C. Three
   D. Four

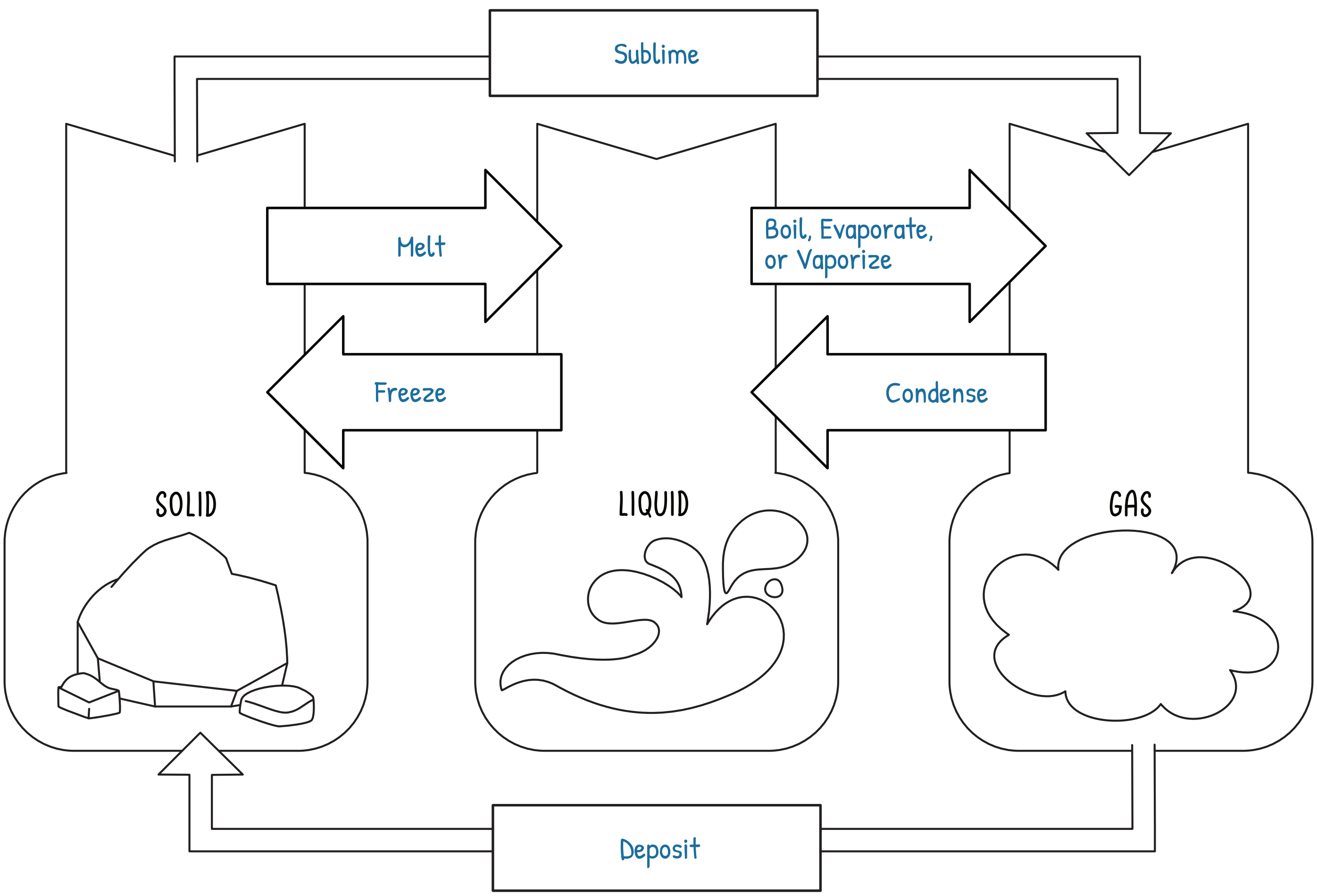
8. What happens to particles when a substance changes from solid to liquid?
   A. They move closer together and more slowly
   B. They spread out and move slower
   C. They move closer together and faster
   D. They spread out and move faster

9. Which element is known for being the lightest and having the atomic number 1?
   A. Helium
   B. Hydrogen
   C. Oxygen
   D. Carbon

10. *Knowing the terms for changes of state is an important skill for our next unit! Use the vocabulary words listed below to label the changes between states in the boxes or arrows.*

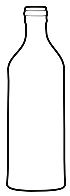
    Note: one of the arrows will have three words.

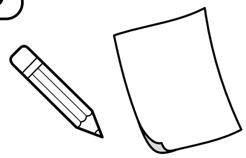
Melt	*Freeze*	*Evaporate*	*Condense*	*Sublime*	*Deposit*	*Boil*	*Vaporize*

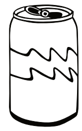


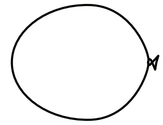
FUN PHYSICS TRICKS

MATERIALS

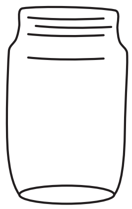

1 bottle with a narrow neck

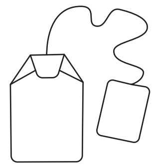

Drawing supplies and paper

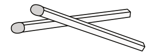

An empty aluminum can


1 balloon or a short length of plastic pipe


A coin


1 glass cup or jar


1 teabag made from filter paper and of the style that is folded over. A plastic or square teabag won't work!

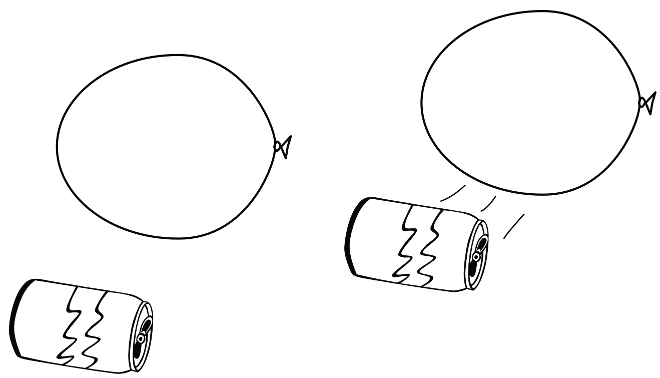

Matches or a lighter

GOALS

- Experience curiosity and wonder about physics!
- Get hands-on experience with physics principles that we will learn about later in this course.
- Bonus: Learn 5 tricks that can stump your friends and family members!

1 Aluminum Can Mover

Can you move an empty aluminum can across a table without blowing on it or touching it?



1. Place an empty soda can on a horizontal surface so that it is laying on its side.

2. Blow up a balloon and tie off the end.

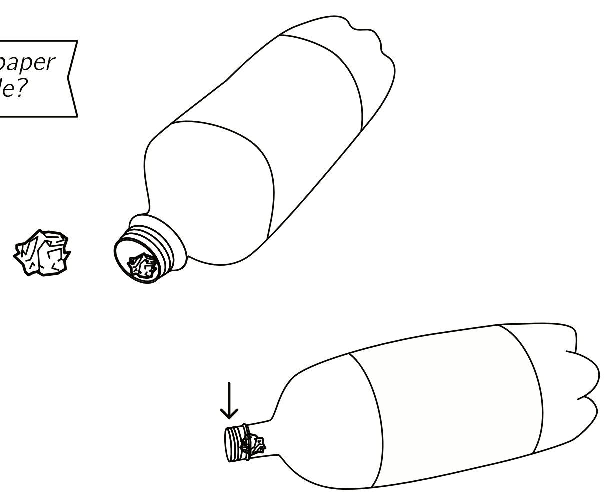
3. Rub the balloon back and forth on cloth or hair to build up a static charge.

4. Hold the balloon close to the can (but don't touch it!) and then move it away from the can. The can will roll towards the balloon.

Tip: If you do not have a balloon, a piece of plastic pipe will also gather a static charge.

2 Paper Wad Challenge

Can you blow the wad of paper into the empty water bottle?



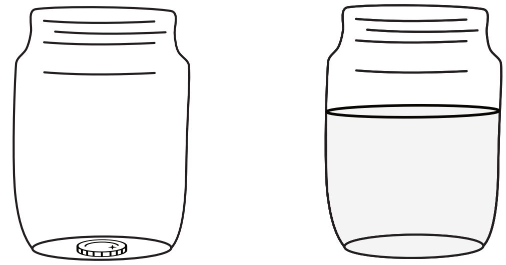
1. Crumple up a small piece of paper and place it in the mouth of an empty 1 L or 2 L bottle laying on its side. The ball of paper should be about 1/3 the size of the opening of the bottle.

2. Challenge a friend to get the paper into the bottle by blowing on it.

3. After they fail, demonstrate the correct way to blow in the paper by blowing gently from directly above the mouth of the bottle.

3 Disappearing Coin

Watch a coin disappear!



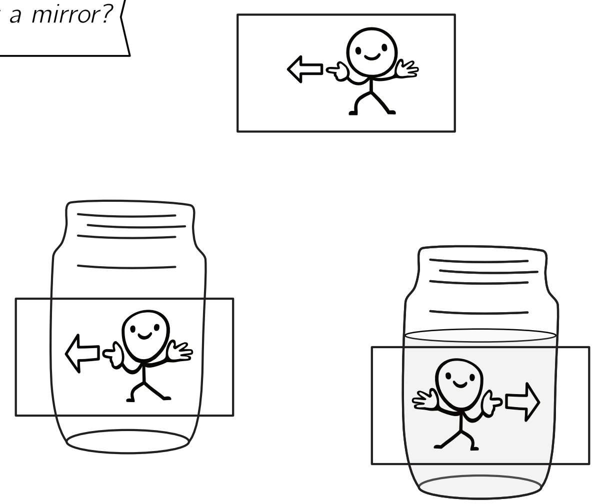
1. Place the coin on a table or counter.

2. Place a clear glass or jar over the coin and ask a person to watch the coin from the side of the jar (rather than looking straight down at the coin)

3. Fill up the jar with water. Do they still see the coin?

4 Image Reverser

Can you reverse an image without a mirror?



1. Draw an image on a piece of paper that is not symmetrical.

2. Get a clear, cylindrical glass, jar, or vase.

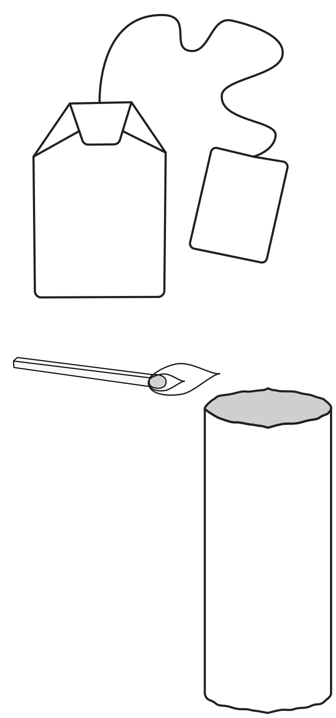
3. Place the image about 10 cm behind the glass. It should look about the same.

4. Now pour water into the glass and watch as the image changes directions!

Note, that you might have to move the drawing closer or further to the glass to see the effect. Experiment until you see the reverse image!

5 Flying Tea Bag

Can you make a tea bag launch into the sky by lighting it on fire?



This activity must be done with adult supervision!

1. Unfold the teabag and remove the string.

2. Empty the tea out. It can be placed in a coffee filter. Pour hot water over and let the water filter through to enjoy a cup of tea!

3. Unfold and straighten out the teabag into a cylinder. Then stand it up vertically. What do you predict would happen if you lit the teabag on fire?

4. Check to be sure that the area surrounding the teabag is open and uncluttered. There should be no flammable material within 7 feet of the teabag.

5. Carefully use a match to light the top of the teabag. Stand back and watch the results!

YOUR THOUGHTS & NOTES!

Tale a moment to make some notes!

Color in the stars to give each physics trick a rating for how satisfying it was. Which one was your favorite? Which of these did you find the most surprising?

Are there any tips you'd give someone else who was trying out these tricks for the first time? Anything you'd like to remember if you were to do these again later?

Most important, what questions did these activities spark? What did you notice, what did you wonder about? Do you have any ideas for why these worked?

You don't need to figure out the answers for how they worked right now. We'll be revisiting each of these physics tricks later in our class!

YOUR RATING
FROM ONE STAR (NOT SATISFYING) TO 5 STARS (VERY SATISFYING!)

1 **ALUMINUM CAN MOVER** ☆☆☆☆☆

Tips for next time (optional): ______________________

Something you noticed or wondered about: ______________________

How or why did it work? Make a guess! ______________________

____

2 **PAPER WAD CHALLENGE** ☆☆☆☆☆

Tips for next time (optional): ______________________

Something you noticed or wondered about: ______________________

How or why did it work? Make a guess! ______________________

____

YOUR THOUGHTS & NOTES!

3 Disappearing Coin

☆☆☆☆☆

Tips for next time (optional): ______

Something you noticed or wondered about: ______

How or why did it work? Make a guess! ______

______

4 Mirror Image

☆☆☆☆☆

Tips for next time (optional): ______

Something you noticed or wondered about: ______

How or why did it work? Make a guess! ______

______

5 Flying Teabag

☆☆☆☆☆

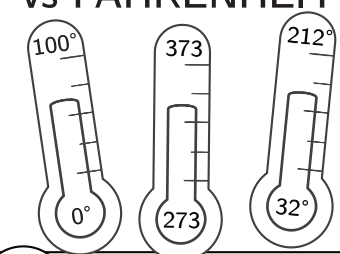
Tips for next time (optional): ______

Something you noticed or wondered about: ______

How or why did it work? Make a guess! ______

______

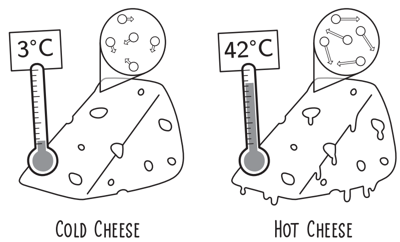
CELSIUS vs KELVIN vs FAHRENHEIT



K °C °F

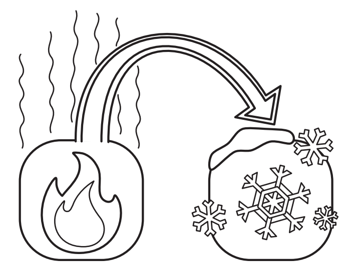
Three different systems for measuring temperature

TEMPERATURE



A measure of the average kinetic energy of the particles in a system.

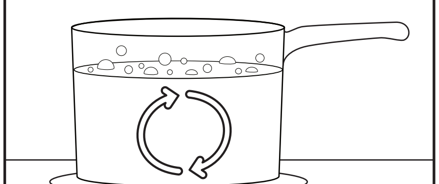
HEAT



cal or J

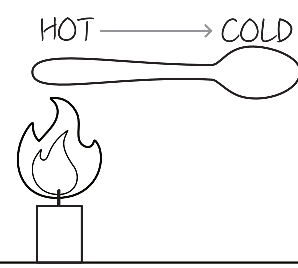
Energy moving from one object to another because of a difference in temperature.

CONVECTION



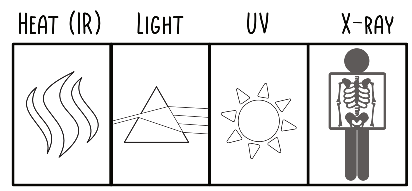
Heat transfer by the movement of fluids (gas or liquid)

CONDUCTION



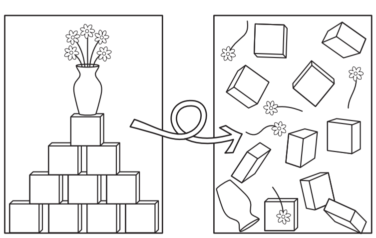
The movement of heat or electricity through a material.

RADIATION



Energy transmitted by electromagnetic waves

ENTROPY



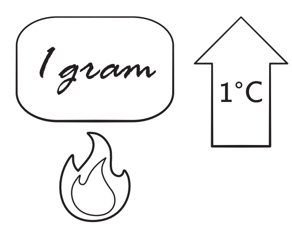
S

A measure of the disorder or randomness in a system

INTERNAL ENERGY

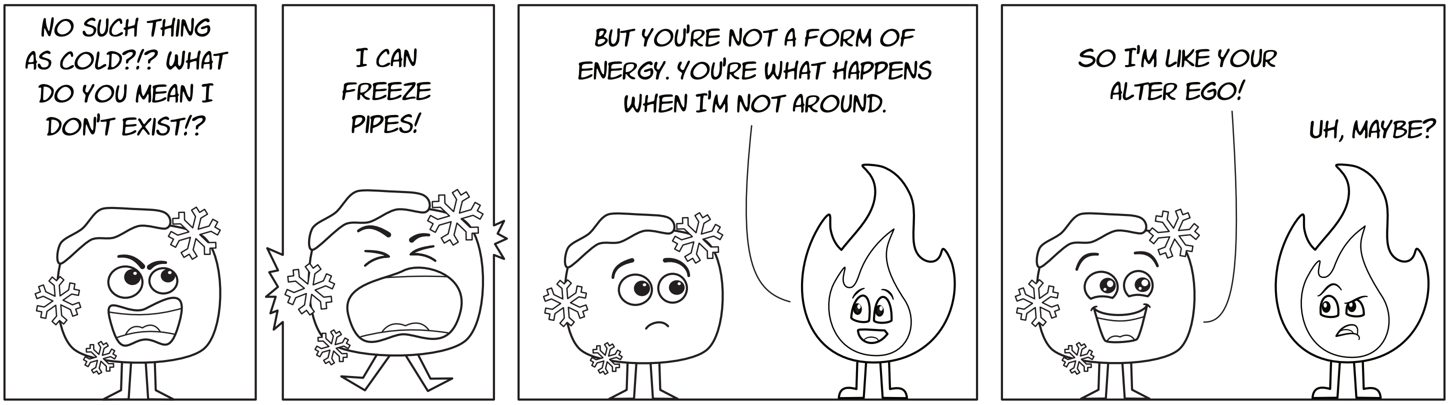
The total kinetic and potential energy of the particles in a system.

SPECIFIC HEAT CAPACITY



The amount of heat required to raise the temperature of 1 gram by 1 °C

No Such Thing as COLD



FILL IN THE BLANKS:

molecules *temperature* *energy* *cold* *absence* *higher* *kinetic*

Temperature is the __kinetic__ energy of the __molecules__ in a substance. The faster the molecules move, the more kinetic __energy__ they have and the __higher__ their measured __temperature__ will be. People often talk about hot and __cold__ as being opposite of each other. But heat is a form of energy. Cold is not. In reality, cold is just the __absence__ of heat.

Record some facts about each temperature measurement system:

C° Celsius (also called centigrade)

0 is freezing point of water, 100 is boiling point.

Most widely-used temp scale in the world.

Invented by Anders Celsius in 1742.

F° Fahrenheit

Has 180 degrees between freezing (32˚) and boiling point (212˚) of water.

Oldest temp scale (invented in 1724)

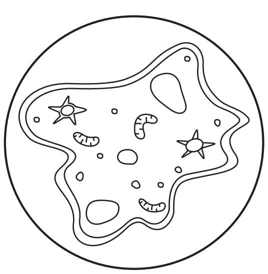
Used primarily in United States.

K Kelvin

Used in scientific fields, the SI unit for temperature.

No negative numbers in this scale. Zero Kelvin is known as "absolute zero." Nothing can be colder.

K =C + 273.15

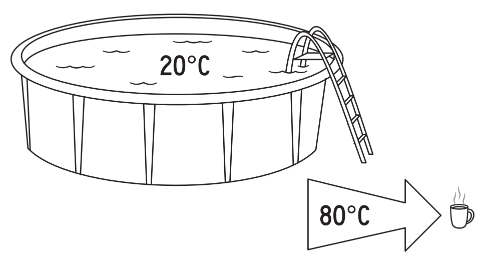


Consider an amoeba that can survive in water as long as the temperature stays ABOVE 15° C (59° F).

Your job is to keep the amoeba alive overnight and you have 2 choices for where to place it:

A 2,000 liter tepid pool of water that is 20° C (68° F)

A ½ liter of very hot water heated to 80° C (176° F)

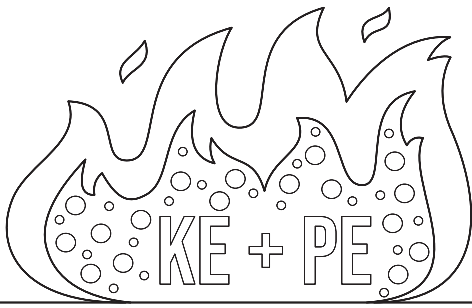


WHICH CONTAINER WOULD KEEP THE AMOEBA WARM THE LONGEST AND WHY? The swimming pool would stay warmer longer because it takes longer to change the temperature of a large body of water than a smaller one. The internal energy of an object is the energy from the movement and interactions of the molecules. This is why a large iceberg has more internal energy than a cup of hot coffee, and a 2,000 liter pool has more than a ½ liter of hot water.

INTERNAL ENERGY VS HEAT

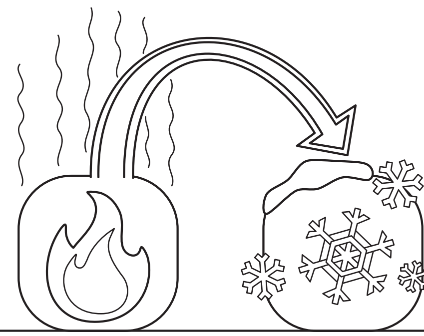
LABEL EACH CARD WITH THE CORRECT TERM AND DEFINITION, THEN DESCRIBE THEIR SIMILARITIES AND DIFFERENCES.

INTERNAL ENERGY



The total kinetic energy (temperature) and potential energy (ex. chemical bonds) of the particles in a system.

HEAT



Energy moving from one system to another because of a difference in temperature.

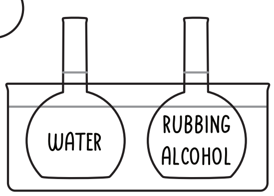
SOMETHING SIMILAR: Both measured in Joules.

SOMETHING DIFFERENT: Heat is a process. Internal energy is the total energy of a system or object.

THERMAL EXPANSION

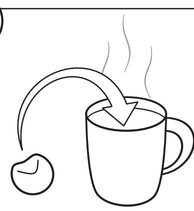
Record what happens in each case below. Is it what you expected?

1



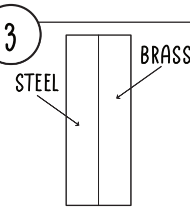
COLD FLASKS OF FLUID ARE PLACED IN A HOT WATER BATH.

2



A DENTED PING PONG BALL IS PUT IN ALMOST BOILING WATER.

3



A BIMETALLIC STRIP OF METAL IS HEATED

The rubbing alcohol rises higher than the water

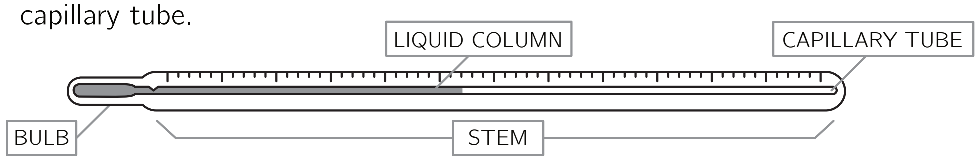
Ping pong ball inflates

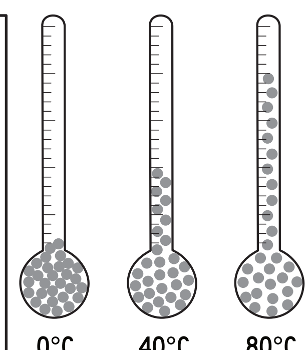
Strip of metal bends because brass expands more than steel

HOW A THERMOMETER WORKS

A thermometer has a bulb connected to a narrow capillary tube. The tube contains both gas (usually nitrogen) and a liquid such as alcohol, kerosene, or mercury.

