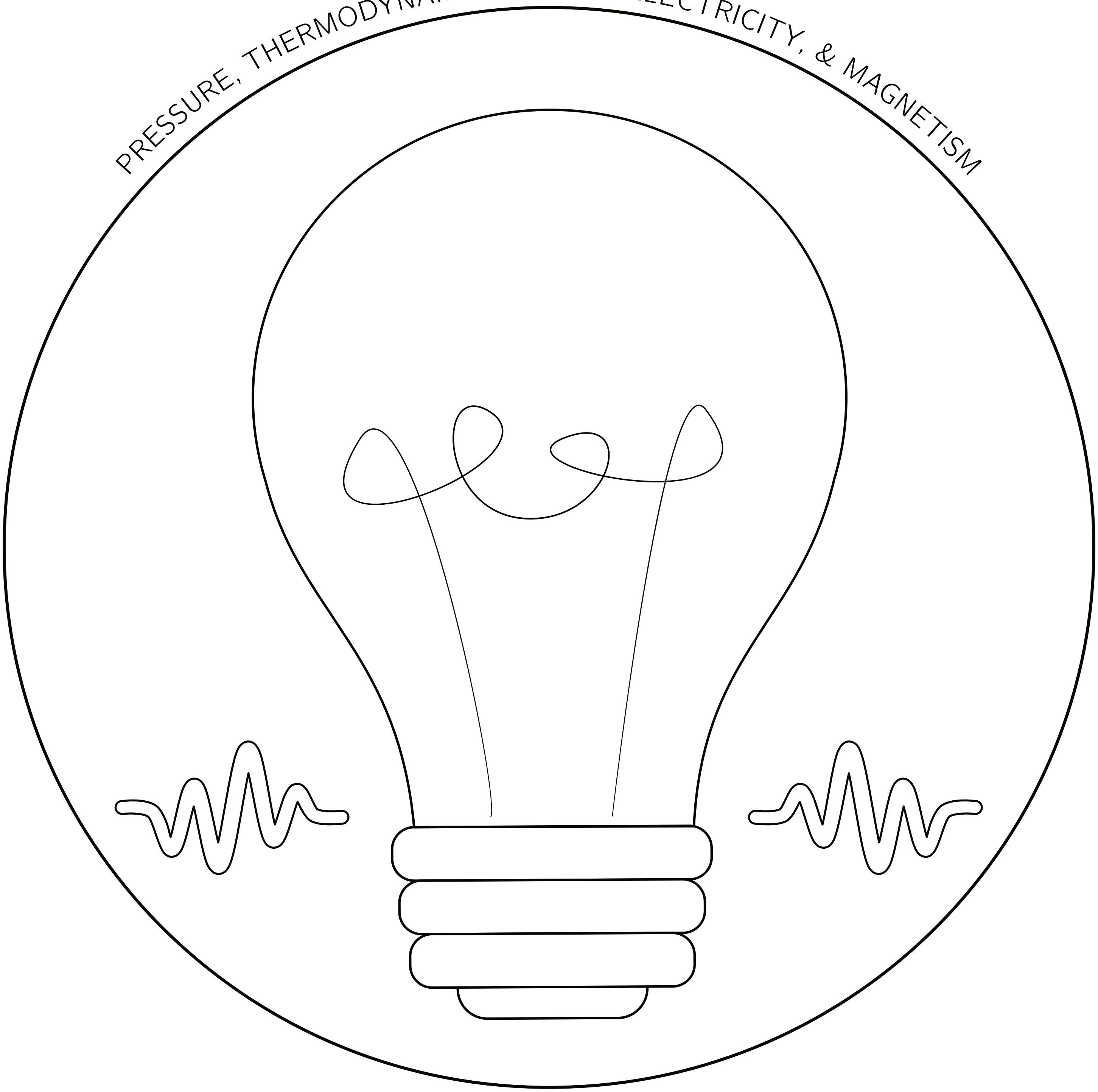
Physics 2

PRESSURE, THERMODYNAMICS, WAVES, ELECTRICITY, & MAGNETISM



Physics 2

Pressure, Thermodynamics, Waves, Electricity, & Magnetism

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

Make your own instrument
- Supplies depend on the instrument

Tabletop Kaleidoscope
- 2 flat mirrors, tape, and small object for viewing such as a dice or pebble

SUPPLY LIST:

Sticky Balloons

- Two balloons
- A soft cloth for charging the balloon
- A wall, a window, and various furniture items

Levitating Ring

- Balloon or a short length of PVC pipe
- A soft cloth for charging the balloon
- A very thin plastic bag (such as the type used grocery stores in the produce department)
- Scissors

Paper Vacuum & Scooting Bubbles

- Balloon or short length of PVC pipe
- A soft cloth for charging the balloon
- Tissue paper
- Scissors
- Bubble solution or water and dish soap
- A flat counter or table

Bending Water

- Balloon or short length of PVC pipe
- A soft cloth for charging the balloon
- A faucet or or container that can create a thin stream of water

LED Holiday Card

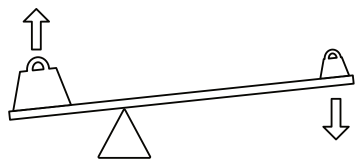
- 1 piece of cardstock
- 2 button batteries (CR2032 3-volt batteries work well.)
- Between 3 to 20 LED lights (3 mm)
- 0.5 m of conductive maker tape
- Scissors
- Push pin OR sewing needle
- Printed templates Or pencil and pen to create your own design
- Glue stick and tape
- A small piece of cardboard (optional)
- Coloring supplies

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!