As temperature increases, the molecules in the liquid move faster and take up more space. The gas molecules are also moving faster, but since they were so spread out to begin with, they simply move faster within a smaller space as the liquid moves up the capillary tube.





Practice Problems – No such thing as cold

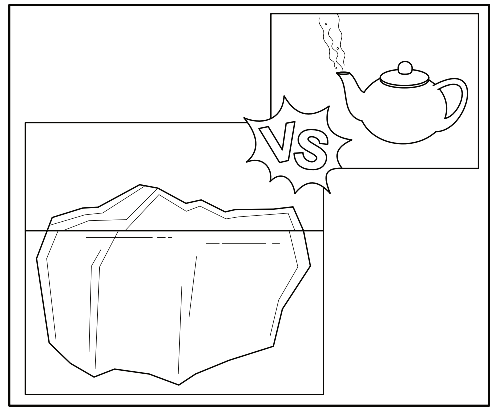
① List 3 examples of thermal expansion that occur in every day life?

Examples could include joints or gaps in sidewalks and bridges, which prevent the structures from cracking due to temperature changes. The shape of overhead power lines (on cold days there is less sag, more on warmer days), railway tracks have gaps between sections as well so they don't heat and warp. Sea level rises as the ocean warms etc.

② What has a higher **temperature**, an iceberg 1 kilometer wide or a tea kettle with 0.5 liters of boiling water? Explain.

The tea kettle of boiling water is hotter than the ice. The obvious answer here is correct!

Boiling water has a higher temperature than ice. Another way to say this is that the average kinetic energy of the molecules in the teakettle is higher than in the iceberg.



③ What has more total **internal energy**, a large iceberg that is 1 km wide or a teakettle with 0.5 liters of boiling water?

Explain. Although the average kinetic energy of the molecules in an iceberg is lower, the enormous number of molecules in the iceberg means their TOTAL kinetic and potential energy (internal energy) is higher than the tea kettle. To use an over-simplistic analogy: 5 molecules with a rating of 10 each (high energy) have less total energy ($5 \cdot 10 = 50$ units) than 1 million molecules with a rating of 1 for lower energy ($1 \cdot 1$ million $= 1$ million units)

Note: This is a hypothetical question or thought experiment. In real life applications, internal energy is challenging to quantify and is often measured indirectly (such as by changes to volume or temperature).

④ Absolute zero is sometimes defined as the temperature at which:

A. Molecular motion would cease.

B. Thermal energy is at its maximum

C. Heat transfer is at its maximum

D. Thermal expansion is rapid

In theory, absolute zero is the temperature at which molecular motion would cease entirely. However, according to quantum mechanics, molecules still retain movement and energy (called zero-point energy) even at absolute zero. This motion is not thermal (i.e., not related to heat), but rather arises from the inherent principles of quantum mechanics.

Experiments have managed to cool substances to temperatures a fraction of a degree above absolute zero. According to our current scientific understanding, it's impossible to reach absolute zero.

⑤ What is heat?

A. The kinetic energy of an object

B. The movement of energy from one object to another

C. The energy arising from the position and interactions of the molecules within an object

⑥ What is temperature a measure of?

A. The total energy of a substance

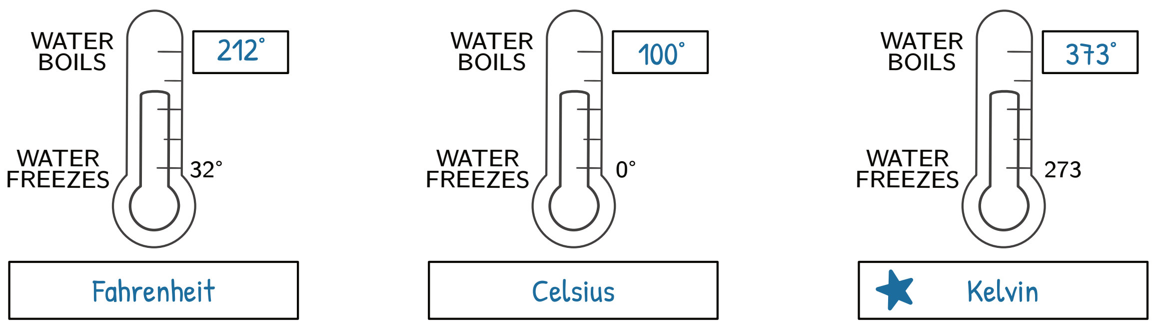
B. The transfer of thermal energy between two systems

C. The average kinetic energy of the molecules in a substance

D. The lack of energy in a substance

Practice Problems – No Such Thing As Cold

7. Label the three thermometers according to their temperature scales (°C, °F, or K) and write the temperature at which water boils. Then put a star by the scale that doesn't have negative numbers.



8. What causes thermal expansion in substances?
   - A. Loss of heat
   - B. Reflection of heat
   - C. Decrease in molecular motion
   - D. Increase in molecular motion

9. What happens to the motion of molecules when the temperature of a substance increases?
   - A. The motion decreases
   - B. The motion increases
   - C. The motion remains constant
   - D. The motion changes directions

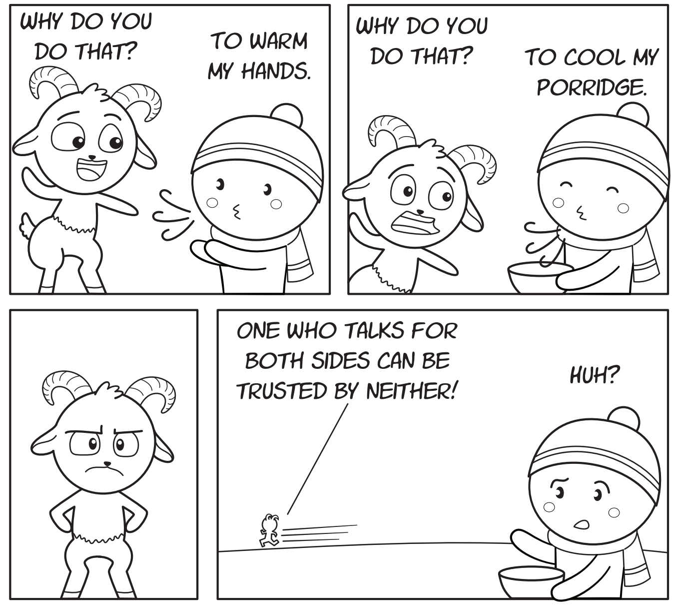
10. In the thermal expansion experiment, why does the level of the fluid rise when the flask is placed in hot water?
    - A. The temperature increases
    - B. The temperature decreases
    - C. The molecules move more quickly and are further apart from each other
    - D. The molecules move more slowly and are closer together to each other
    - E. Both B and D
    - F. Both A and C

Heat Transfer

In Aesop's fable "The Satyr and the Traveler," a man is wandering in a forest during winter. A satyr sees him and invites him to its home. The satyr observes the man blow on his fingers to warm them and then blow on soup to cool it.

The satyr is bothered by the duplicity and leaves saying that it can't trust a being that blows both hot and cold in the same breath!

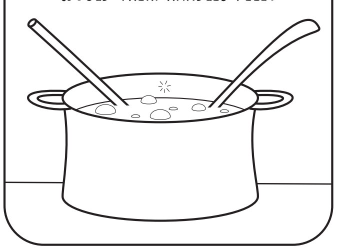
In actuality, the temperature of the man's breath was always the same. How can you explain the fact that the same breath can be used both to cool and warm something?



Because heat always flows from the warmer object to the cooler object. If the object is cooler than the breath, the breath will warm the object. If the object is hotter than the breath, then the breath will be warmed as it blow across (and the object will be cooled because it warmed the breath).

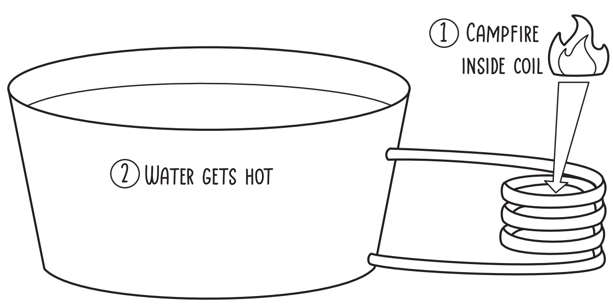
*What is your prediction for each situation below? Check the box you agree with, then describe how the heat is being **transferred**.*

2 SPOONS ARE PLACED IN A POT OF BOILING WATER FOR 5 MINUTES. HOW WOULD THEIR HANDLES FEEL?



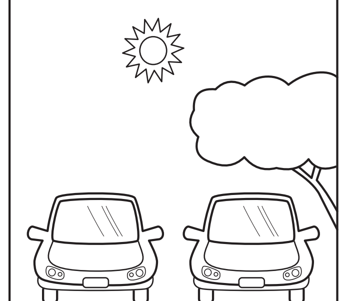
- [ ] *Both spoons are hot*
- [x] *Metal spoon is hot, wooden spoon is cool*
- [ ] *Wooden spoon is hot, metal spoon is cool*
- [ ] *Both spoons are cool*

A PORTABLE HOT TUB IS ATTACHED TO A METAL PIPE THAT HAS A COIL. IT CAN BE HEATED BY A CAMPFIRE AND DOESN'T REQUIRE ANY OTHER POWER SOURCE.



- [x] *This would work*
- [ ] *This would not work*

TWO IDENTICAL CARS ARE PARKED SIDE BY SIDE. WHICH CAR WILL BE HOTTER?



- [x] *Car in the sun*
- [ ] *Car in the shade*

What is TRANSFERRING the heat?

Rapidly moving molecules that bump into each other. (water to metal spoon, atoms of metal to other atoms of metal). The free electrons in the metal also convey heat through the metal.

Rapidly moving molecules that bump into each other. As the campfire heats the water in the coiled pipe, the hot water molecules move more rapidly. This hotter water rises, moving out to the top of the tub. This creates a current that draws cooler water into the coils from the bottom of the tub.

Light and infrared radiation (heat) pass through the window and into the car. The air molecules in the car are heated by this radiation.

The 3 main types of heat transfer are listed below. Draw lines to match the term to its corresponding tag or label.

CONDUCTION | CONVECTION | RADIATION

The transfer of heat between currents of a gas or liquid due to a difference in temperature.
ONLY IN FLUIDS

The transfer of heat between two objects in direct contact with each other.
FASTEST FORM OF HEAT TRANSFER

The transfer of heat by electromagnetic waves.
CAN TRAVEL THROUGH A VACUUM

The ability of a material to conduct or insulate heat depends on its thermal *conductivity*, which is a measure of how quickly heat can flow through the material.

Materials like copper and aluminum have high thermal conductivity and are called **thermal conductors**.

Materials such as wood, styrofoam, and air have low thermal conductivity. These are called **thermal insulators**.

SCAVENGER HUNT!

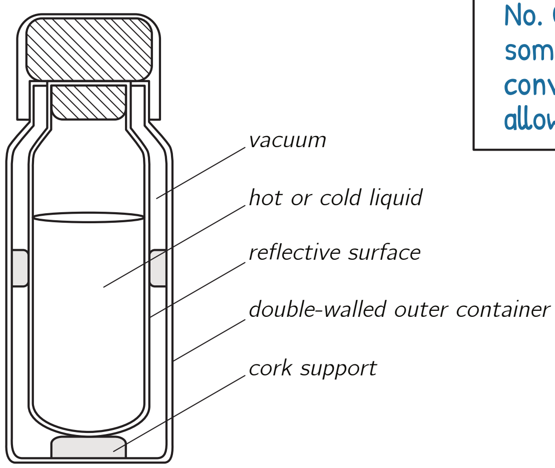
FIND 3 EXAMPLES OF THERMAL CONDUCTORS IN YOUR HOME:

Examples could include: metal cooking pots and pans, copper pipes, oven racks, toaster (the metal filaments inside), hair dryer, an iron for ironing clothes, metal doorknobs and handles (which feel cool to the touch because they are conducting heat away from your hand)

FIND 3 EXAMPLES OF THERMAL INSULATORS IN YOUR HOME:

Examples could include: double paned windows (the air in between the glass insulates the window), fiberglass insulation in walls, the cloth, foam, or rubber in an oven mitt, a styrofoam cup, a thermos with a layer of air in between the layers, etc.

DIAGRAM OF A THERMOS



The gap between the outer and inner container of this thermos contains a vacuum. Would the thermos work better if this space contained air instead?

No. Convection and conduction both need to happen through some kind of matter. The vacuum has no matter, so there is no convection or conduction heat transfer through it. Air would allow some heat transfer (although not a great deal)

What type of heat transfer is reduced by the reflective surface of the inner container?

Radiation or radiative heat transfer.

Practice Problems - Heat Transfer

1. Which of the following is NOT a type of heat transfer?
   A. Conduction
   B. Convection
   C. Radiation
   D. Combustion

2. A cup of hot chocolate is placed on a table. Would placing a lid on a cup of hot chocolate cause it to stay warm longer or make no difference in how quickly it cooled? Explain.

   The lid would cause the hot chocolate to cool down more slowly or stay warmer longer. The lid would stop steam from rising up into the air. The layer of warm air under the lid would also act a bit like an insulating layer.

3. Why do dark surfaces get warmer than light surfaces under sunlight?
   A. Dark surfaces reflect all radiation.
   B. Dark surfaces are usually thicker.
   C. Dark surfaces absorb more radiation.
   D. Dark surfaces conduct heat better.

4. In which situation is heat being transferred by conduction?
   A. Using a fan to cool a room
   B. Cooking food in a microwave
   C. Melting ice in your hand
   D. Steam rising from hot water

5. When you touch a cold metal pole in winter, your hand feels cold because:
   A. Heat is moving from your hand to the pole through conduction.
   B. The pole is giving cold to your hand.
   C. The pole radiates cold air around it.
   D. Convection currents move cold into your hand.

6. What makes air a good insulator?
   A. It conducts heat very well.
   B. It is dense and heavy.
   C. It has a lot of moisture.
   D. It has low density and its molecules are spread out.

7. On a cold day, Emily touches her hand to a metal railing and then a wooden fence post. Both objects have the same temperature, but the metal railing feels colder. Explain why.

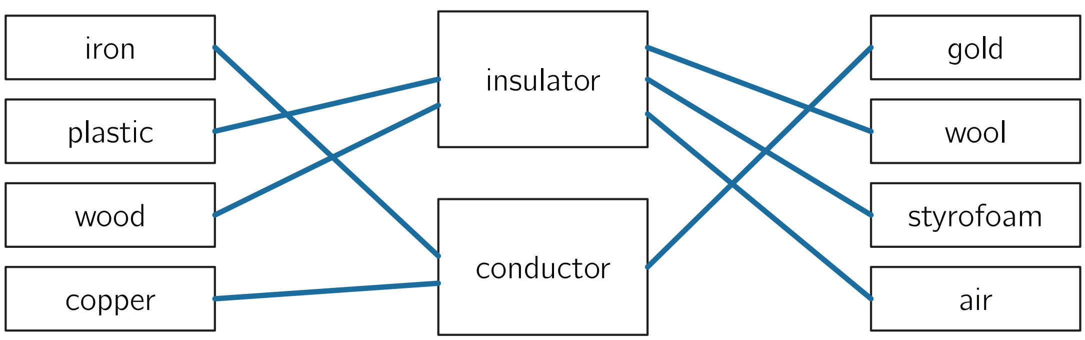
   Metal feel colder than wood at the same temperature because metals are better conductors of heat. When Emily touches the metal railing, it conducts heat away from her skin more efficiently than the wooden post. The higher heat transfer means the metal feel colder, even though both are at the same temperature.

Practice Problems – heat transfer

7. Which of the following is an example of convection?
   A. A metal handle getting hot on a pot of boiling water
   B. Feeling the heat from a light bulb without touching it
   C. Warm air rising near a radiator
   D. Heat from the Sun warming the Earth

8. Which of the following is an example of radiation?
   A. Boiling water in a pot
   B. A metal rod getting hot at one end after the other end is placed in a flame
   C. Feeling warmth from a campfire from a distance
   D. Wind blowing warm air

9. Draw a line to classify each material as either a thermal conductor or insulator.



10. What makes a substance a good thermal conductor?

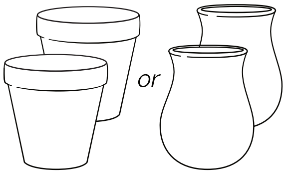
A substance is a good thermal conductor if it allows heat to flow easily through it. This is often due to its atomic or molecular structure, which allows energetic particles to quickly transfer their energy to neighboring particles.

11. Why do insulators prevent the transfer of heat?

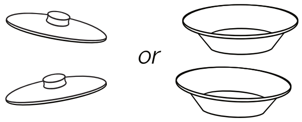
Insulators have a structure that restricts the flow of heat. Their atoms or molecules do not transfer energy as effectively as conductors, so they slow down or prevent the transfer of heat.

MAKE A FRIDGE FROM CLAY AND SAND

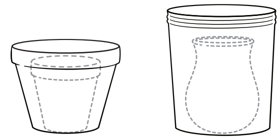
MATERIALS



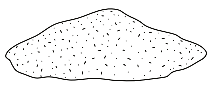
2 small clay pots or vases



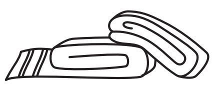
2 metal lids or aluminum pie tins that can cover the top of the clay pots



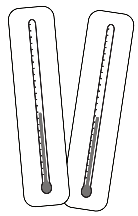
2 buckets or clay pots that are larger than the small clay pots



Enough dry sand to fill the space between the small and large pots or buckets



2 small towels



2 thermometers

water

GOALS

- Design and modify a device that absorbs thermal energy.
- Learn more about the transfer of energy and refrigeration.

Steps:

1.Place each small clay pot inside the larger pot or bucket.

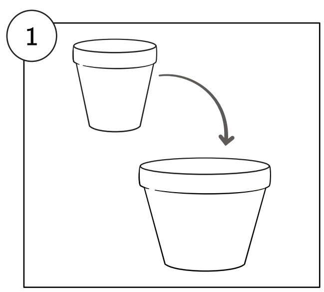
2. Fill the space between the small pots and the larger containers with sand. Label one setup "wet" and the other one "dry."

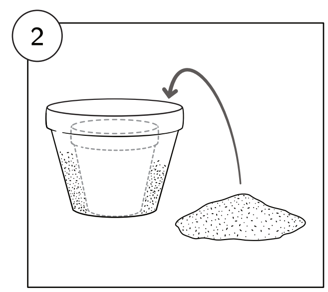
3. Pour water into the sand of the pot labeled as "wet" until the sand is completely moist. Be careful not to pour water into the inner pot. Leave the sand in the "dry" pot as is.

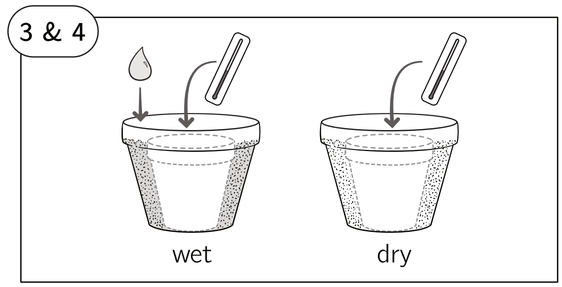
4. Place a thermometer inside each clay pot and take a temperature reading. Then cover both of the clay pots with metal lids.

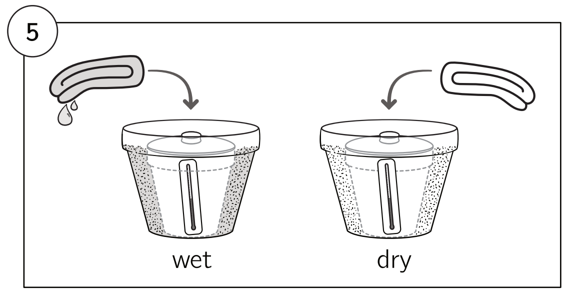
5. Get one of the towels completely wet and ring out excess water. Place it over the clay pot that has wet sand. Place the other towel over the dry clay pot.

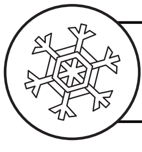
6. Check both pots every hour over the next 8 hours and record the temperatures on the thermometers of the inside pot. If the towel or sand in the "with water" pot appears dry, add more water so that they become damp again.











When water evaporates, it absorbs heat from its surroundings. This principle is used in many cooling methods such as sweating, swamp coolers, misters, cooling towers in industrial plants, and "pot in pot" refrigerators or Zeer pots.

A Cool Experiment

Label temperature on the Y axis

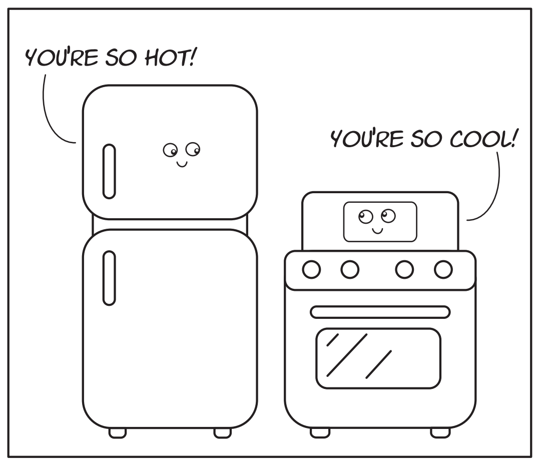
Use a different color to record for the data for each pot.

☐ Wet
☐ Dry

Label time on the X axis

Which clay pot fridge had lower temperatures inside?

____



What caused the differences in temperature between the 2 pots?

____

____

____

What environmental factors influence the effectiveness of the clay pot fridge and how would they impact it? Consider things like air temperature, air flow, and humidity.

____

____

____

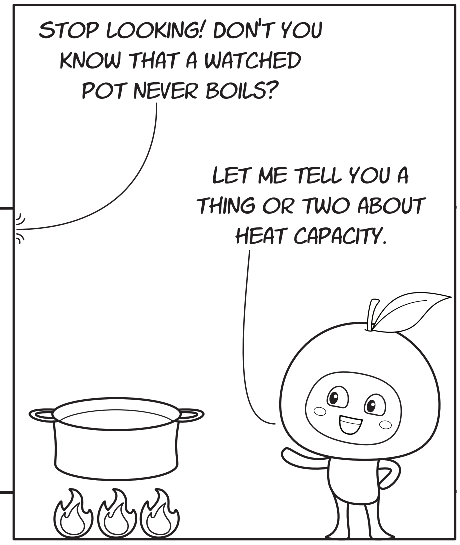
What could be changed to improve the clay pot fridge? Could it preserve food and keep the internal temperature near 3 to 5 °C or 40° F? Why or why not?

____

____

____

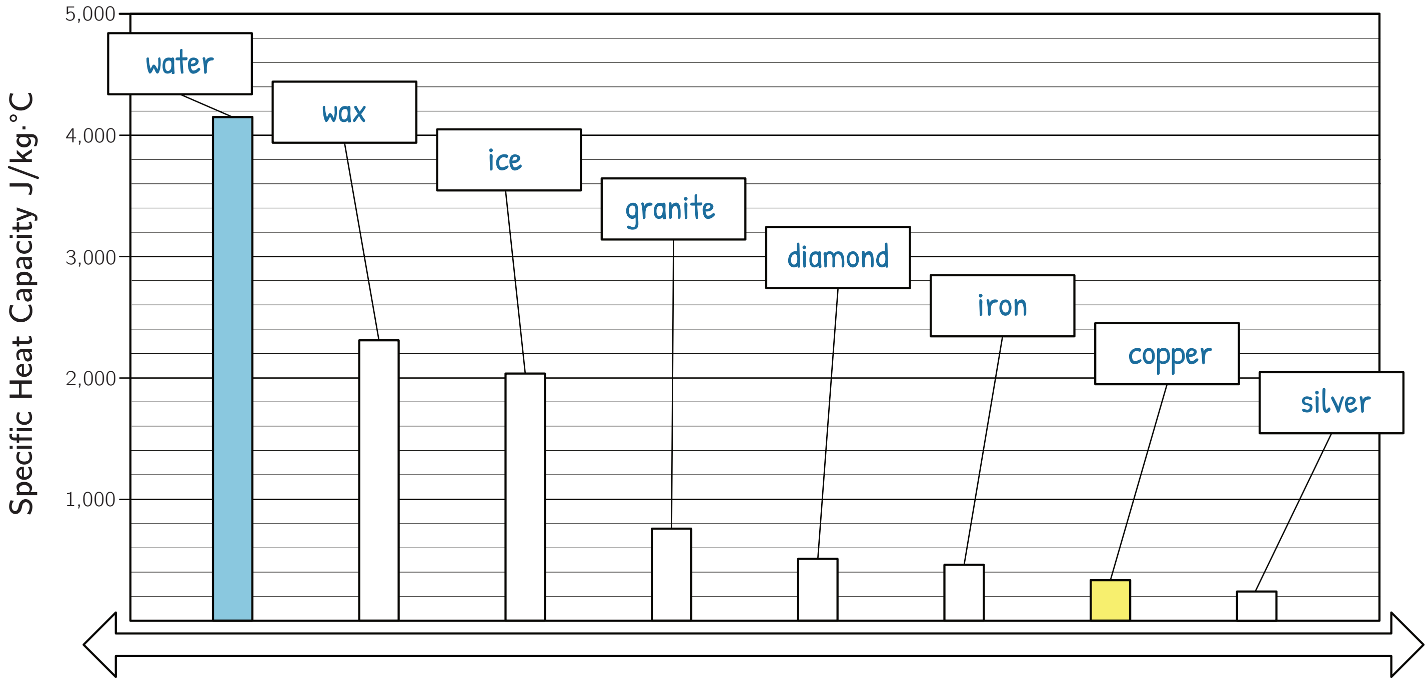
Specific Heat Capacity



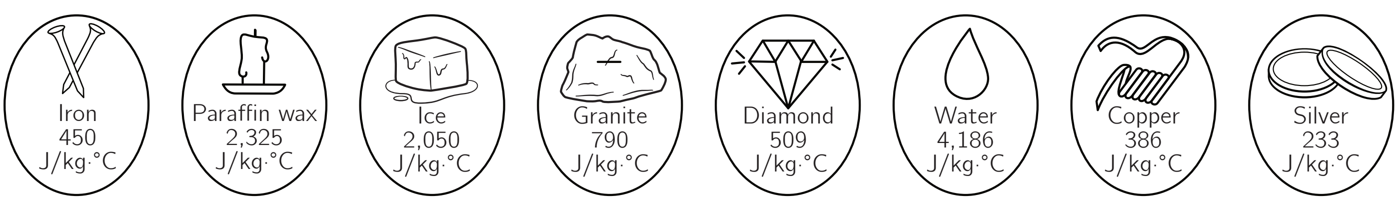
FILL IN THE BLANKS:

heated *energy* *degree* *gram*

Specific Heat is the amount of heat energy required to raise the temperature of one gram of a substance by one degree Celsius. It is a measure of how easily a substance can be heated or cooled.



USE THE INFORMATION IN THE CIRCLES BELOW TO LABEL THE CHART ABOVE. COLOR THE BAR FOR WATER BLUE AND COPPER YELLOW.



LIST 2 OR 3 EXAMPLES WHERE OBJECTS RESPOND DIFFERENTLY WHEN EXPOSED TO THE SAME AMOUNT OF HEAT:

Examples could include:
*A metal seat buckle in a hot car vs cloth seat belt.
*Water vs sand at a lake or beach
*Metal vs plastic playground slide
*Copper bottom pot vs stainless steel pot

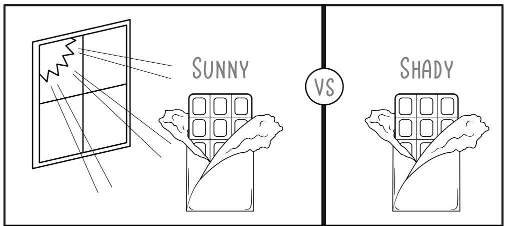
DID YOU KNOW?

Intermolecular forces *are the forces that hold molecules together.*

Materials with strong intermolecular forces require more heat to change their temperature than materials with weak intermolecular forces.

Change of Phase

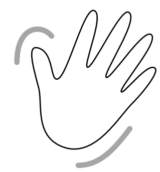
Do melting & vaporization ABSORB or RELEASE energy? *Consider these questions before answering:*



Two pieces of chocolate in different locations. Both experience the same air temperature of 23 °C or 75 °F.

Which one will melt? Which location is experiencing an input of energy?

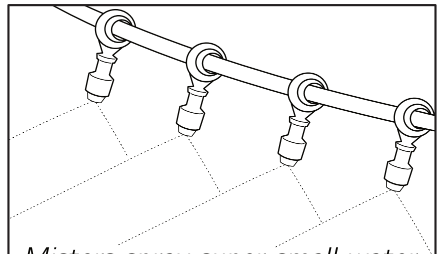
Melting = ABSORB. The chocolate in the sunny location melts as it is receives heat energy (in the form of radiation) from the Sun.



A hand being waved in the air because it is wet with too much hand-sanitizer.

Will the hand feel warmer or colder? Is heat transferring happening?

Evaporating = ABSORB. The hand feels cool because the alcohol absorbs energy/heat from the hand as it evaporates.

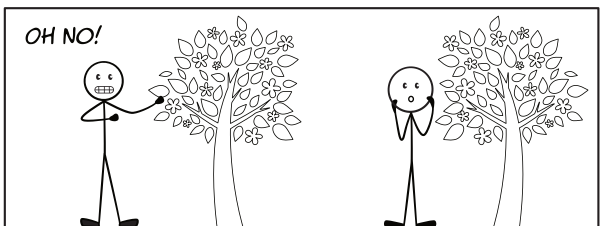


Misters spray super small water droplets into the air, which then evaporate.

Why do the misters cool the area underneath?

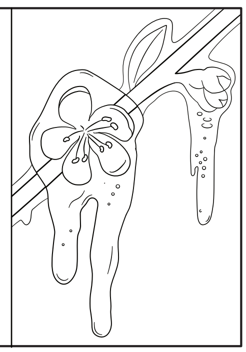
Evaporative = ABSORB. As the water evaporates it absorbs heat from the surroundings. Evaporative cooling!

Do freezing and condensation ABSORB or RELEASE energy? *Consider this example:*



Two farmers have orchards. A late frost is in the forecast and if the blossoms freeze, the farmers will lose the entire year's harvest.

Deja turns on sprinklers all night, covering the trees in a layer of ice. Bob doesn't turn on sprinklers.



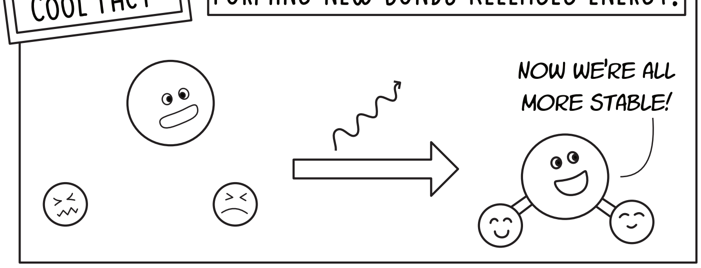
Deja's trees have flowers after the frost. Bob's trees lose all of their blossoms.

The practice of "frost irrigation" is commonly used in real life to protect orchards and other crops from frost damage. Why does it work? How can 'freezing' plants in a layer of ice keep them warm?

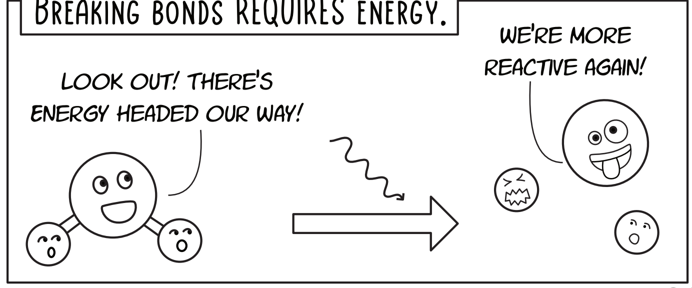
When water changes from liquid to solid (freezes), it releases heat. This released heat is absorbed by the surrounding environment. Even though the water on the plants is turning into ice, the process of freezing actually releases enough heat to keep the plants at a temperature just above freezing. This only works in certain conditions. If it is too cold, frost irrigation won't keep the plants from freezing. It also only works if the water is continuously being applied over the course of the night or frost period..

COOL FACT:

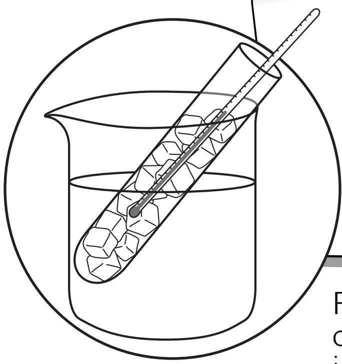
FORMING NEW BONDS RELEASES ENERGY.



BREAKING BONDS REQUIRES ENERGY.



Change of Phase



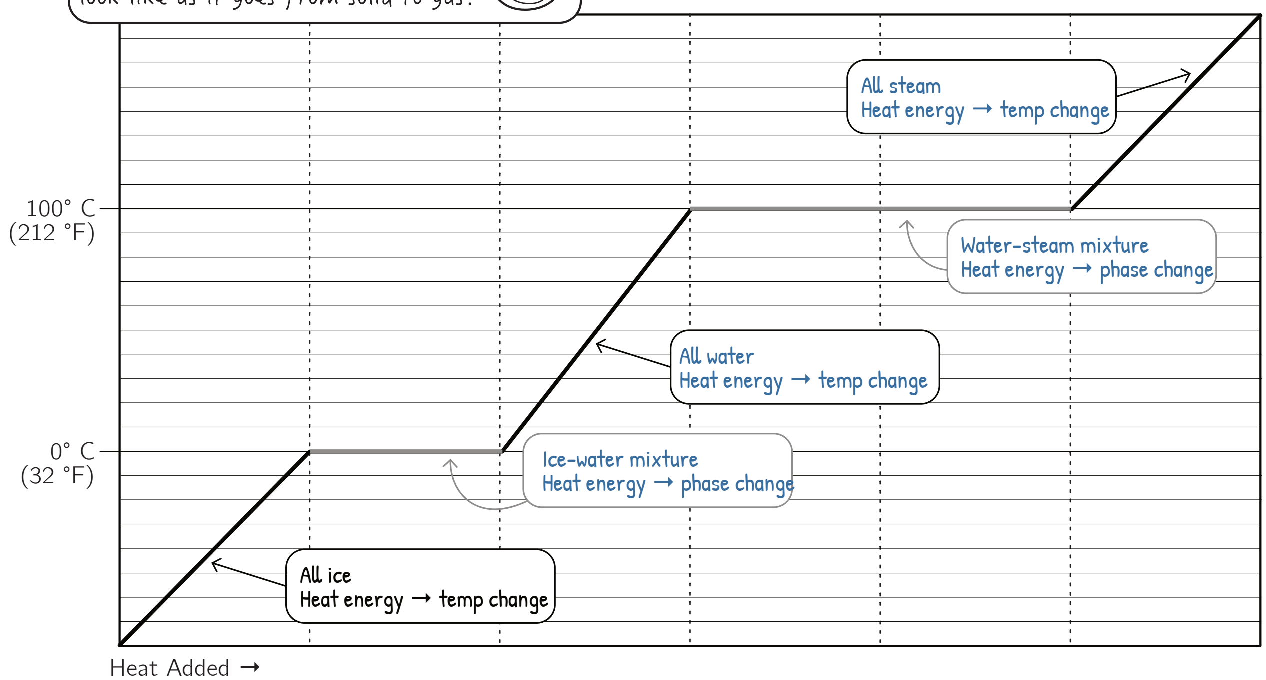
FROZEN WATER IS PLACED IN A GLASS TUBE ALONG WITH A THERMOMETER THEN HEATED UNTIL IT MELTS AND THEN BOILS INTO GAS.

BELOW IS A GRAPH OF THE TEMPERATURE CHANGE AS HEAT IS ADDED. THIS IS CALLED A HEATING CURVE.

Fill in the labels to indicate what state of matter is present (ice, water, steam, or a mixture of states). Also indicate whether the heat energy is driving a change in **temperature** or **phase**. The first label has been filled in as an example.

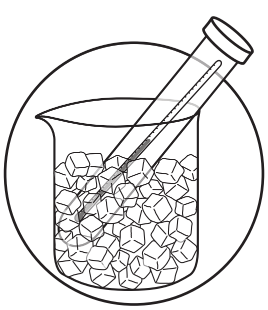
HEATING CURVE

What will the temperature change look like as it goes from solid to gas?

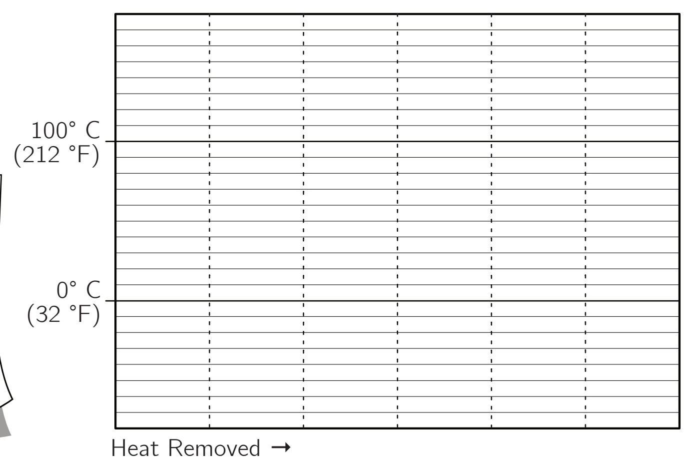


COOLING CURVE

What about from gas to solid?



GASEOUS WATER IS PLACED IN A CONTAINER ALONG WITH A THERMOMETER THEN COOLED UNTIL IT CONDENSES AND THEN FREEZES. DRAW THE COOLING CURVE!



Practice Problems – Heat Capacity & Change of Phase

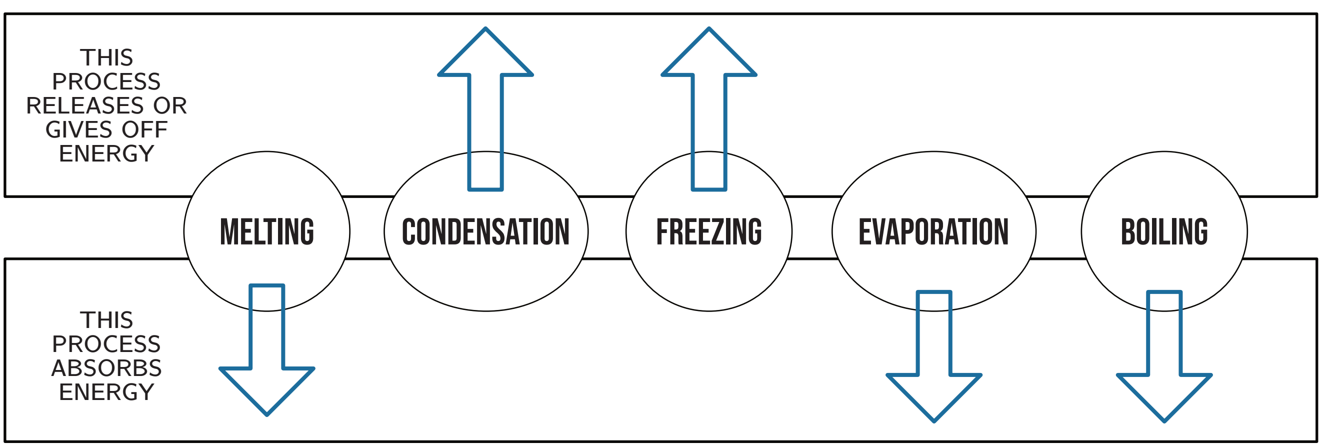
1. When water is boiling, it is undergoing which phase change?
   A. Melting
   B. Freezing
   C. Vaporization
   D. Condensation

2. Which phase change is exothermic, meaning it releases heat?
   A. Melting
   B. Vaporization
   C. Freezing
   D. Sublimation

3. When a cold glass of water "sweats" in a warm room, which phase change is occurring on the outside of the glass?
   A. Vaporization
   B. Condensation
   C. Melting
   D. Freezing

4. A substance has a high specific heat if:
   A. It always remains warm.
   B. Relatively little heat is required to change its temperature.
   C. A lot of heat is required to change its temperature.
   D. Its temperature remains constant regardless of the environment.

5. Draw an “up arrow” above each change of phase where heat energy is **released** and a “down arrow” under each phase where heat is **required or absorbed**.



Practice Problems – Heat Capacity & Change of Phase

6. Describe the difference between melting and freezing in terms of heat transfer.

Melting occurs when a substance changes from a solid to a liquid state and requires heat to be added (endothermic). Freezing is when a substance changes from a liquid to a solid state and involves heat being released (exothermic).

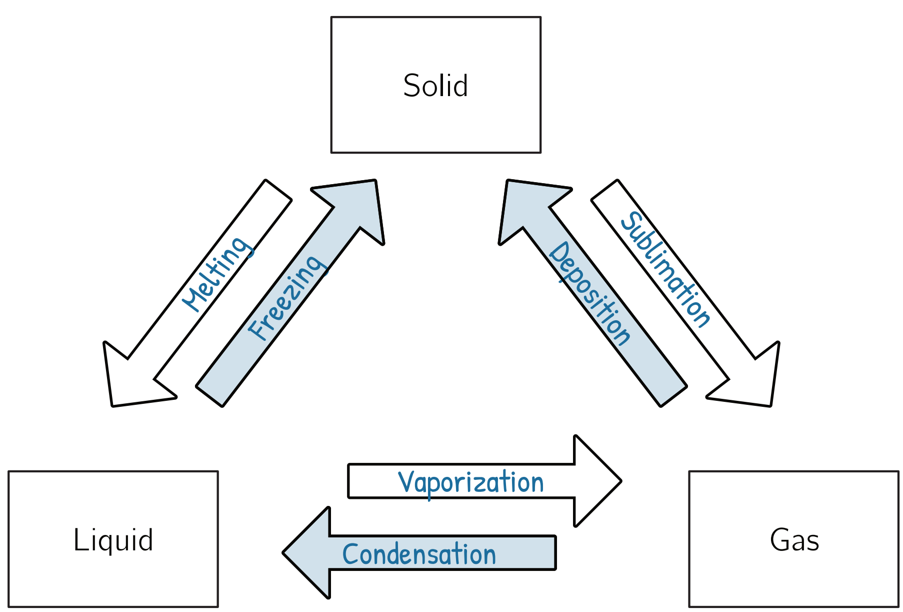
7. What is the difference between vaporization and condensation when considering heat transfer?

Vaporization is when a substance changes from a liquid to a gas and requires heat to be added (endothermic). Condensation is when a substance changes from a gas to a liquid state and involves heat being released (exothermic).

8. Why might some substances have a higher heat capacity than others?

Different substances have different atomic or molecular structures, which can affect how they store and transfer energy. A substance with a higher heat capacity can absorb more heat without a significant rise in temperature compared to another substance with a lower heat capacity.

9. Label each arrow in the diagram below with the term that describes the change of phase. Shade in the arrows that represent an exothermic phase change.

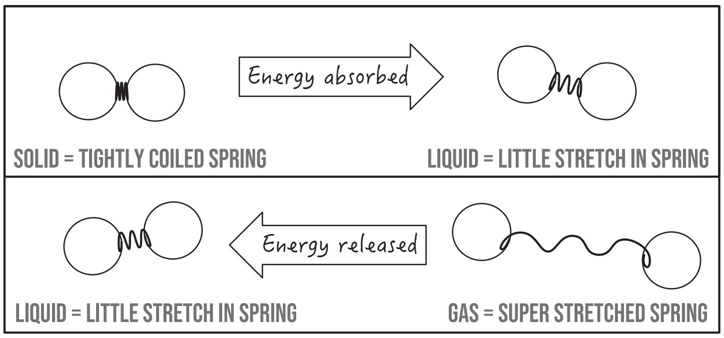


Thermodynamics

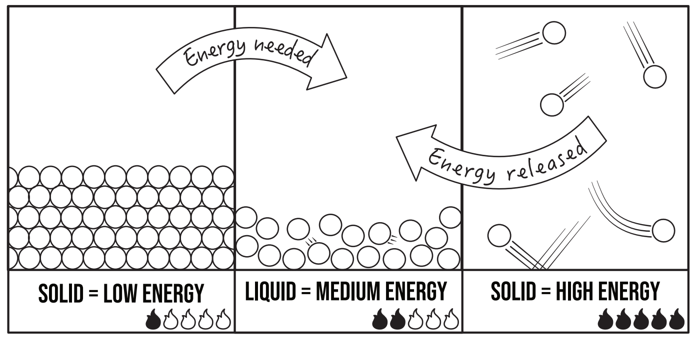
Review: Bob has water condensing on the outside of his fish tank and wants to know if the condensation is warming up or cooling down the tank. In other words, does condensation absorb or release heat? How would you explain the answer to Bob?

Answers will vary, but hopefully include the fact that condensation involves moving from a higher energy state (gas) to a lower energy state (liquid) so heat will be released. The condensation is releasing heat. Although this process is warming the tank, it may or may not be a significant amount of warming depending on the size of the tank.

BONDS BETWEEN ATOMS ARE LIKE SPRINGS. IT TAKES ENERGY TO STRETCH THEM APART AND SNAPPING BACK IN PLACE RELEASES ENERGY.



EACH STATE OF MATTER IS AN ENERGY LEVEL. LEVELING UP REQUIRES AN INPUT OF ENERGY. LEVELING DOWN RELEASES ENERGY.



Bob would like an analogy to help him remember how heat is transferred when a substance changes state. Which of the analogies above would you recommend and why?

Answers will vary.

Review: The words heat and temperature are sometimes used interchangeably in non-scientific settings. But in physics, heat and temperature are two very different things! Match each term to it's correct description. Then draw diagrams or pictures to represent each concept.

HEAT

Diagrams or pictures will vary. Something with an arrow or other visual to show the transfer of energy would be great!

TEMPERATURE

Diagrams or pictures will vary. Something with particles and something to show their motion/movement would be great!

A measurement of the average kinetic energy of the particles in a substance.

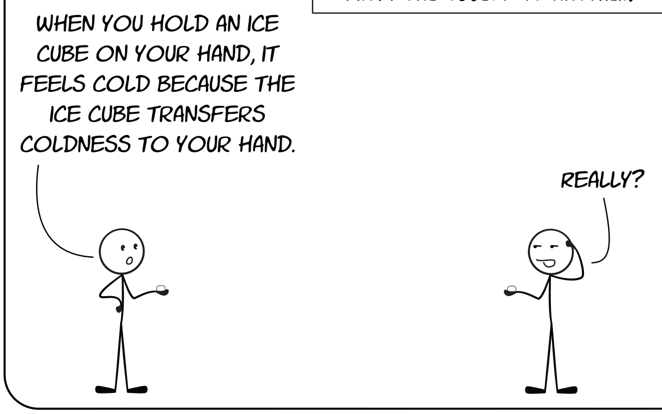
Thermal energy that is transferred from a warmer object to a cooler one.

CORRECT THE MISCONCEPTIONS

Below are two common misconceptions about thermodynamics, along with an example that seems to support each of them. Correct each statement and explain what is happening with the example.

MISCONCEPTION #1

COLD IS A TRANSFERABLE ENTITY. IT CAN BE EMITTED OR TRANSFERRED FROM ONE OBJECT TO ANOTHER.



Correct the misconception:

Cold is not a transferable entity! Cold is the absence of heat.

When there is an ice cube on a person's hand, the hand feels colder because heat is flowing from the hand to the ice.

MISCONCEPTION #2

A HIGHER AMOUNT OF HEAT ALWAYS = HIGHER TEMPERATURE. FOR EXAMPLE, IF OBJECTS W AND X BOTH RECEIVE THE SAME AMOUNT OF HEAT, THEN THEIR TEMPERATURES WILL INCREASE THE SAME AMOUNT.

WHEN FILLED WITH BOILING WATER, WILL ALL THREE OF THESE CUPS BECOME TOO HOT TO HOLD COMFORTABLY WITH BARE HANDS?

Correct the misconception:

While higher heat correlates with higher temperatures, objects with different heat capacities will experience different changes in temperature when exposed to the same amount of heat.

For example, a copper and steel cup will both get very hot when filled with boiling water. A styrofoam cup, on the other hand, will not have nearly as much of a temperature increase when filled with boiling water even though it was exposed to the same amount of thermal energy.

PUTTING IT ALL TOGETHER

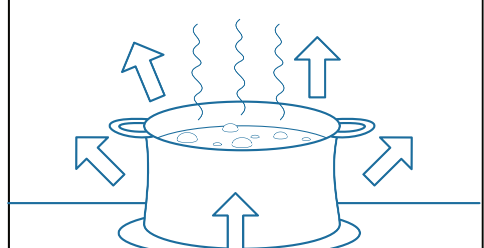
Much of what we've learned in this unit can be summarized in the three laws of thermodynamics.

Fill in the words that are missing from each law on the following page. Then find an example of heat transfer in your own home. As a bonus (optional) extension, can you identify any laws that are involved? Draw a picture of where heat is flowing and why.

Answers will vary. Possibilities include a cup of tea getting cold when it is left out. A refrigerator transferring heat from inside to the back, anything involving cooking or heating a home in winter time or cooling it in summer etc.

HEAT TRANSFER EXAMPLE

Heat from boiling pot of soup is transferred to air and kitchen.

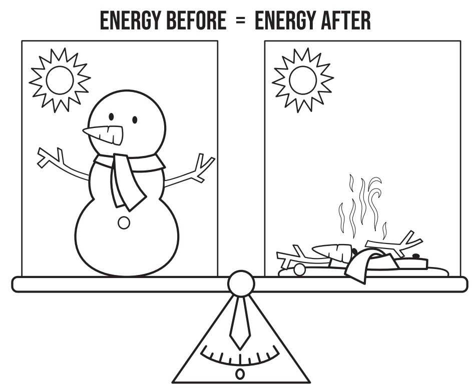


1^{st} law: Electric energy is transformed into heat in the stovetop.

2^{nd} law: the transfer of energy is not 100% efficient.

First Law of Thermodynamics

Also known as the Law of Energy Conservation!



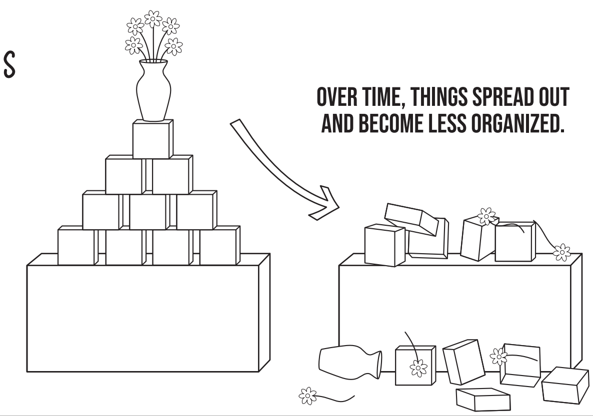
In a closed or isolated system, energy cannot be created or destroyed. It can only be transferred from one form to another.

$$\Delta U = Q - W$$

The change in the internal energy of a system is equal to the heat added or lost to the system and the work done by the system on its surroundings.

Second Law of Thermodynamics

Also known as the Law of Entropy!



In any process, the overall disorder or messiness of things tends to increase. The transfer of energy cannot be 100% efficient!

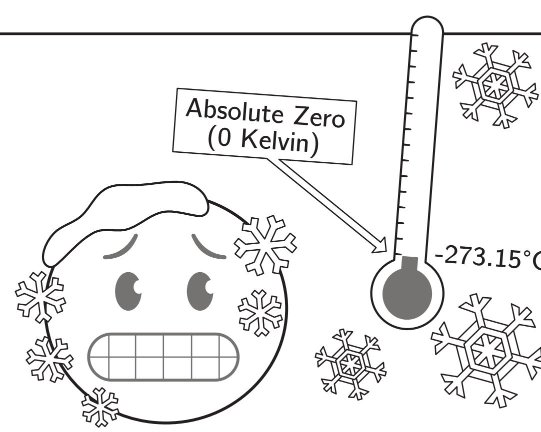
In other words, entropy is always increasing.

S Entropy

The entropy of an isolated system not in equilibrium will increase over time, approaching a maximum value at equilibrium. Heat cannot spontaneously flow from a colder body to a hotter body.

Third Law of Thermodynamics

All about absolute zero



At absolute zero, all motion would stop.

As the temperature approaches absolute zero,

the entropy of the system decreases.

At absolute zero, the entropy of a perfect crystal would be exactly zero. But absolute zero cannot be reached! The closer you get, the harder it is to remove heat. Also, being at absolute zero would violate the Heisenberg Uncertainty Principle.

Practice Problems – Thermodynamics

1. What does the first law of thermodynamics state?
   A. Energy can be created and destroyed.
   B. Energy is always conserved.
   C. Heat flows from cold objects to hot objects.
   D. Energy increases with temperature.

2. Explain entropy in your own words and give an example where entropy increases:

   ____

   ____

3. The second law of thermodynamics explains that:
   A. Energy cannot be transferred or transformed.
   B. Heat flows from hot objects to cold objects.
   C. Total energy of an isolated system decreases over time.
   D. Heat is a form of kinetic energy.

4. What is absolute zero?
   A. The temperature at which a substance freezes.
   B. The highest possible temperature.
   C. The temperature at which all particle motion stops.
   D. The temperature of a vacuum

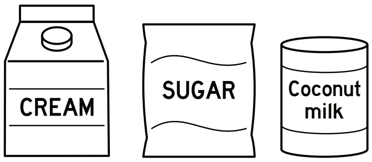
5. If you leave a hot cup of coffee in a cold room, what will happen according to the second law of thermodynamics?
   A. The coffee will get hotter.
   B. The temperature of the coffee and the room will equalize.
   C. The room will become hotter than the coffee.
   D. Nothing; the temperature will remain the same.

6. When a system goes from a more ordered state to a less ordered state:
   A. Its entropy decreases.
   B. Its entropy increases.
   C. Its temperature always increases.
   D. It violates the first law of thermodynamics.

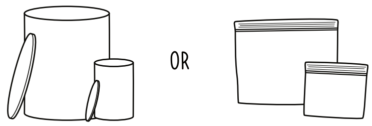
7. If energy is conserved in a closed system, what does this imply?
   A. The total energy in the system will increase over time.
   B. The energy can change forms but the total amount remains constant.
   C. Energy flows from cold objects to hot objects.
   D. Marmoset.

MAKE YOUR OWN ICE CREAM

MATERIALS



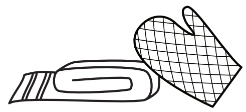
Ingredients for ice cream
(For a dairy-based dessert, use sugar, cream, and desired flavorings. For a dairy-free dessert, use coconut milk, dates, and cocoa powder.)



2 metal cans of different sizes with lids OR 2 ziplock bags of different size

Ice

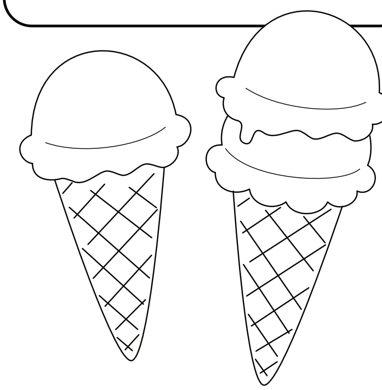
Rock salt



Oven mitts or towels (to keep hands warm)

GOALS

- Observe and better understand freezing point depression
- Celebrate the end of the thermodynamics unit with a delicious treat!



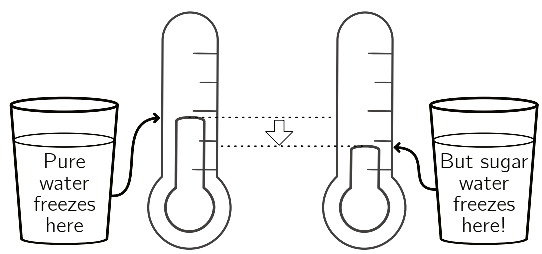
Pre-lab Questions:

① Have you ever seen someone salt a driveway or sidewalk? If yes, did you see what happened after the salt was applied?

② Why do you think it's common for salt to be applied to roads in snowy climates?

HAVE YOU EVER NOTICED... THE ORANGE JUICE CONCENTRATE IN YOUR FREEZER DOESN'T SEEM AS "FROZEN" AS THE ICE CUBES?

When another substance is dissolved in a liquid, the freezing point DROPS



This is called freezing point depression!

③ When making homemade ice cream, salt is added to the ice. What is the purpose of adding salt? Will it increase or decrease the temperature? If you are unsure, do an experiment! Set up 2 sets of bags or cans. Then add salt to the ice in one of them but not the other. Observe what happens.

INSTRUCTIONS:

1. **Prepare the Ice Cream Mixture:** In a small ziplock bag or a coffee can, mix the ingredients for your ice cream. Seal the bag or can and check to be sure the seal is water tight.
2. **Refrigerate for 1 hour:** This step is optional but it will help the ice cream making go much quicker!
3. **Add the Ice and Salt:** Place the small bag or can with the ice cream mixture inside the larger bag or can. Add ice and salt. If using bags, seal the large bag tightly. If using cans, use duct tape to attach the lid to the outer can.
4. **Chill and Shake**: If using bags, squeeze or shake the bag vigorously for about 10 minutes. Use towels or gloves to protect your hands from the cold. If using cans: Roll the can back and forth on the ground for about 10 minutes.
5. **Check and Adjust:** Open the large can or bag and drain out any melted water. Then check the inner bag or can to see if the ice cream is done. ***Be careful! You don't want to get salty water in the ice cream.*** If the ice cream mixture is still runny, add more ice and salt to the outer container. Mix or roll again for about 5 minutes. Check again. Adjust the ice and salt levels as needed. Keep rolling or squishing until the ice cream is firm.
6. **Complete Worksheets and Enjoy:** Finish filling out the worksheets and enjoy your delicious ice cream!

INGREDIENTS FOR A DAIRY-BASED ICE CREAM

- 1 cup cream or half-and-half
- 2 Tbsp granulated sugar
- Flavorings of your choice such as:
  - 1 Tbsp chocolate syrup
  - ½ tsp vanilla extract
  - ½ tsp peppermint extract
  - ½ cup of your favorite candy, chopped
  - ½ cup berries or other fruit

INGREDIENTS FOR A COCONUT-BASED ICE CREAM

- 1 can coconut milk
- ¼ cup sugar
- Flavorings of your choice such as:
  - Fresh dates (7-10) and cocoa powder
  - ½ tsp vanilla extract
  - ½ cup of your favorite candy, chopped
  - 1 cup fresh pineapple, cubed

**If using the pineapple or date versions, use a blender or food processor to thoroughly blend the mixture.*

CONNECTIONS AND EXTENSIONS

PICK ONE OF THESE QUESTIONS TO STUDY OR MAKE YOUR OWN. THEN LOOK UP ADDITIONAL INFORMATION AND MAKE NOTE OF WHAT YOU LEARNED!

WHY DOES ICE CREAM CONTAIN AIR?

Air makes up between 30 to 50% of the volume of commercial ice cream!

WHAT ABOUT SORBET?

Could this method be used to make sorbet or sherbet instead of ice cream?

WHO INVENTED ICE CREAM?

The dessert is hundreds of years older than modern refrigeration methods. Can you discover some of the earliest recipes?

PLASTIC VS METAL?

Would ice cream freeze faster in metal cans or plastic bags? Can you map the heat transfer in this activity?

Which question did you choose to study?

____

List 3 sources of information you found useful in answering your question.

Then, for each source, list the publisher or author and at least one reason you believe the information is accurate.

If the source is a **book**, who is the publisher? Do you think they hired a fact checker or an expert reviewer to verify the contents of the book? For non-fiction books, this is standard practice with reputable publishers. Sometimes you might see mention of an expert reviewer or fact checker in the acknowledgements.

If the source is from a **website** or other online material, who wrote it? What type of reputation does the group, company, or person have? If it's from a personal story, what aspects of the story or person make them seem trustworthy? Is there any reason to suspect bias?

Source 1: ________________________________

Publisher or Author: ________________________________

Evidence of accuracy? ________________________________

Any reason to suspect bias or misinformation? ________________________

Source 2: ________________________________

Publisher or Author: ________________________________

Evidence of accuracy? ________________________________

Any reason to suspect bias or misinformation? ________________________

Source 3: ________________________________

Publisher or Author: ________________________________

Evidence of accuracy? ________________________________

Any reason to suspect bias or misinformation? ________________________

What is the answer to your question? Summarize it here!

____

____

____

Thermodynamics Assessment

In your own words!

(Answers will vary, but the overall meaning should be similar to what is written here)

Define each of the following terms in your own words! Explain the terms without looking them up. Then, after writing your definitions, compare what you wrote with the definitions in the notes. Make corrections as needed.

CONDUCTION: The transfer of heat through a substance, particle to particle.

CONVECTION: The transfer of heat by currents moving within a gas or liquid.

ENTROPY: The amount of disorder or chaos something has.

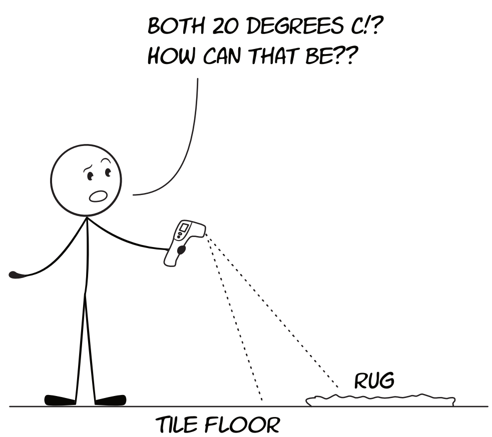
HEAT: The energy that flows from one object to another due to a difference in their temperatures. Heat is measured in calories or joules.

Bob has a fancy new infrared thermometer. When he points the thermometer at a surface, it gives a digital reading of the temperature. Bob is very worried that his new device is broken because it gives the same temperature for the tile on the bathroom floor as it does for the rug. Yet, when Bob steps on the rug vs the tile, the tile feels cooler. Neither the rug nor the tile are being influenced by an outside power source such as sunlight or a heating vent.

What would you tell Bob? Should he return his new thermometer and demand a refund, or is the thermometer working?

Bob's understanding of thermodynamics is the thing that needs to be fixed here, not the thermometer!

The bathroom tile feels cooler to the touch because it is more efficient at transferring heat to Bob. The rug is a poorer conductor of heat, so there is less heat transfer. If the rug and tile were both very hot (say 90 °C) then the floor would feel hotter than the rug.



THERMODYNAMICS ASSESSMENT

IN YOUR OWN WORDS!

Define each of the following terms in your own words! Explain the terms without looking them up. Then, after writing your definitions, compare what you wrote with the definitions in the notes. Make corrections as needed.

HEAT CAPACITY: The quantity of heat required to raise the temperature of one gram of a substance by 1˚C.

RADIATION: Energy that is transmitted by electromagnetic waves.

TEMPERATURE: A measure of the average translational kinetic energy per molecule of a substance.

INTERNAL ENERGY: The total energy in the atoms and molecules within a substance

1. During melting:
   A. Particles stop moving
   B. Particles reach maximum movement
   C. Heat is absorbed
   D. Heat is released

2. What is absolute zero?
   A. The temperature where water freezes
   B. The temperature where all molecular motion stops
   C. The lowest recorded temperature
   D. The highest recorded temperature

3. Which statements about heat are true?
   A. Heat is the transfer of thermal energy from one object to another
   B. The terms temperature and heat are synonymous and have the same meaning
   C. Heat always flows from an area of low energy to an area of high energy
   D. None of the above are true

Thermodynamics Assessment

4. Thermal expansion occurs because:
   A. Particles lose energy when heated
   B. Particles attract each other when heated
   C. Heated particles move less and take up less space
   D. Heated particles move more and take up more space

5. What is an example of conduction?
   A. Sunlight warming the earth
   B. Hot water rising from a hydrothermal vent at the sea floor
   C. A metal spoon becoming warmer after being in a pot of hot soup

6. What is thermal energy or internal energy?
   A. The total kinetic and potential energy of the particles in an object.
   B. Only the kinetic energy of the particles in an object
   C. Energy that is transferred to the object's surroundings

7. What is temperature?
   A. The transfer of thermal energy
   B. The amount of coldness
   C. The average kinetic energy of particles in a substance
   D. The total potential energy of a substance

8. Circle the letter **C** if the material is a good thermal conductor and **I** if the material is a good thermal insulator:
   C I Air
   C I Copper
   C I Steel
   C I Wood
   C I Aluminum
   C I Fiberglass
   C I Iron
   C I Styrofoam

9. Which of the following statements are true?
   A. Convection occurs in fluids (gas and liquids) but not solids.
   B. Heat transfer by radiation must involve direct contact between objects.
   C. Conduction is the fastest form of heat transfer
   D. A and C are both true
   E. None of the above statements are true

10. When a substance freezes, heat is:
    A. released
    B. absorbed
    C. There is no change in heat

11. When a liquid vaporizes, heat is:
    A. released
    B. absorbed
    C. There is no change in heat

12. The first law of thermodynamics states that:
    A. Entropy is always increasing
    B. In an isolated system, energy will always be conserved
    C. Heat flows from cold to hot objects

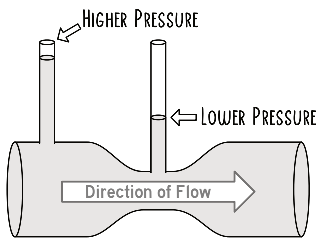
13. Which phase change below releases heat?
    A. Evaporation
    B. Sublimation
    C. Melting
    D. Freezing

14. True or False? Heat capacity is the same for all states of matter.
    A. True
    B. False

Unit 3: Fluids and Pressure

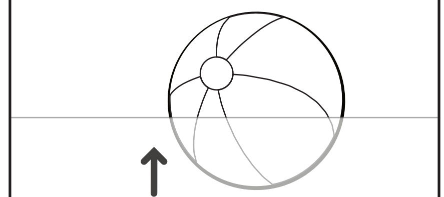
Liquids and gases are both fluids!

BERNOULLI'S PRINCIPLE



As the speed of a fluid increases, the pressure decreases

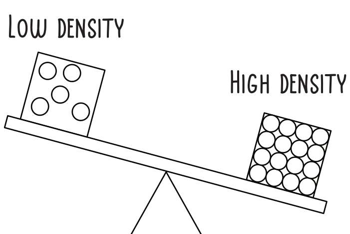
BUOYANCY



$\vec{F}_b = -\rho g V$

The upward force exerted by a fluid on an object

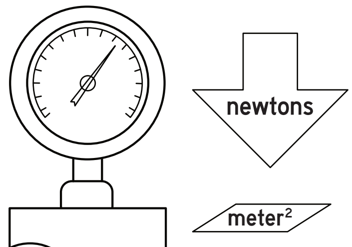
DENSITY



$\rho = \frac{m}{V}$

How compact something is or how much mass per unit of volume

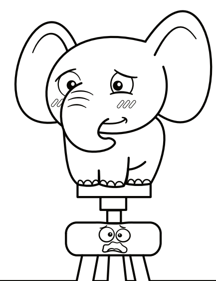
PASCALS



Pa

A measure of pressure: newtons per square meter

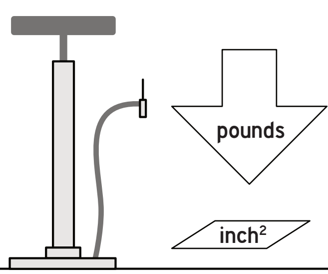
PRESSURE



$P = \frac{F}{A}$

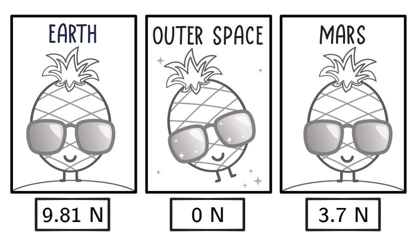
The amount of perpendicular force applied per unit of area

PSI



A measure of pressure: pounds per square inch

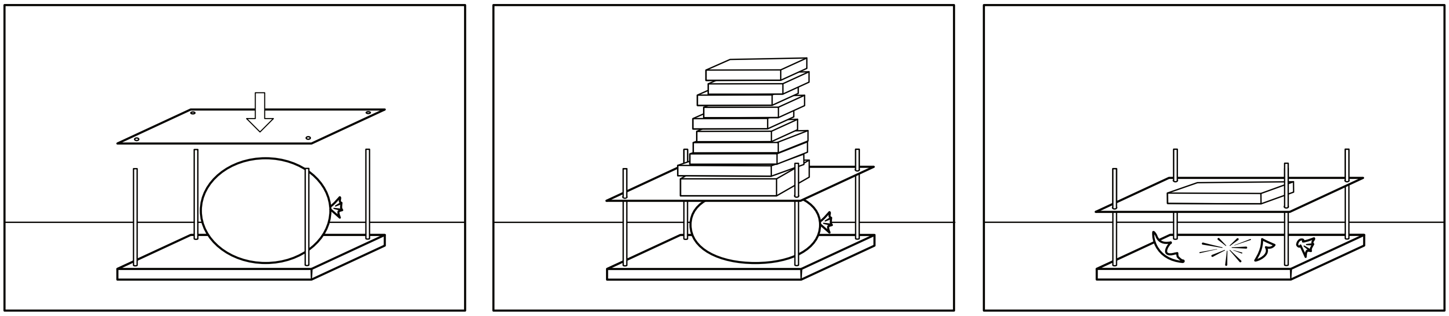
WEIGHT



$W = m \cdot g$

The force acting on an object due to gravity

Pressure



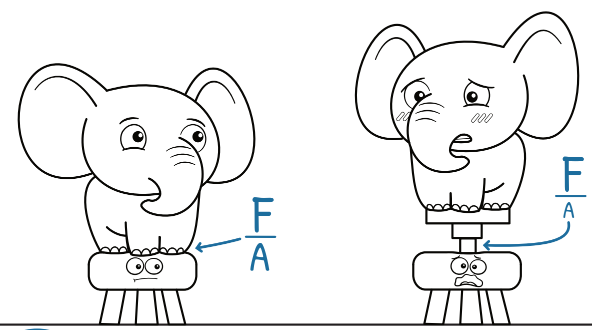
A balloon can support the weight of 10 books before popping. But if a pin is placed on the bottom of the press, then the balloon pops under the weight of one book. Why?

Answers will vary, but hopefully this introduction got you thinking about how the same amount of weight can feel very different depending on how much area it is applied to.

PRESSURE VS WEIGHT

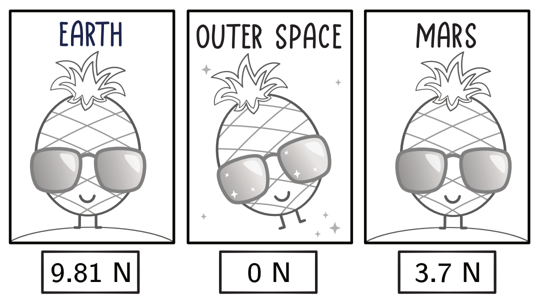
LABEL EACH CARD WITH THE CORRECT TERM AND DEFINITION, THEN DESCRIBE THEIR SIMILARITIES AND DIFFERENCES.

PRESSURE



$P = \frac{F}{A}$ The amount of perpendicular force applied per unit of square area.

WEIGHT



$W = m \cdot g$ The force acting on an object due to gravity

SOMETHING SIMILAR: Both can cause things to move or bend. Weight can cause pressure.

SOMETHING DIFFERENT: Weight is a force and tells you nothing about area. Pressure has area in the units. Also, weight is a vector, pressure is not (it's a scalar quantity)

$$P = \frac{F}{A}$$

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

Pressure is measured in many different units!

Pascal (Pa) or Kilopascal (kPa)
The SI unit for pressure (N/m^2)

Millimeters of Mercury (mmHg)
Blood pressure measurements. The standard 120/80 is in mmHg

Torr
Used with vacuum applications

Pounds per square inch (PSI)
Mechanical and structural engineering, tire pressure

Atmosphere (atm)
Atmospheric pressure

Bar or millibar (mb)
Meteorology and geology

1 CALCULATING PRESSURE IN PSI

Pounds per square inch (PSI) is commonly used in sports equipment, the automotive industry, hydraulics and pneumatics, plumbing systems, and heating, ventilation, and air conditioning (HVAC) systems.

Bob weighs 140 lbs and wears shoes that have perfectly rectangular soles measuring 4 x 10 inches. How much pressure does Bob exert on the ground in PSI?

Pressure = Force/Area.

The area of the sole of each shoe is 40 in^2. When Bob is standing on both feet his weight is applied across both shoes, so the pressure is 140 lbs/80 in^2 = 1.75 PSI or 1.75 pounds per square inch.

Does the pressure change when Bob stands on one foot? If yes, by how much?

Yes. It doubles.

Bob is standing on one foot, all of his weight is applied on one shoe-print (40 in^2) so the pressure is 140 lbs/40 in^2 = 3.5 PSI or 3.5 pounds per square inch.

Use the conversion table to calculate the pressure of Bob's footprints in kPa and atmospheres (atm).

When standing on 2 feet, Bob is applying 12.07 kPa of pressure or 0.119 atm of pressure:

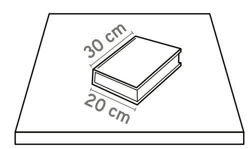
$$1.75 \text{ PSI} \; \frac{6.895 \text{ kPa}}{1 \text{ PSI}} = 12.07 \text{ kPa} \qquad 12.07 \text{ kPa} \cdot \frac{1 \text{ atm}}{101.3 \text{ kPa}} = 0.119 \text{ atm}$$

When standing on 1 foot, the pressure is doubled (24.14 kPa or 0.238 atm)

2 CALCULATING PRESSURE IN KPA

Pascals is the SI unit for pressure, but it's a SMALL measurement. One pascal is roughly equal to the pressure a piece of paper exerts on a table. So the kilopascal (kPa) is more commonly used.

A book with a mass of 1.5 kg (weighing 14.7 N) rests on a table. The entire surface of the 20 cm x 30 cm cover is in contact with the table. How much pressure is the book exerting on the table in pascals (newtons/m^2)? How much in kilopascals?

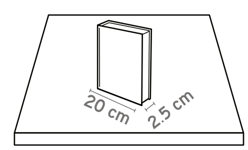


Pressure = Force / Area. To calculate the force the book is exerting on the table in pascals, we need to be sure we have the correct units of newtons/m^2.

The area where the force (weight) is being applied is 20 cm · 30 cm = 600 cm^2 = 0.06 m^2.

The pressure = 14.7N/0.06 m^2 = 245 Pa or 0.245 kPa

Now the book is balanced on its edge so the surface in contact with the table is 2.5 cm x 20 cm. How much pressure does the book exert now? This time calculate both pascals and kilopascals.



The area where the force (weight) is being applied is 20 cm · 2.5 cm = 50 cm^2 = 0.005 m^2.

The pressure = 14.7N/0.005 m^2 = 2,940 Pa or 2.94 kPa

BONUS: FIGURE IT OUT FOR YOU!

HOW MUCH PRESSURE DO YOU EXERT ON THE GROUND? TRACE YOUR FEET ON GRAPH PAPER AND ESTIMATE THE AREA, THEN WEIGH YOURSELF AND CALCULATE THE PRESSURE!

CONVERSIONS

1 PSI = 6.895 kPa
1 Pa = 1,000 kPa
1 atm = 101.3 kPa

FLUIDS

Gases and liquids are both called **fluids** and share a fundamental property: the ability to flow. Make notes about some of their key characteristics in the spaces below:

FLOW

Fluids move or deform in response to stress or force. This flow behavior results in the fluid spreading out & filling up space.

Ex. Air and CO_2 - can be 'poured' from one cup to another

DENSITY

Like solids, fluids have density (mass/volume)

But fluids can have more dramatic changes in their density when temperature or pressure change.

Ex. Remember cold vs hot water / rubbing alcohol (thermal expansion)

VISCOSITY

Viscosity is the resistance to deformation or flow. All fluids have some viscosity, but it's much more noticeable in liquids than gases.

Ex. Honey is more viscous than water, water is more viscous than gasoline

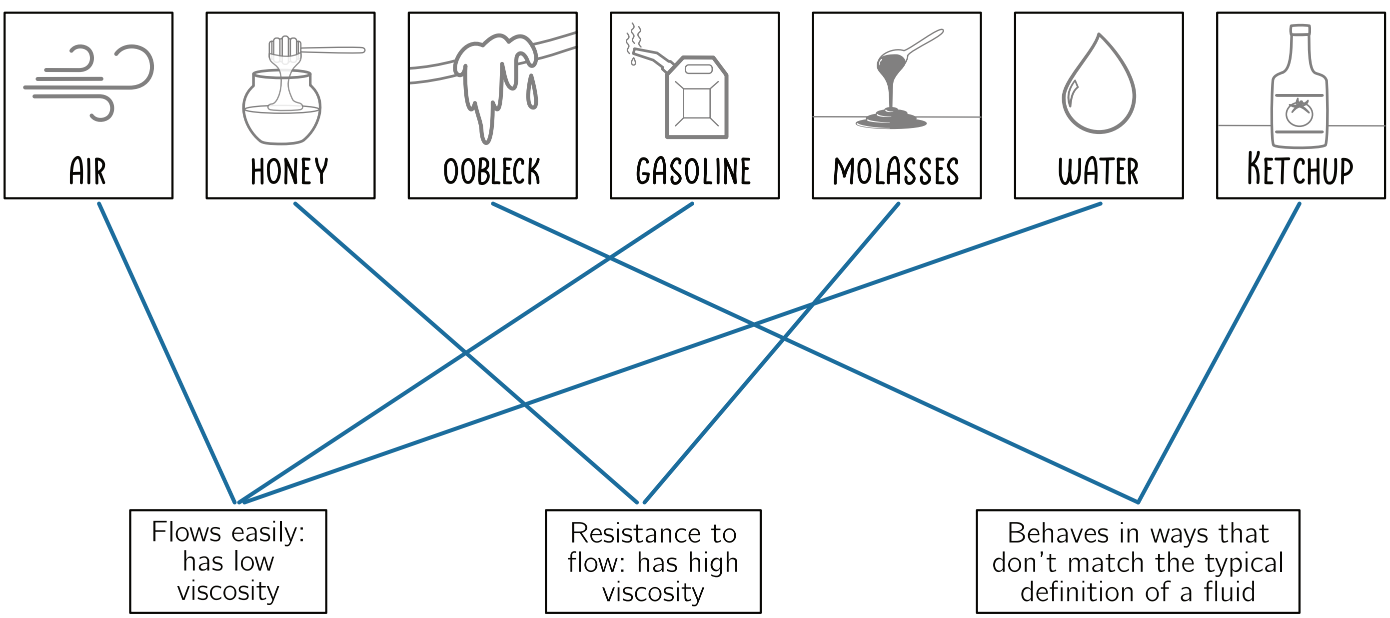
PRESSURE DISTRIBUTION

Key property!

Fluids exert pressure evenly in all directions. Their molecules are moving rapidly and randomly - this results in an even pressure on all sides of the container.

Ex. Round balloon, fish tank

As with most categories and labels, some items fit within the norm and others do not conform! Draw lines to match each of the following fluids with their best description:



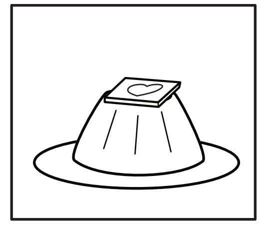
Practice Problems – Pressure & Fluids

1. If a force of 10 newtons is applied over an area of 2 square meters, what formula is needed to calculate the pressure? What will the units be?

$P = \frac{F}{A}$ Pressure = Force divided by area. Newtons divided by square meters gives the unit of pascals.

$\frac{10\text{ N}}{2\text{ m}^2} = 5\text{ N/m}^2 = 5\text{ Pa}$

2. A decorative book with a weight of 12 N is resting on top of a gelatin dessert at a wedding reception. If the base surface area of the book is 0.04 m^2. How much pressure (in pascals) is the book applying on the gelatin dessert?

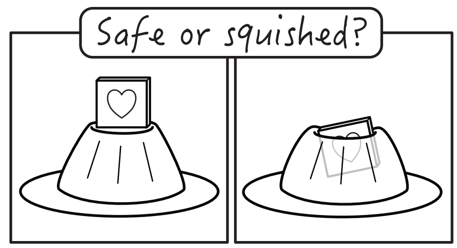


$\frac{12\text{ N}}{0.04\text{ m}^2} = 300\text{ Pa}$

The book is applying 300 pascals of pressure on the dessert.

3. The gelatin desert can withstand pressure of 400 pascals before collapsing. The wedding planner wants the book to be set on edge so it has better visibility. Is this a good idea, or would the new orientation squish the desert?

The base surface area when the book is upright is 0.003 m^2.



$\frac{12\text{ N}}{0.003\text{ m}^2} = 4{,}000\text{ Pa}$ The pressure from an upright book will squish the dessert, but putting a not-too-heavy plate underneath the book would fix that!

4. The pressure exerted by a fluid is evenly applied in all directions. Explain why this is the case.

The molecules in a fluid are moving constantly with rapid motion. The collisions of the molecules against the other object will produce an even pressure that is the same in all directions.

5. If an elephant with a mass of 4000 kg stands on 2 feet, each with a surface area of 0.2 m^2, what is the pressure exerted on **each foot** in kPa? (Tip: 1kg = 9.8 N on Earth.)

Each foot is supporting 2000 kg for a total force of $2000\text{ kg} = 2000\text{ kg} \cdot \frac{9.8\text{ N}}{1\text{ kg}} = 19{,}600\text{ N}$.

The total pressure is force divided by area:

$$\frac{\text{force}}{\text{area}} = \frac{19{,}600\text{ N}}{0.2\text{ m}^2} = 98{,}000\ \frac{\text{N}}{\text{m}^2} = 98{,}000\text{ Pa} = 98\text{ kPa}.$$

7. If the **area** over which a force is applied **increases**, what will happen to the pressure?
   A. It increases
   B. It decreases
   C. It remains the same

8. A 10 N force is applied to a region of area 2 m^2 while a 20 N force is applied to a region of area 4 m^2. Which force created more pressure?
   A. The 10 N force
   B. The 20 N force
   C. Both created the same amount of pressure
   D. There is no way to know

   10N/2m^2 = 5 Pa of pressure
   20N/4m^2 = 5 Pa of pressure

9. What unit is used to measure tire pressure in the US, Canada, and the UK?

   PSI or pounds per square inch

10. Rank the following activities from MOST to LEAST pressure applied on a surface. (Assume that the same person is doing all 5 actions)
   A. Lying down B. Sitting on bench C. Standing on tiptoes D. Standing on one foot.

   C, D, B, A.

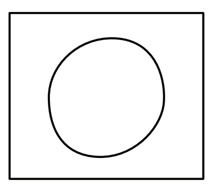
   The same weight applied to a smaller area of contact will result in greater pressure.

11. Which statement about oobleck (a 1:1 mixture of cornstarch and water) is true?
   A. More stress or force causes the viscosity to increase
   B. More stress or force causes the viscosity to decrease
   C. Stress or force has no effect on viscosity
   D. Oobleck is called a "Newtonian fluid"

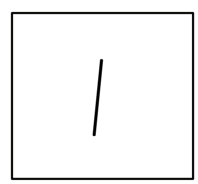
12. Which will exert more pressure on the ground, the footprint of a person wearing ice skates or an elephant? The ice skates are worn by a 110 lb person. The elephant has a mass of 8,800 lb. Each of them have all of their feet on the ground. Calculate the pressure (PSI) for each.
   A. Ice skater
   B. Elephant

   Skater pressure : $\frac{\text{force}}{\text{area}} = \frac{110 \text{ lb}}{2 \cdot 1.5 \text{ in}^2} \approx 36.7 \text{ PSI}$

   Elephant pressure : $\frac{\text{force}}{\text{area}} = \frac{8,800 \text{ lb}}{4 \cdot 250 \text{ in}^2} \approx 8.8 \text{ PSI}$



Surface area of elephant footprint = 250 in^2



Surface area of single ice skate = 1.5 in^2

13. Next the ice skater and elephant each balance on one foot. Who exerts more pressure on the ground?
   A. Ice skater
   B. Elephant

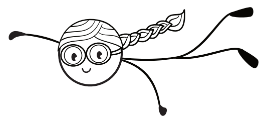
   Skater pressure : $\frac{\text{force}}{\text{area}} = \frac{110 \text{ lb}}{1.5 \text{ in}^2} \approx 73.3 \text{ PSI}$

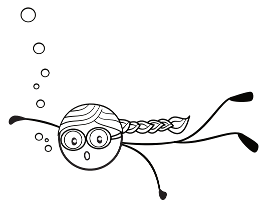
   Elephant pressure : $\frac{\text{force}}{\text{area}} = \frac{8,800 \text{ lb}}{250 \text{ in}^2} \approx 35.2 \text{ PSI}$

Going for a Swim

Think about it:

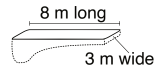
At surface:
Ears don't pop



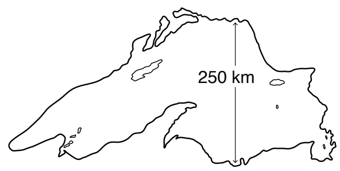


8 feet deep:
Ears pop

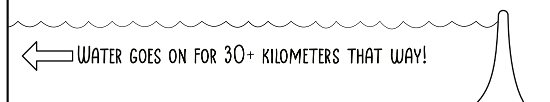
Backyard pool:
48 cubic meters



Average depth = 2 m



Lake Superior:
12.1 trillion cubic meters



Large lake, 3 meters deep and over 30 km wide

Koi pond, 3 meters deep and 1.5 meters wide

When Emily dives 8 feet deep in a backyard pool, she feels her ears "pop" as the pressure changes. Would there be more, less, or the same pressure diving to 8 feet in Lake Superior?

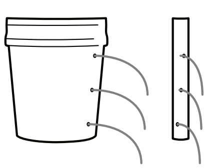
Answers will vary, but students might know from experience that the feeling of increased pressure from being a certain depth underwater is the same regardless of how large the pool or lake is.

Which of these dams would experience more pressure? The one holding back a large lake or koi pond?

Predictions will vary! The actual answer is that the height is the same for both dams so the pressure is also the same.

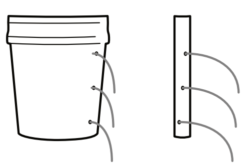
Holes are drilled in a 5 gallon bucket and a narrow piece of pipe. The holes are the same diameter and depth. Which of these drawings matches your prediction for how the water will flow out?

A



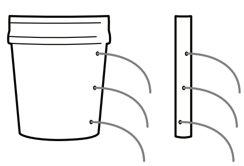
Stronger spouts from bucket but same from all holes. Hole position doesn't matter but container size does.

B



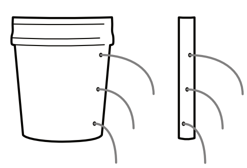
Stronger spouts from pipe but same from all holes. Hole position doesn't matter but container size does.

C



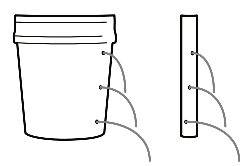
Same-sized spouts from all of the holes. Position and container shape make no difference.

D



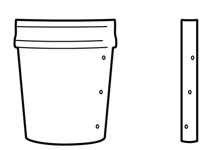
Stronger spouts from top but same pattern from bucket and pipe. Hole position matters, not container size.

E



Stronger spouts from bottom but same pattern from bucket and pipe. Hole position matters, not container size.

F



Something different? Draw your prediction here!

Make a prediction and give a reason to support it.

Predictions will vary! Any prediction is valid so long as there is a reason to support it.

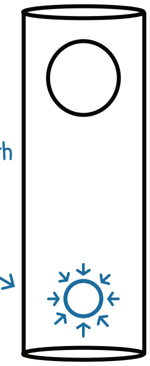
Record the results:

The results demonstrated in class will show that option E is what happens. Depth from the surface is what determines the pressure, not the volume of the container.

Going for a Swim

What shape would a balloon have deep under water?

A balloon would be smaller at greater depth but stay spherical.



$P_{(fluid)} = \rho gh$

The pressure of a fluid is the product of its density (ρ), acceleration due to gravity (g), and the height of the fluid column (h).

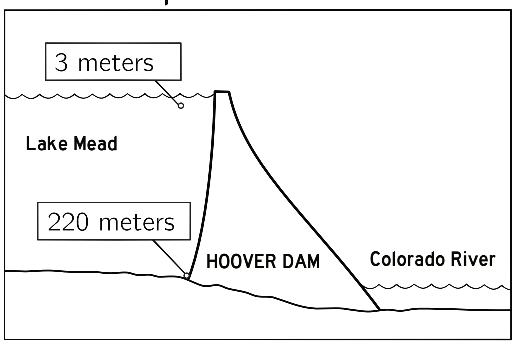
On Earth, $g = 9.8\ m/s^2$

A CONFINED FLUID APPLIES PRESSURE ___EVENLY___ IN ___EVERY___ DIRECTION.

Fluids with higher density exert more pressure (ex water vs air, molasses vs water)

Pressure increases with depth! In any liquid, the deeper you go , the higher the pressure.

Calculate the pressure:



Calculate the water pressure behind Hoover Dam near the top of the dam (3 m deep) and at the bottom of the dam (220 m deep). The density of water is 1,000 kg/m^3.

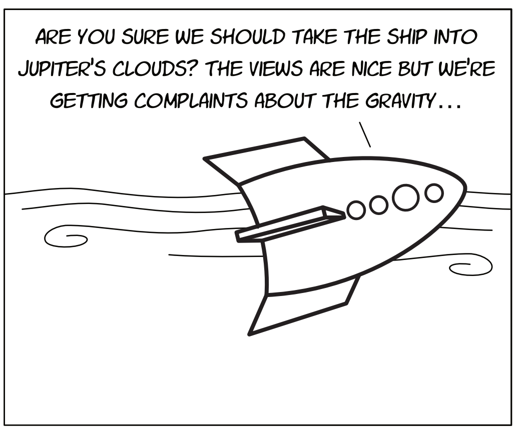
Pressure = ρgh (density · gravity · depth)

Pressure at 3 m = 1,000 kg/m^3 · 9.8 m/s^2 · 3m = 29,400 pascals

Pressure at 220 m = 1,000 kg/m^3 · 9.8 m/s^2 · 220m =2,156,000 pascals

The pressure is much higher at the bottom of the dam!

In kPa, the pressures are 29.4 kPa and 2,156 kPa.



Calculate the pressure someone would experience if they were swimming at 3 m deep in a pool of water on Jupiter, where the acceleration due to gravity is 24.79 m/s^2.

How deep would someone need to swim on Earth to experience the same pressure?

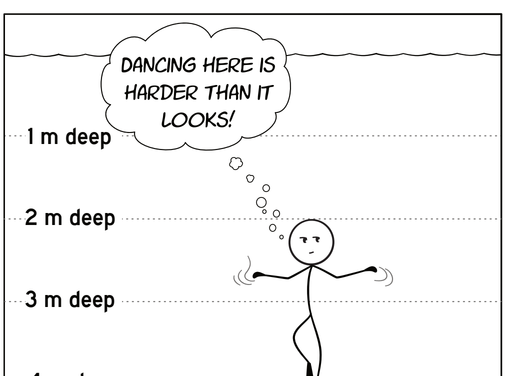
Pressure = ρgh (density · gravity · depth)

Pressure at 3 m = 1,000 kg/m^3 · 24.79 m/s^2 · 3m = 74,370 pascals

To find the depth, use $P = \rho gh$ where P = 74,370 Pa and h is unknown:

74,370 Pa = 1,000 kg/m^3 · 9.8 m/s^2 · h

Solving for h, we find that the depth would be 7.59 meters (close to 25 feet deep)

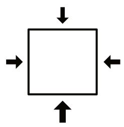


Bob is performing an underwater dance while standing on the bottom of a swimming pool. Calculate the water pressure at Bob's head (2 m deep) and his feet (4 m deep).

Pressure at 1 m = 1,000 kg/m^3 · 9.8 m/s^2 · 2m = 19,600 pascals

Pressure at 3 m = 1,000 kg/m^3 · 9.8 m/s^2 · 4m = 39,200 pascals

Going for a Swim

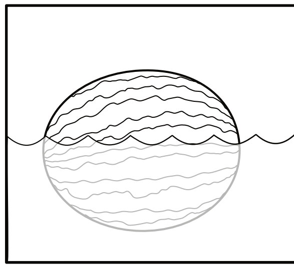


Because pressure increases with depth, the pressure against the bottom of an object in a fluid will always be greater than the pressure against the sides or top. This net upward force is called the **buoyant force**.

ARCHIMEDES PRINCIPLE

An immersed object will be buoyed up by a force equal to the weight of the water it displaces!

Example 1: floating watermelon



The melon displaces 5.91 kg of water. The weight of 5.91 kg of water is approximately 58 newtons.

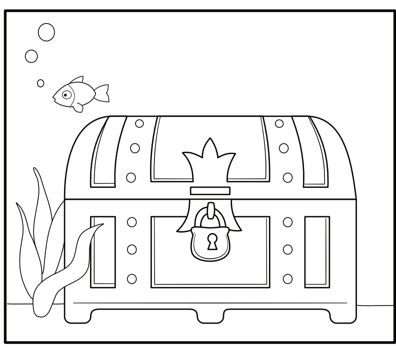
WHAT IS THE BUOYANT FORCE ON THE WATERMELON?

58 N

IS THE WEIGHT OF THE WATERMELON MORE, LESS, OR EQUAL TO 58 NEWTONS?

Equal

Example 2: treasure chest at ocean bottom



The chest displaces 475 kg of water. The weight of 475 kg of water is about 4,660 newtons.

WHAT IS THE BUOYANT FORCE ON THE CHEST?

4,600 N

IS THE WEIGHT OF THE TREASURE CHEST MORE, LESS, OR EQUAL TO 6,622 NEWTONS?

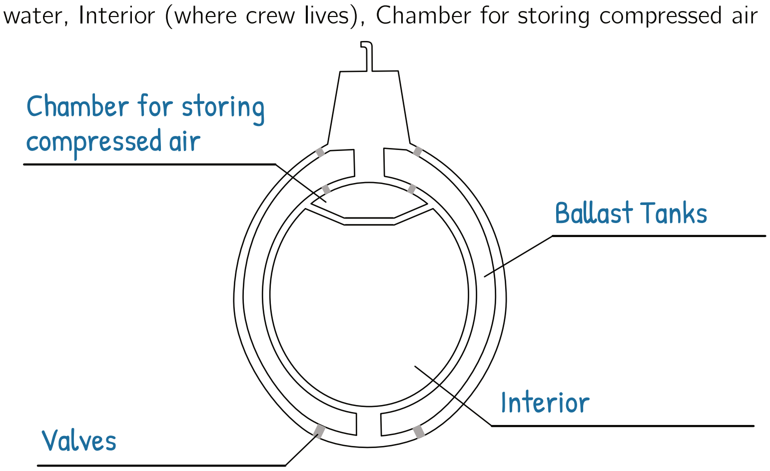
More. If the weight of the chest were equal or less than the buoyant force, then it would be suspended in water or floating.

WHY DOES THE WATERMELON FLOAT WHILE THE TREASURE CHEST SINKS?

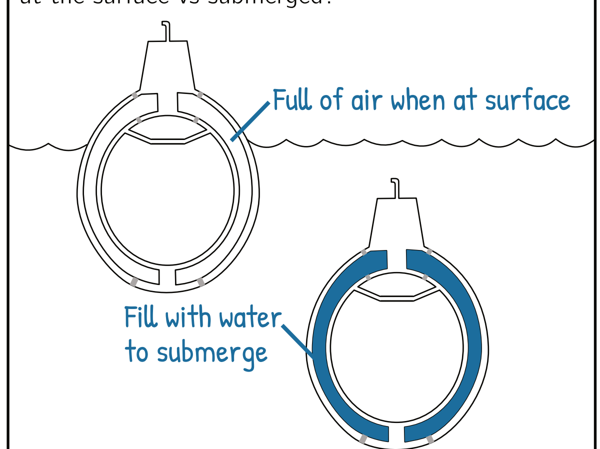
The chest weighs more than the weight of the water it displaces so the chest weighs more than 4,600 N (1,034 pounds). This is true of all objects that sink. Floating objects have a weight equal to the weight of the water they displace. So the weight of the watermelon weight must be equal to 58 N (13 pounds) for it to float.

How a submarine works

Label the following: Ballast Tanks, Valves to release or intake air or water, Interior (where crew lives), Chamber for storing compressed air



How do the ballast tanks differ when the sub is at the surface vs submerged?



Practice Problems – Going for a Swim

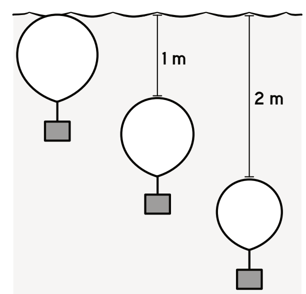
1. How does the volume of a completely submerged object compare with the volume of the water displaced?
   A. The submerged object has more volume than the water displaced.
   B. The submerged object has the same volume as the water displaced.
   C. The submerged object has less volume than the water displaced.
   D. It depends on the exact shape of the object.

2. How does the weight of a floating object compare with the weight of the water displaced?
   A. The floating object has more weight than the water displaced.
   B. The floating object has the same weight as the water displaced.
   C. The floating object has less weight than the water displaced.
   D. It depends on the exact shape of the object.

3. Why is it easier to lift an object submerged in liquid?

   The buoyant force upward is equal to the weight of the water that has been displaced, so the object loses the weight of the water that is displaced.

4. A balloon is attached to a heavy weight and placed in water. Arrange the buoyant force on the balloon from least to greatest for these positions: at the surface, 1 m below the surface, and 2 m below the surface.



   The balloon will compress smaller as it sinks, so it displaces less water the lower it goes. The buoyant force decreases as the amount of water displaced decreases.

   buoyant force at 2 m < buoyant force at 1 m < buoyant force at the surface.

5. Will a basketball float higher in fresh or salt water, or will it have the same amount of ball floating above the water in each type? Explain.

   Salt water is more dense than fresh water. A basketball will displace water equal to its weight, so it will displace less salt water than fresh water. The result is that more of the volume of the basketball will be above the water line in salt water.

6. A 15-lb bowling ball seems to weigh just 3 lb when submerged in water. What is the weight of the water it displaced?

   The buoyant force upward had a magnitude of 12 lb to account for the difference in weight of the ball in water. From Archimedes principle, we know the bowling ball displaced 12 lb of water.

Practice Problems – Going for a Swim

(7) Explain why most of an iceberg is underneath the water.

Ice is just a little less dense than water. The iceberg displaces its weight worth of water which would have a volume just a little less than the iceberg itself, so most of the iceberg is beneath the surface.

(8) When an ice cube floating in a glass of water melts, what will happen to the water level in the cup? Will it rise, fall, or remain unchanged?

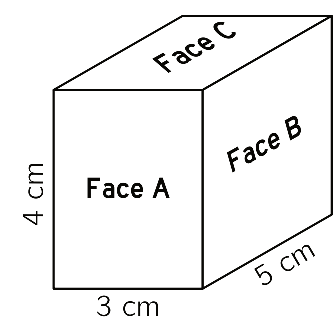
The water level remains unchanged. An ice cube displaces its weight of liquid water. When the ice cube melts, its volume matches exactly the water that it displaced when it was solid.

(9) Explain why a sharp knife cuts better than a dull knife.

A sharp knife has a much smaller surface area along the blade than a dull knife Pressure = force/area, so the pressure the sharp knife exerts for a given amount of force is greater than the pressure a dull knife (with a larger area) exerts.

(10) A box measures 3 cm × 4 cm × 5 cm and weighs 6 N. Calculate how much pressure it exerts on the table when it is laying on each of its faces.

Pressure = force/area. The areas and pressures will be:



FACE A: 3 cm × 4 cm = 12 cm^2=0.0012 m^2,
Pressure = 6 N/0.0012 m^2 = 5,000 Pa = 5 kPa

FACE B: 4 cm × 5 cm = 20 cm^2=0.002 m^2,
Pressure = 6 N/0.002 m^2 = 3000 Pa = 3 kPa

FACE C: 3 cm × 5 cm = 15 cm^2=0.0015 m^2,
Pressure = 6 N/0.0015 m^2 = 4,000 Pa = 4 kPa

(11) What would exert greater pressure, swimming 1 m deep (3.28 ft) in honey or swimming at a depth of 2 m (6.56 feet) deep in water? Both pools are located on Earth. The pool of water has a density of 1,000 kg/m^3 and the pool of honey has a density of 1,400 kg/m^3.

Pressure = density · acceleration due to gravity (9.8 m/s^2) · depth

(If using kg/m for density and m for depth, the units work out to be N/m which = pascals)

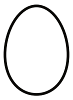
WATER PRESSURE at 2 m deep = 1,000 kg/m^3 · 9.8 m/s^2 · 2 m = 19,600 pascals (19.6 kPa)

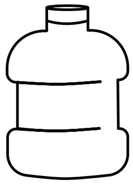
HONEY PRESSURE at 1 m deep = 1,400 kg/m^3 · 9.8 m/s^2 · 1 m = 13,720 pascals (13.72 kPa)

The water exerts more pressure than honey at these depths. But we still wouldn't recommend swimming in honey.

EGG IN A BOTTLE

MATERIALS


2 to 3 medium-size hard boiled eggs


A bottle or container with an opening just a little smaller than an egg.

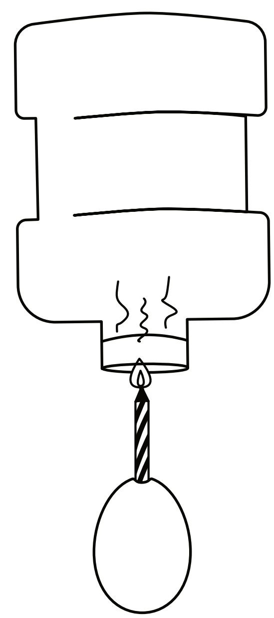

A small candle


A lighter or a match

GOALS

- Change the pressure in a container by altering the temperature.
- Demonstrate the strength of atmospheric pressure.

Pre-lab Question: What is suction, and how is it created?

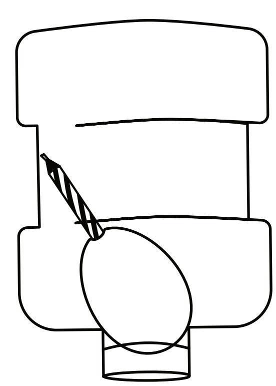


INSTRUCTIONS:

1. Peel a hard boiled egg.
2. Obtain a container that has a mouth that is a little smaller than the hard boiled egg so that the egg will block the opening.
3. Stick the candle in the narrow end of the egg and light the candle.
4. While holding the egg and candle upright, slowly lower the container to cover the egg.
5. Watch in amazement as the egg is pulled inside the container.

EXPLANATION:

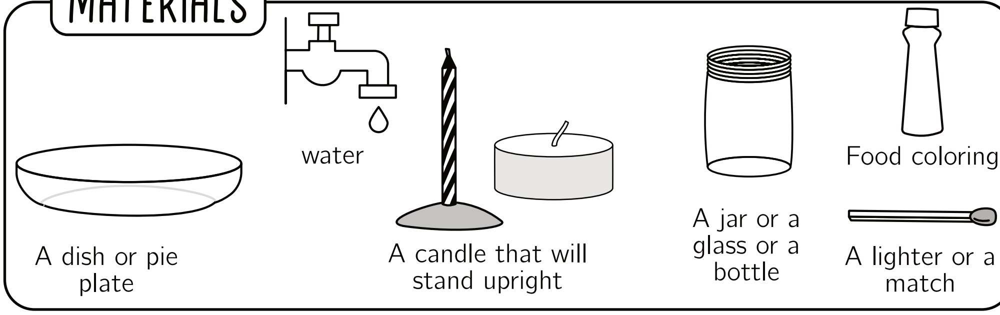
The hot flame heats up the air inside the bottle causing the air to expand as its molecules get excited. Without the heat of the flame, the air molecules cool quickly. Normally, other air would rush in to fill the bottle as the cooler air inside contracts, but the egg blocks the opening. The pressure outside the bottle is higher than the pressure inside the bottle, so it pushes the egg until it is pulled inside.



Did it work? If not, then write about what might have gone wrong. If so, then write some advice that would help another student carry out this demonstration.

RISING WATER

MATERIALS



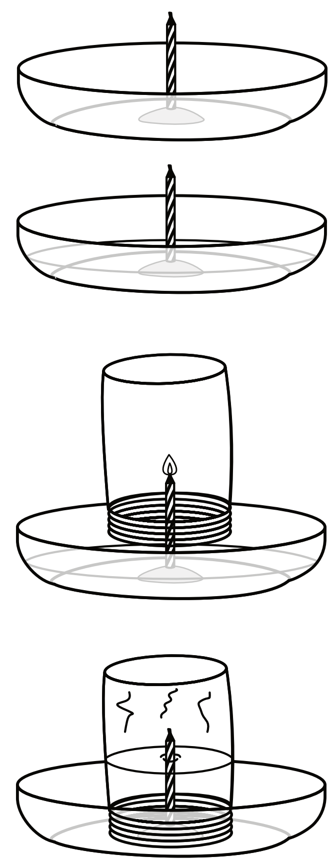
GOALS

- Create "suction" using a drop in temperature.
- Demonstrate the strength of atmospheric pressure.

Pre-lab Question: What is a vacuum? How is one created?

INSTRUCTIONS:

1. Place an upright candle in the center of a dish. If needed, use dough or gum to get your candle to stand on its own.
2. Use food coloring to color the water and add it to the dish so that it is more than a centimeter deep.
3. Light the candle.
4. Invert the jar, and slowly lower it over the candle and set it upside down on the dish.
5. Watch as the candle goes out and the water is pulled into the jar.



EXPLANATION:

The hot flame heats up the air inside the jar causing the air to expand as its molecules get excited. Without the heat of the flame, the air molecules cool quickly. Normally, other air would rush in to fill the jar as the cooler air inside contracts, but the water at the bottom blocks any air from coming in. The pressure outside the jar is higher than the pressure inside the bottle, so water is pushed into the jar.

Did it work? If not, then write about what might have gone wrong. If so, then write some advice that would help another student carry out this demonstration.

____

____

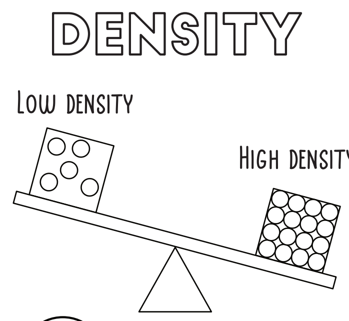
____

Density

Density is a measure of how much mass or matter

Is in a given amount of space or volume.

Common units = g/cm³ or kg/L or kg/m³. Note: 1 ml = 1 cm³



$\rho = \frac{m}{V}$ Density = $\frac{\text{mass}}{\text{volume}}$

Good to Know

The density of water: 1 g/cm³ or 1 kg/L or 1,000 kg/m³*

**It's actually 0.9998395 g/ml at 4.0° Celsius or 39.2° Fahrenheit. But in most cases, 1 g/cm³ is close enough!*

1 A cube of sugar has a volume of 2 cubic centimeters and a mass of 3.6 grams. What is its density?

Density = mass/volume, so 3.6g/2cm³ = 1.8 g/cm³

* A sugar cube sinks in oil because it is has a higher density than the oil

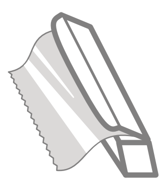
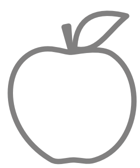
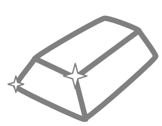
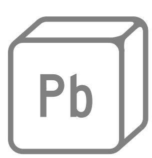
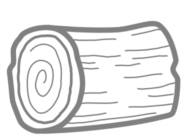
2 250 milliliters of olive oil weighs 215 grams. What is the density of olive oil?

Density = mass/volume. Remember ml = cm³, so 250 ml = 250 cm³

so 215g/250cm³ = 0.86 g/cm³

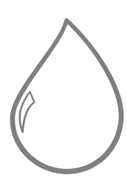
Will it sink or float?

Complete the table to show whether the 9 objects below would float or sink in the following liquids.

 Air at sea level 1.2 kg/m³	 Aluminum 2,700 kg/m³	 Apple 814 kg/m³
 Gold 19,300 kg/m³	 Frozen water 917 kg/m³	 Lead 11,340 kg/m³
 Platinum 21,090 kg/m³	 Sea water at 25°C 1,024 kg/m³	 Wood (maple) 700 kg/m³

*While certain shapes of aluminum can float on water (such as an aluminum foil boat) a solid cube or bolt of aluminum sinks.

	Water at 4°C	Honey	Mercury
Platinum	SINK	SINK	SINK
Gold	SINK	SINK	SINK
Lead	SINK	SINK	FLOAT
Aluminum *	SINK	SINK	FLOAT
Sea Water	SINK	FLOAT	FLOAT
Frozen Water	FLOAT	FLOAT	FLOAT
Wood (maple)	FLOAT	FLOAT	FLOAT
Apple	FLOAT	FLOAT	FLOAT
Air	FLOAT	FLOAT	FLOAT



Density of water at 4 °C is 1,000 kg/m³

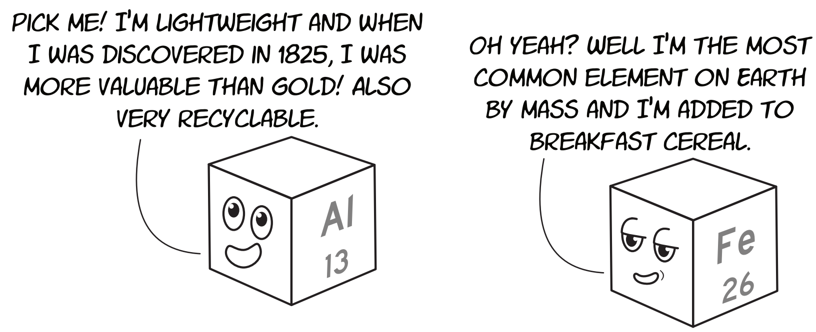
Density of honey is 1,400 kg/m³

Density of mercury is 13,590 kg/m³

Buoyancy

What has greater buoyancy and why?
A cubic meter of aluminum or a cubic meter of iron?

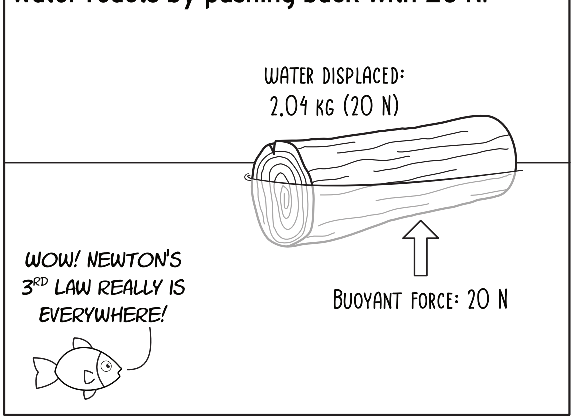
Their buoyancy will be the same! They both displace 1 cubic meter(1,000 kg) of water so they will both experience a buoyant force of 1,000kg·9.81 m/s² = 9,810 N



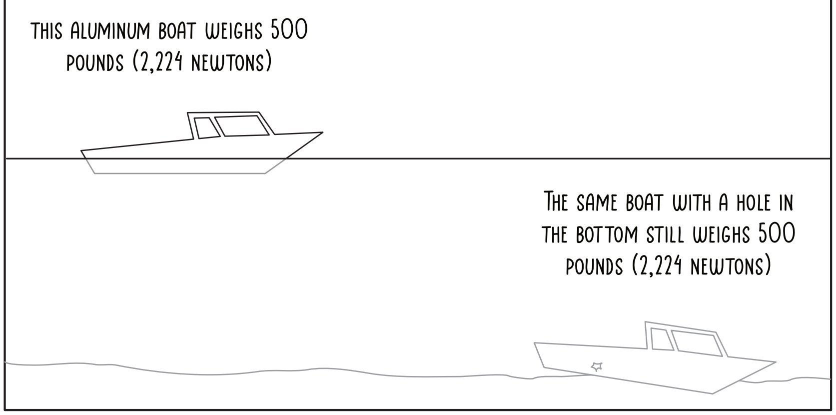
MISCONCEPTION ALERT!

Students sometimes think heavier objects experience more buoyant force, but buoyancy is determined by the VOLUME of an object, not its WEIGHT. Here are 2 cartoons to help you avoid this trap. Which do you like best?

If the log pushes 20 N of water aside, then the water reacts by pushing back with 20 N!



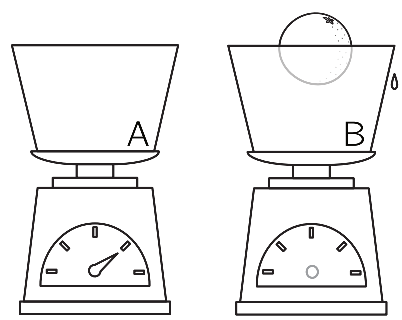
Weight or density alone won't tell you if an object will sink or float!



Use the floatation principle to answer the following questions:

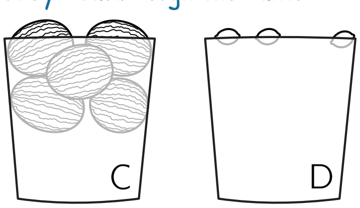
1. A container **full to the brim** with water weighs 30 newtons (A). How much would the container weigh after a grapefruit is placed in the water (B)? *Note: adding the fruit will cause water to spill over the edge.*

   30 newtons! As long as the container was full of water, it would weigh the same no matter what was floating in it.



2. What would weigh more, a 40 liter bucket **full to the brim** with water with 5 watermelons floating in it (picture C) or a 40 liter bucket with 3 floating lemons (D)?

   They would weigh the same.

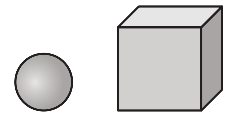


FLOATATION PRINCIPLE:

A FLOATING OBJECT ALWAYS DISPLACES A WEIGHT OF FLUID EQUAL TO ITS OWN WEIGHT.

Practice Problems – Density & Buoyancy

1. What has higher density, a 1 kg sphere of iron or a 10 kg cube of iron?
   A. The sphere
   B. The cube
   C. They have the same density because they're both made of iron
   D. There's not enough information to tell



2. If something weighs 1 gram and has a volume of 1 cubic centimeter, what is its density?
   A. 1 g/cm^3
   B. 1,000 kg/m^3
   C. Both A and B
   D. None of the above

$$\frac{1\,\text{g}}{1\,\text{cm}^3} = \frac{1\,\text{g}}{1\,\text{cm}^3} \cdot \frac{1\,\text{kg}}{1000\,\text{g}} \cdot \left(\frac{100\,\text{cm}}{1\,\text{m}}\right)^3 = 1000\,\frac{\text{kg}}{\text{m}^3}.$$

3. Rank the following substances from most to least dense: air, gold, ice, wood, and water.

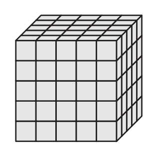
gold	water	ice	wood	air
MOST DENSE				LEAST DENSE

4. What is more dense, 10 grams of gold or 500 grams of aluminum?

Gold is more dense than aluminum. The amount present doesn't affect the density.

5. Is it possible that a hollow cube could be more dense than a solid cube? Explain.

Yes. The outer casing of the hollow cube could be made of a dense material, and the solid cube could be made of a very light material.



6. A tank full of ice weighs less than the same tank full of water. Why?

The water is more dense than the ice, so the water weighs more when occupying the same space.

Another way to think about it is that the water would expand when it freezes, so some of it would have to be removed to exactly fill the tank with ice.

7. What will happen to a wooden block's buoyant force if it is submerged deeper in water?
   - A. The buoyant force will increase because the block is deeper.
   - B. The buoyant force will decrease because the block is under more water.
   - C. The buoyant force will remain the same regardless of how deep the block is submerged.
   - D. The wooden block will dissolve, making the buoyant force irrelevant.

Answer: C. The buoyant force will remain the same regardless of how deep the block is submerged because it depends on the volume of water displaced by the object, which does not change with depth.

8. A baseball has a volume of 212 cm^3 and a mass of 0.145 kg. Is it more or less dense than water? Would you expect the baseball to float or sink in water?

The baseball has a density of 145 g/ 212 cm^3 = 0.684 g/cm^3 which is less than the density of water (1 g/cm^3) so the baseball would float on water.

9. Cork has a density of 300 kg/m^3. What would be the mass in grams of a sample of cork with a volume of 100 cm^3?

$$\frac{300\text{ kg}}{\text{m}^3}\cdot 100\text{ cm}^3 = \frac{300\text{ kg}}{\text{m}^3}\cdot 100\text{ cm}^3\cdot\left(\underbrace{\frac{1\text{ m}}{100\text{ cm}}}_{1}\right)^3\cdot\underbrace{\frac{1000\text{ g}}{1\text{ kg}}}_{1} = 30\text{ g}$$

10. If an object is lighter than the air it displaces, what will happen to the object?
    - A. It will rise until it reaches an area of air with similar density.
    - B. It will fall to the ground
    - C. It will rise indefinitely
    - D. It will remain stationary where it is.

11. A cube of sugar has a volume of 2 cubic centimeters and a mass of 3.6 grams. What is its density?

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{3.6\text{ g}}{2\text{ cm}^3} = 1.8\,\frac{\text{g}}{\text{cm}^3}.$$

12. A rubber ball floats in water so that it is exactly half submerged. What is the density of the rubber ball?

The ball must have half the density of water. Imagine if all the mass of the ball were in the submerged half. Then we could remove the top half without changing the mass, but the density would double and be exactly equal to the density of water. Since water has a density of 1000 kg/m^3, the ball has a density of 500 kg/m^3.

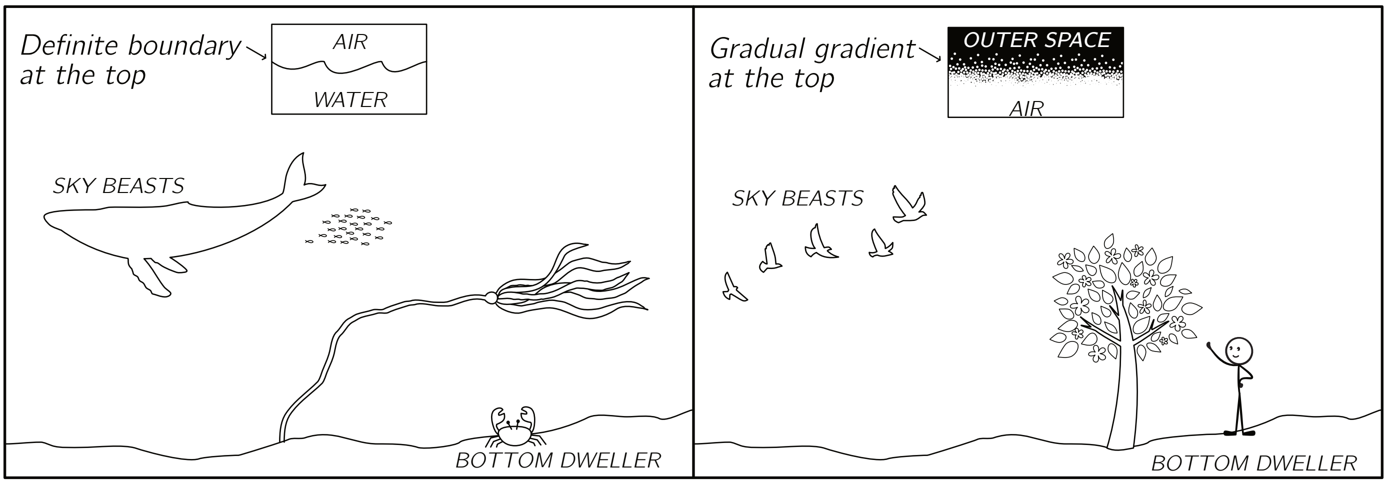
An Ocean of Air

Fill in the blanks:

expand *pressure* *fluids* *decreasing* *increasing*

Water and air are both fluids, and they share several characteristics in common. Higher temperatures will cause the volume of both substances to expand. Both air and water also have increasing pressure at increasing depth. We live submerged in an ocean of air! Since humans live at the bottom of the atmosphere, we often talk about pressure decreasing with elevation.

OCEAN OF WATER   OCEAN OF AIR



When Math Dad stands on two feet, he exerts a pressure of 2.51 PSI on the floor. Using that as a reference, how much pressure do you think the atmosphere is exerting on you right now?

- [ ] 1/10 smaller
- [ ] 1/5 smaller
- [ ] Equal
- [x] 5x bigger
- [ ] 10x bigger

Which demonstration from class was your favorite? How did it work?

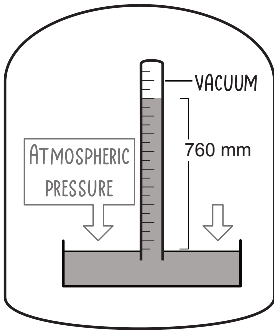
Answers will vary! Brief explanations are:

Can crush: If a certain amount of steam takes up 1 unit of space, when it condenses it will only occupy 1/1600 as much volume. But when the can is inverted and cooled, a partial vacuum forms inside the can. Atmospheric pressure then crushes the can.

Break Ruler with Newspaper: When the ruler is pushed downward it must lift up the paper. Atmospheric pressure on the paper is strong enough that the ruler will break if it is pushed down quickly.

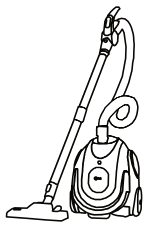
Magdeburg sphere: If air is pumped out, the atmospheric pressure on the spheres is so strong, they can't be pulled apart!

An Ocean of Air



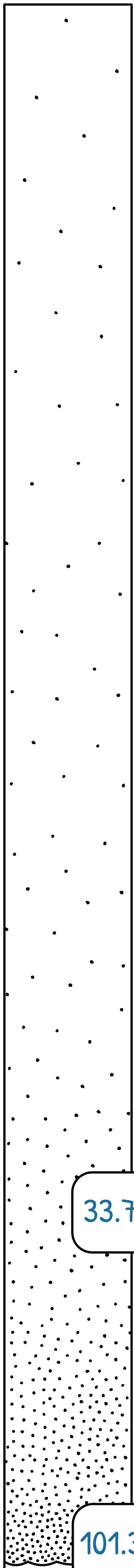
Italian physicist Evangelista Torricelli believed that air had weight and could apply pressure to support a column of water. To test this idea, he filled a glass tube with mercury and inverted it into a dish that was also filled with mercury. This groundbreaking experiment in 1693 led to the development of the mercury barometer, and is why air pressure in weather forecasting is sometimes given in mmHg.

What is Wind? The movement of air molecules, caused (most often) by a pressure difference! Wind is primarily air moving from a region with high pressure to a region with lower pressure.



A physicist says there's no such thing as suction. If this is true, how does a vacuum work?

What we commonly refer to as "suction" is actually the result of differences in air pressure. A vacuum creates an area of low pressure and the pressure of the atmosphere pushes material into it. The same vacuum machine would work better at sea level than at a higher elevation.



33.7 kPa — Air pressure at Mount Everest

101.3 kPa — Air pressure at Sea Level

Boyle's Law

$$P_1V_1 = P_2V_2$$

When temperature is constant, pressure of a gas is inversely proportional to volume.

- Breathing (diaphragm expands, air flows in)
- Syringe (pull plunger and fluid draws in)
- Carbonated beverages (gas dissolved under high pressure, bubbles expand when pressure is lowered)
- Scuba diving

Practice Problems – An Ocean of Air

1. If a sealed 2 liter container contains gas at a pressure of 100 kPa, what will happen to the pressure when the volume is reduced to 1 liter? Assume the temperature remains the same.

   The pressure will double to 200 kPa. Because of Boyle's law ($P_1V_1=P_2V_2$) we know that 2 liter · 100kPa = 1 liter · P_2. Solving for the second pressure gives 200 kPa.

2. When an air bubble rises in water, what happens to the volume of the air?
   A. It increases
   B. It decreases
   C. It remains the same

3. When an air bubble rises in water, what happens to the mass of the air?
   A. It increases
   B. It decreases
   C. It remains the same

4. When an air bubble rises in water, what happens to the density of the air?
   A. It increases
   B. It decreases
   C. It remains the same

5. What keeps a suction cup pressed against a window?
   A. There is more pressure outside the cup than inside the cup
   B. There is less pressure outside the cup than inside the cup
   C. Pressure does not matter, the cup is attached to the window by chemical bonds.

6. Explain in your own words what happens to the air pressure inside a syringe when the plunger is pulled back while its tip is sealed.

   The pressure drops because the same number of air molecules now occupy a bigger space.

Practice Problems – An Ocean of Air

7 Calculate the volume of a room in your home in cubic meters.

Answers will vary but the volume of a room should be calculated by multiplying the width, height, and depth.

8 Estimate the mass of the air in kilograms by using the table provided on this page. Choose an elevation that is most similar to your own.

Answers will vary based on elevation and room size. But as an example:

A 20 m^3 room at sea level would contain 24.12 kg of air.

$20m^3 \cdot 1.206\ kg/m^3 = 24.12\ kg$

Elevation (ft)	Elevation (m)	Weight of 1 m^3 of air at 20 °C
Sea level	Sea level	1.206 kg
1,000 ft	305 m	1.192 kg
2,000 ft	610 m	1.177 kg
3,000 ft	914 m	1.163 kg
4,000 ft	1,219 m	1.149 kg
5,000 ft	1,524 m	1.135 kg
6,000 ft	1,829 m	1.120 kg
7,000 ft	2,134 m	1.106 kg
8,000 ft	2,438 m	1.092 kg
9,000 ft	2,743 m	1.077 kg
10,000 ft	3,048 m	1.063 kg
11,000 ft	3,353 m	1.049 kg
12,000 ft	3,658 m	1.035 kg

Fun Fact: 76 of the 195 countries in the world have capitals that are coastal cities (think Amsterdam, Bangkok, Copenhagen, Jakarta, Tokyo, Washington DC, etc). Here are the elevations of some other capitals:

Beijing, China: Elevation 144 feet (44 meters)	**Bern, Switzerland**: Elevation 1,778 feet (542 meters)
Brasília, Brazil: Elevation 3,540 feet (1,079 meters)	**Nairobi, Kenya**: Elevation 5,550 feet (1,680 meters)
Mexico City, Mexico: Elevation 7,350 feet (2,240 meters)	**La Paz, Bolivia**: Elevation 11,942 feet (3,650 meters)

Bonus content! We didn't have time to focus on the awesome equation PV = nRT, but it's another way you can calculate the mass of air in a room. Just rearrange to solve for number of moles (n):

$$n = PV/RT$$

*Remember **P** should be in kPa (if your atmospheric pressure is unknown, you can calculate the mass of air in your room if it were at sea level: 101.3 kPa)*

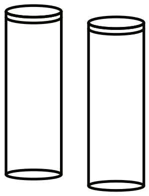
***R** is the ideal gas constant (8.314 J/(mol·K)*

***T** should be in degrees kelvin.*

*Once moles are found, use the average molar mass of air to convert to kilograms. (multiply the value of **n** by 0.029 kg/mol)*

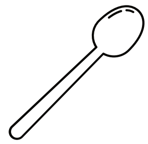
OPTION 1: DENSITY COLUMN

MATERIALS

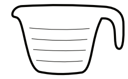


2 tall narrow clear containers

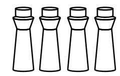
Several liquids of different densities OR sugar and water



Spoon



Measuring cup



Food coloring (optional)

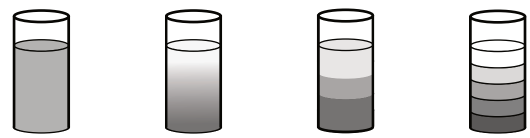
GOALS

- Better understand the concept of density
- Make observations, record data, and communicate conclusions

Pre-lab Questions:

① What is density? Describe it in your own words:

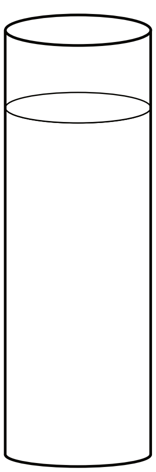
② What do you think will happen when 5 liquids with different densities are layered? Will you see no layers at all? Very blurred layers? 3 layers? 5 layers? Or something else?



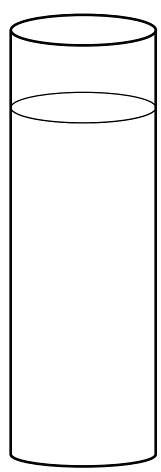
No layers | 2 blurred layers | 3 layers | 5 layers

Draw and explain your prediction for when the liquids are layered from *most dense* on bottom to *least dense* on top (container 1). Also make a prediction for what you expect to see when they are layered from *least dense* on bottom to *most dense* on top (container 2).

PREDICTION FOR CONTAINER 1:



PREDICTION FOR CONTAINER 2:



INSTRUCTIONS:

1. Choose which option of column you want to do and prepare your liquids. If doing the **sugar water column**, make solutions of different concentrations and apply food dye so they are different colors. If doing the **various liquids column**, gather at least 4 of the liquids from the list.
2. Get 2 clear glasses, flasks, or narrow vases of the same size and decide how thick or tall your layers will be. Pour plain water into the vase to see how much of each liquid you will need to make your column. Then pour that water into a measuring cup. This amount indicates how much of each liquid you will use.
3. In the first container, add the amount of liquid you have chosen and arrange the layers from bottom to top. For example, if using sugar water, place the 3:1 sugar water on bottom and plain water on top. If using the layer stack, start with corn syrup on bottom and put rubbing alcohol on top. **Add the layers SLOWLY and CAREFULLY by pouring them onto a spoon held just over the surface**.
4. In the second container, add the liquids in the reverse order.
5. Observe what happens to each layer.

Sugar Water Column
Plain water
1:2 sugar to water ratio
1:1 sugar to water ratio
2:1 sugar to water ratio
3:1 sugar to water ratio

Various Liquids Column
Rubbing alcohol or baby oil
Vegetable oil
Water
Dishwashing soap
Corn syrup or honey

WHAT DID THE COLUMNS LOOK LIKE?

Did your observations match your predictions?

____

____

____

____

CONCLUSIONS

Can you explain the results? What did you learn about density? What tips would you give someone else trying this experiment?

____

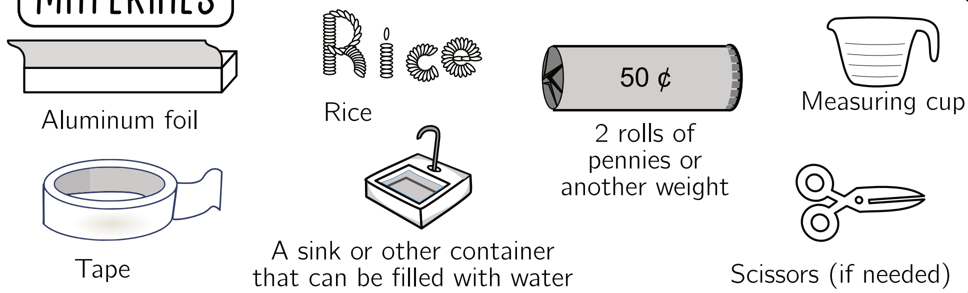
____

____

____

OPTION 2: BOAT FLOAT

MATERIALS



GOALS

Create models to determine if the size and shape of an object affects the maximum density it can support and graph the results

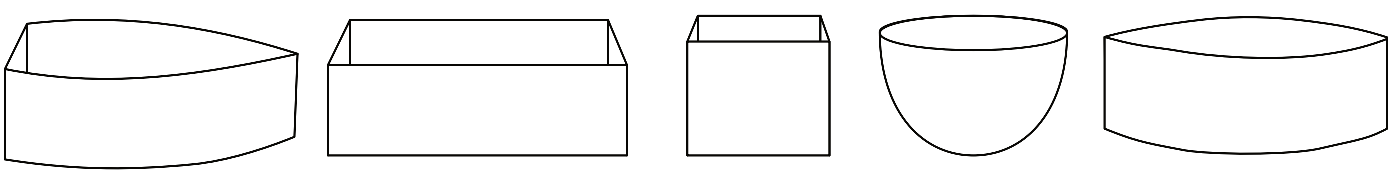
Pre-lab Question:

A bolt or screwdriver made of steel will quickly sink when dropped in water.
How is it that large ships made of steel are able to float?

INSTRUCTIONS:

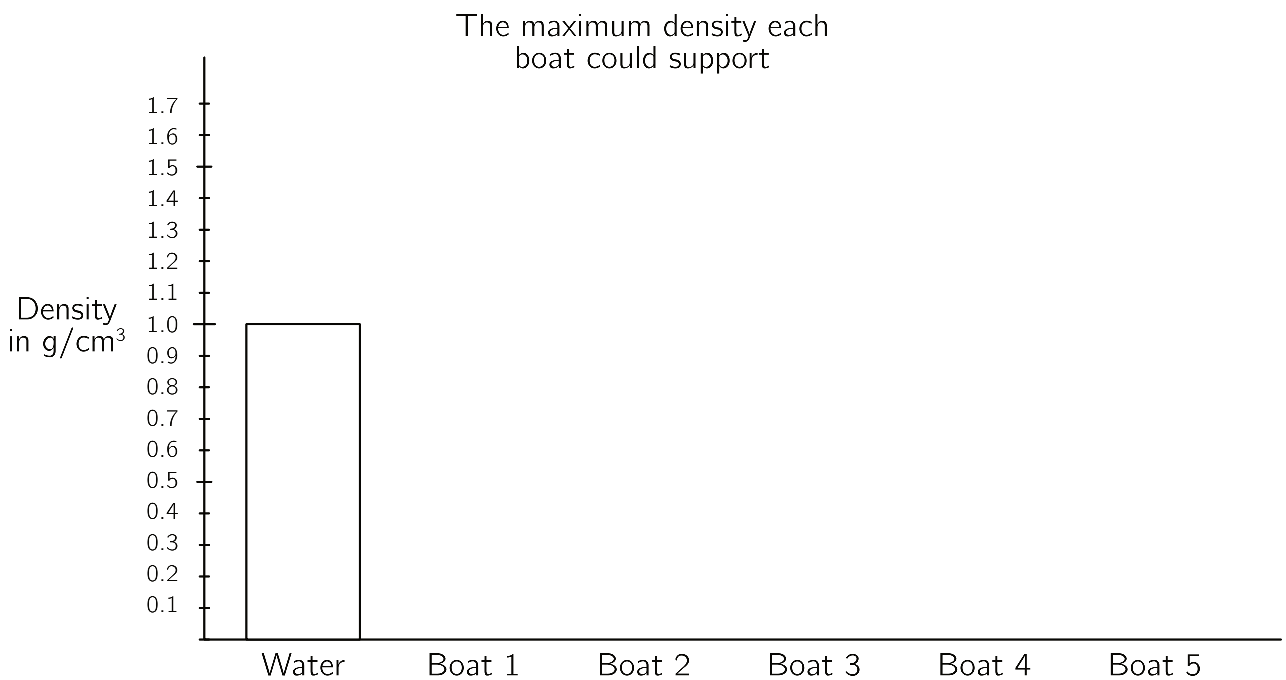
Note: The next page has a chart and a graph that you'll use to complete the project.

1. Use aluminum foil and tape to construct five small boat hulls. Each boat should have a different size and shape (e.g. boxy, pointed, wide, or triangular). Check to make sure your boats do not leak. Each boat should be strong enough to keep its shape when filled with rice.



2. Find the volume of each boat by carefully filling the boat with dry rice. Then pour the rice into a measuring cup with markings for liquids and read the volume in mL. Record the volume in cm^3. Note that 1 mL = 1 cm^3.
3. Measure the buoyancy of each boat hull by floating the boat in a sink or tub and slowly adding dry pennies to the boat. Count the pennies the boat could support before sinking, and then record it.
4. Multiply the number of pennies by 2.5 g/penny to get the mass in grams.
5. Calculate the density of the maximally loaded boat by dividing the number of grams it could support by its volume (recorded in instruction 2. in cm^3).
6. Add bars to the bar chart to display the density of each boat.

Boat	Volume in cm^3 (1 mL = 1 cm^3)	Number of pennies supported	Mass supported (in g)	Density before sinking (in g/cm^3)
1				
2				
3				
4				
5				



Did the shape make a noticeable difference in the maximum density each boat could support?

____

____

Did the total volume make a noticeable difference in the maximum density each boat could support?

____

____

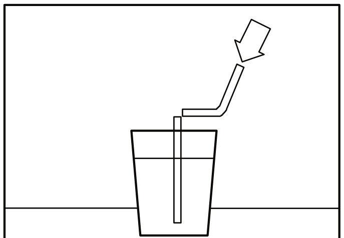
How do you think the results would have turned out differently if you had used a different liquid than water?

____

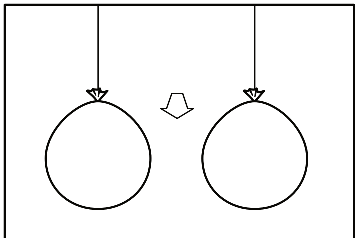
____

Fluids in Motion

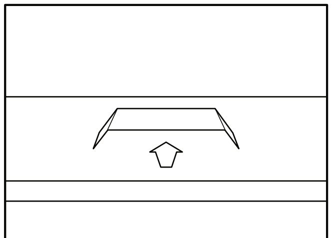
What will happen when the air moves fast in the direction the arrow is pointing?
Draw or record your **prediction** below:



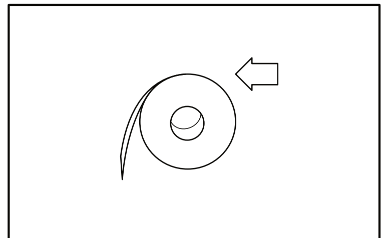
Blowing air over a straw that's in a cup of water



Blowing air between two balloons hanging from string



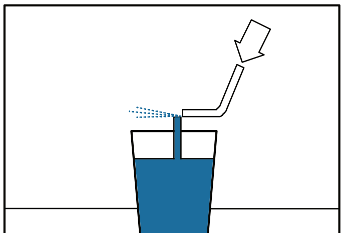
Blowing air under a bent index card resting on a table



Blowing air over the top of a roll of toilet paper

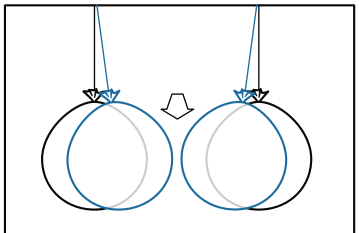
Predictions will vary

Now draw or describe **what happened** when the air moved quickly in these situations:



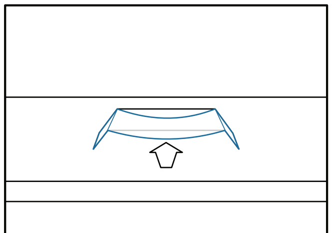
Blowing air over a straw that's in a cup of water

Water goes up and out from the straw!



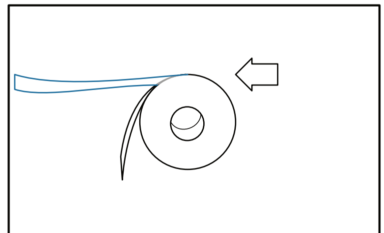
Blowing air between two balloons hanging from string

The balloons move closer together



Blowing air under a bent index card resting on a table

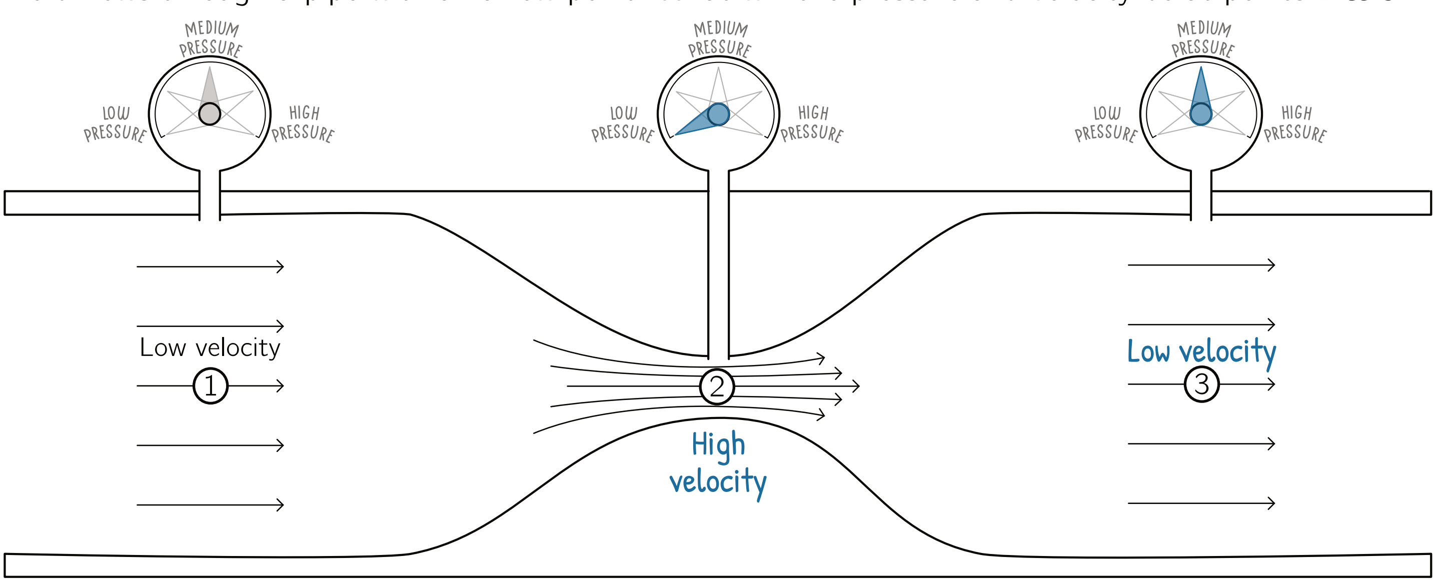
The card pulls down toward the table



Blowing air over the top of a roll of toilet paper

The paper lifts up!

Fluid flows through a pipe with a narrow point. What will the pressure and velocity be at points 2 & 3?

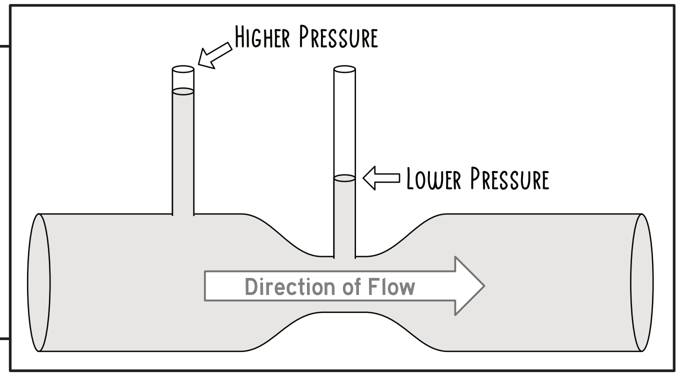


Fluids in Motion

BERNOULLI'S PRINCIPLE

As the velocity of a fluid increases,

the pressure decreases.



Laminar Flow

Fluid moves smoothly in parallel layers with minimal mixing.

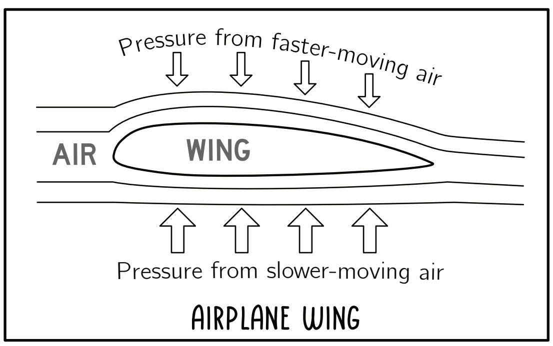
- Predictable
- Less friction or energy loss due to drag
- Movement of objects through fluids are more efficient with laminar flow

Turbulent Flow

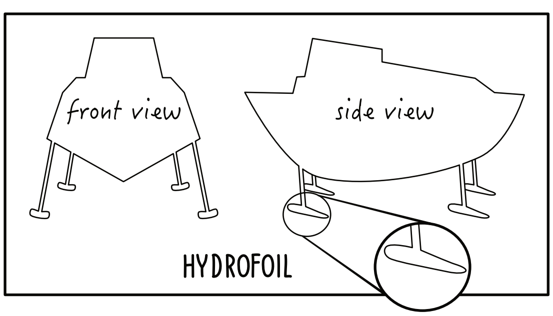
Fluid movement is chaotic and irregular with rapid changes in pressure and flow velocity.

- Unpredictable
- Usually occurs at high velocities or in fluids with low viscosity (ie air)
- Enhances heat transfer and mixing

Here are simple diagrams of an airplane wing, hydrofoil, spoiler, and a reentry capsule. Make a note about how the design of each object interacts with the flow of air or water around it:

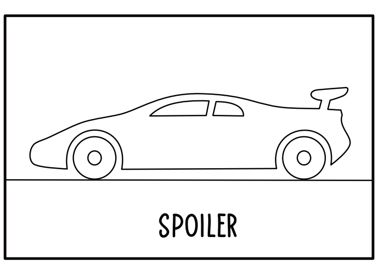


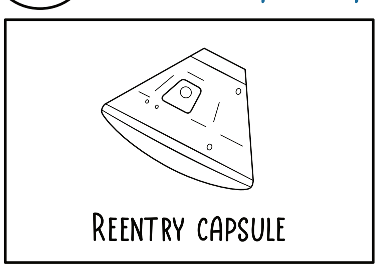
Airplane wing: the curved edge (airfoil) causes air to move faster over the top. As speed increases, lift increases.



Hydrofoil: Similar shape to an airplane wing, but designed for water. As speed increases, lift increases, raising the boat and reducing drag.

Spoiler: Similar shape to an airplane wing, but upside down! The faster the car travels, the more "downforce" the spoiler provides.





Reentry capsule: The blunt front creates a shock wave which deflects intense heat away from the capsule.

The angle and smooth sides encourage laminar flow.

Practice Problems – Fluids in Motion

1. "It is dangerous to stand near a fast-moving train because the Bernoulli effect could cause you to be pulled toward the train."
Is the above statement true or false? Explain.

It is true. The air close to the train is moving with high velocity and thus has lower pressure than air further away from the train. This pressure differential can create a suction effect that can throw other objects off balance and move them toward the train. For the same reason, it's also dangerous for fast moving boats to travel too close to other boats because they can be pulled together and collide.

2. Bernoulli's principle states that as the speed of a fluid increases, its:
A. Temperature increases
B. Temperature decreases
C. Pressure increases
D. Pressure decreases

3. Which of the following is an example of laminar flow?
A. Honey flowing from a spoon
B. Smoke rising from a chimney
C. Water in a fast-moving river
D. Steam erupting from a geyser

4. Which of these principles or laws explains why shower curtains get sucked inward when a shower is running?
A. Newton's 3rd law
B. Boyle's law
C. Archimedes principle
D. Bernoulli's principle

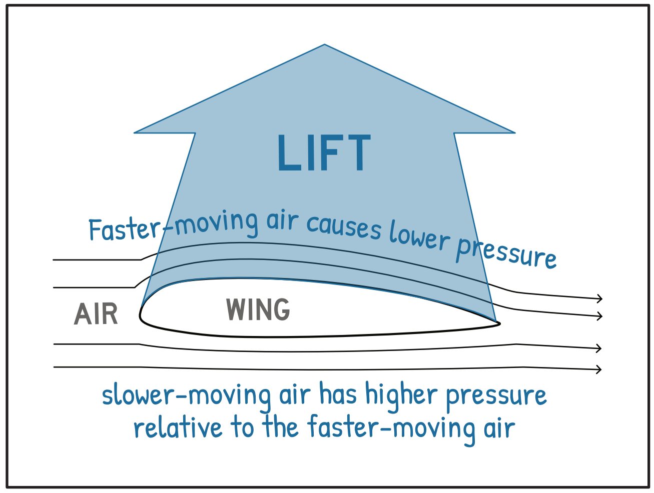
It's the combined result of the Bernoulli effect and hot air rising that pulls the curtain inward

5. Assuming that the fluids are of the same material and temperature, if a fluid is moving at higher speed, it will have:
A. Higher pressure than a slower-moving fluid
B. Lower pressure than a slower-moving fluid
C. The same pressure as a slower-moving fluid
D. There is no way to know whether the pressure will be higher or lower.

6. Laminar flow is most likely to occur in:
A. Narrow, smooth pipes
B. Fast-moving rivers
C. High-velocity air currents
D. Stormy ocean currents

(7) Without looking at the previous pages, can you explain how the shape of an airplane wing generates lift? Diagram this drawing and/or explain below.

Where is the air speed highest? Where is the pressure highest? Where is it lowest?



The wing is curved more on the top and flatter on the bottom, which makes air travel faster over the top surface than the bottom. The faster-moving air has lower pressure and this difference in pressure produces lift. The angle of attack (the angle between the wing and the oncoming air) also contributes to lift.

(8) In most cases, if the cross-sectional area of a pipe decreases, what happens to the flow speed of the fluid?

A. It decreases

B. It increases

C. It remains the same

D. It becomes turbulent

(9) Fluid flowing through a pipe experiences a decrease in pressure when:

A. The pipe widens

B. The pipe narrows

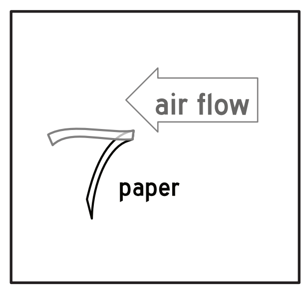
(10) Consider a piece of tissue paper that is hanging vertically in the air as shown. Why does the paper lift up when air is blown over it?

A. Gravity decreases

B. Gravity increases

C. The air flow creates an area of lower pressure above the paper

D. The air flow creates an area of high pressure above the paper



(11) Explain Bernoulli's principle in your own words:

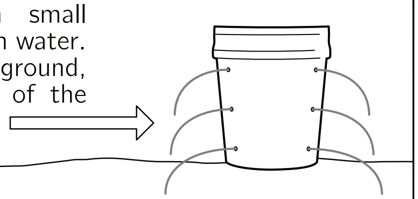
Faster-moving fluid = lower pressure

When Push Comes to Shove

We've learned some neat things about pressure and fluids in this unit! Use what you know to make predictions about what will happen in these 3 demonstrations. Then record what actually happens, and why!

1

A bucket with small holes is filled with water. When on the ground, water flows out of the bucket as shown.



What will happen when the bucket is dropped?

What do you predict will happen and why?

____

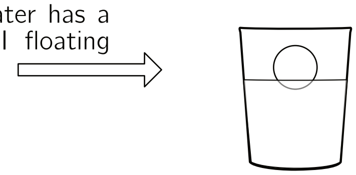
____

____

What actually happened?

2

A cup with water has a ping pong ball floating on the surface.



What will happen when the cup is dropped?

What do you predict will happen and why?

____

____

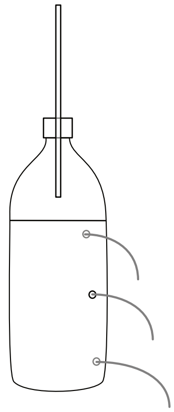
____

3

A bottle filled with water has a hole in the lid. A straw is placed in the hole. The straw fits tightly in the hole. The only way for air to enter the bottle is through the straw.

There are also 3 holes in the side of the bottle.

When the straw is positioned as follows, water flows out of the holes.



What will happen when the straw is lowered into the bottle?

What do you predict will happen and why?

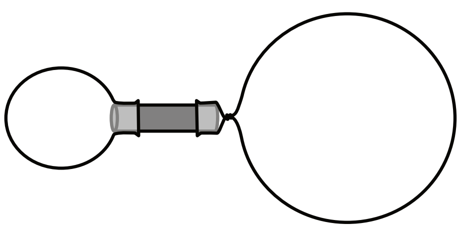
____

____

____

4

Two balloons are connected with a hollow tube as shown, but one of them is twisted so no air can flow in or out.



What will happen when air is allowed to flow?

What do you predict will happen and why?

____

____

____

Practice Problems – When Push Comes to Shove

1. How does drinking through a straw work? Bonus question: why is someone who has had their wisdom teeth out told to avoid drinking anything with a straw for several days?

When someone drinks through a straw, they reduce the air pressure inside their mouth compared to the atmospheric pressure outside the container. This difference in pressure causes the liquid to be pushed up the straw and into the mouth. It's the higher atmospheric pressure acting on the surface of the liquid that does the pushing.

During wisdom teeth removal, a clot forms over the wound which is important for proper healing. If the clot is dislodged it can result in a painful condition called dry socket.

2. What is free fall?
   - A. Movement under the influence of gravity alone.
   - B. Falling without any resistance.
   - C. Falling in a vacuum.
   - D. Any downward movement in air.

3. What does Archimedes' principle state about buoyancy?
   - A. An object will float if it is heavier than the fluid it displaces.
   - B. An object in a fluid experiences a buoyant force equal to the weight of the fluid displaced.
   - C. Buoyancy only applies to objects in water.
   - D. The buoyant force is directly proportional to the depth submerged.

4. Which statement about fluid flow is correct?
   - A. The mass of the fluid entering a system is equal to the mass exiting the system.
   - B. As the cross-sectional area of a pipe decreases, the velocity of the fluid flow also decreases
   - C. As the cross-sectional area of a pipe decreases, the pressure increases
   - D. None of the above

5. Why do objects feel or appear to be weightless when in a state of freefall?

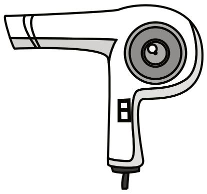
Because the only force acting on them is gravity, and gravity is a non-contact force. Everything inside a freefalling system moves at the same rate.

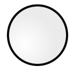
6. A cruise ship can weigh around 200,000 imperial tons, which is over 200 million kilograms! How can such a heavy boat float in water?

Because it is displacing more than 200,000 tons of water, and therefore experiences a buoyant force that is more than its weight.

PING PONG LAUNCH

MATERIALS


Blow Dryer


Ping Pong Ball


Paper towel tube or toilet paper tube

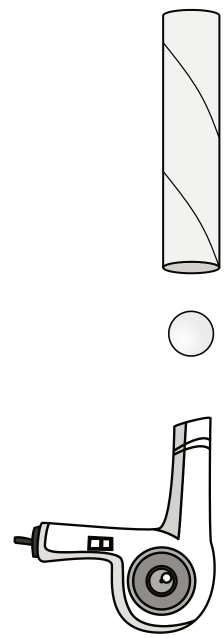
GOALS

- Demonstrate Bernoulli's principle.
- Explain a surprising change in motion using the language of physics.

Pre-lab Question: What is Bernoulli's principle?

INSTRUCTIONS:

1. Turn on the blow dryer on its highest speed setting.
2. Point the blow dryer upward and release a ping pong ball in the air stream so that the ball hovers in place.
3. Tilt the blow dryer to the side to see how far you can tilt it before the ball will fall out of the air stream.
4. While blowing the ping pong ball upward, slowly lower the paper towel tube over the ping pong ball.
5. Watch in amazement as the ball is launched into the air.



EXPLANATION:

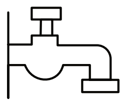
The ping pong ball stays in place because the net forces are balanced. The flowing air pushes against the ball, while gravity pulls the ball. The atmospheric pressure pushes against the ball while a lower pressure from the fast moving air pushes with less force from below the ball. As the blow dryer tilts, the atmospheric pressure is strong enough to push the ball toward the lower-pressure of the fast-moving column of air until it tips far enough that the forces are no longer balanced.

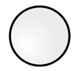
Would this demonstration work with a leaf blower that can blow air much faster than a blow dryer? If so, explain why. If not, what might go wrong?

A BALL ON A STRING

MATERIALS


Tape or a glue gun


Faucet


Ping Pong Ball


String

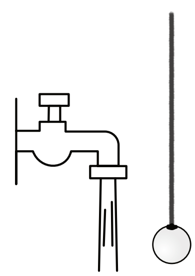
GOALS

- Demonstrate Bernoulli's principle.
- Create a low pressure column of water and air.

Pre-lab Question: Is the air pressure higher or lower in a straw when you are blowing air through it than when the air is not moving?

INSTRUCTIONS:

1. Attach a ping pong ball to a string using a glue gun or tape.
2. Turn on a water faucet so there is a steady stream of water coming out.
3. Dangle the ping pong ball near the column of water.
4. Watch as the ball is pulled into the stream of water.
5. Experiment to see whether the amount of water makes a difference. How far away can the ping pong ball be held from the water and still get pulled over to the stream?



EXPLANATION:

The moving water also moves the air creating a region of lower pressure as predicted by Bernoulli's principle. The ball is pushed by the atmosphere into the region of lower pressure. Even though the collision of the water and ball pushes the ball away, the lower pressure is enough to keep the ball in place.

Would this demonstration work if we replaced the ping pong ball with a golf ball? Explain.

FLUIDS & PRESSURE ASSESSMENT

IN YOUR OWN WORDS!

Define each of the following terms in your own words! Explain the terms without looking them up. Then, after writing your definitions, compare what you wrote with the definitions in the notes. Make corrections as needed.

DENSITY: The amount of stuff in a given amount of space (or mass/volume etc)

BUOYANCY: The upward force that acts on an object in a fluid (from the displaced fluid)

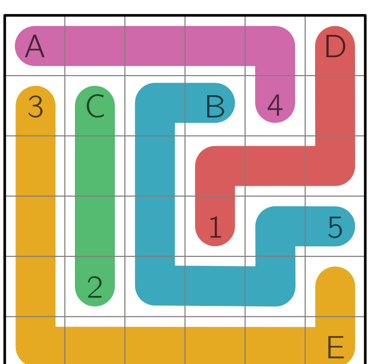
FLUID: Gas or liquid - something that can flow and does not have a fixed shape.

PASCALS: Newtons per meter squared! A unit of pressure.

PRESSURE: How much force is applied to an area, pascals and PSI are measures of pressure.

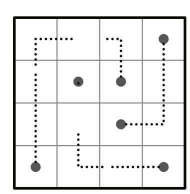
PSI: Pounds per square inch.

PIPE FLOW MATCHING



Match each unit with the quantity being measured by joining them with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

1. pressure	A. m^2
2. temperature	B. kg/m^3
3. heat	C. K
4. area	D. N/m^2
5. density	E. J



1. What is density?:
   A. How heavy something is
   B. The amount of mass per unit of volume
   C. The force of gravity on an object
   D. The amount of surface area something has

2. Which of the following would increase the pressure a weight exerts on a surface?
   A. Spreading out the weight over a larger area
   B. Placing the weight on a softer surface
   C. Concentrating the weight over a smaller area
   D. Lightening the weight

3. What happens to the pressure experienced as you dive deeper into the ocean?
   A. It decreases
   B. It stays the same
   C. It increases
   D. It first increases, then decreases

4. If you quadruple the volume of a gas and keep the temperature constant, what happens to the pressure?
   A. The pressure is ¼ of what it was before
   B. It stays the same
   C. It is quadrupled
   D. It first increases, then decreases

5. What is true about air pressure at higher altitudes?
   A. It increases because you are closer to the Sun
   B. It stays the same as at sea level
   C. It decreases because the air is thinner
   D. It increases because the air is colder

6. Why does ice float in water?
   A. Because it is colder than water
   B. Because it has a lower density than water
   C. Because water expands when it freezes
   D. B and C

7. Which principle explains why ships made of steel can float on water?
   A. Boyle's Law
   B. Bernoulli's Principle
   C. Principle of Buoyancy
   D. Principle of Relativity

8. If you squeeze the middle of a closed, half-full water bottle, what happens to the air pressure inside the bottle?
   A. It decreases
   B. It stays the same
   C. It increases
   D. It first decreases, then increases

9. Which of the following would float in freshwater?
   A. A rock with density 3 g/cm^3
   B. An ice cube with density 0.92 g/cm^3
   C. A piece of metal with density 7.8 g/cm^3
   D. A rubber ball with density 1.5 g/cm^3

10. Why do your ears pop when you go up a mountain or take off in an airplane?
    A. Because the air pressure outside your body decreases, causing pressure to build up inside your ears
    B. Because the air pressure outside your body increases, causing your eardrums to expand
    C. Because of the change in oxygen levels at high altitudes
    D. Because the temperature changes affect the air inside your ears

11. As altitude increases, air pressure:
    A. Increases
    B. Decreases
    C. Stays the same
    D. Initially decreases, then increases

12. Which statement best describes why fish are able to float at different depths in water?
    A. Fish change their volume by inflating or deflating air bladders, adjusting their density
    B. Fish constantly swim upward to stay afloat
    C. The water's density changes to accommodate the fish
    D. Fish have less mass than the water

13. Why does a helium balloon rise into the air?
   A. The helium leaks through the balloon propelling the balloon upward
   B. The buoyant force on the balloon is more than the weight of the balloon
   C. The negative charge of the helium ions is repelled by the positive charges on the ground
   D. Convection currents cause the air to flow upward

14. How does wearing snowshoes prevent you from sinking into the snow?
   A. They decrease your mass
   B. They increase the pressure you exert on the snow
   C. They decrease the area over which your weight is distributed
   D. They increase the area over which your weight is distributed, reducing pressure

15. What is the primary reason airplanes fly at higher altitudes?
   A. Air is denser at higher altitudes, which improves lift.
   B. Air is less dense at higher altitudes, reducing drag on the airplane
   C. It is colder at higher altitudes, which improves engine performance.
   D. There is more oxygen at higher altitudes, which improves combustion.

16. Why does a diver feel more pressure as they dive deeper?
   A. Because water temperature decreases with depth, increasing pressure
   B. Because the volume of water above the diver increases, increasing pressure
   C. Because the density of water increases with depth
   D. Because of increased oxygen levels in deeper water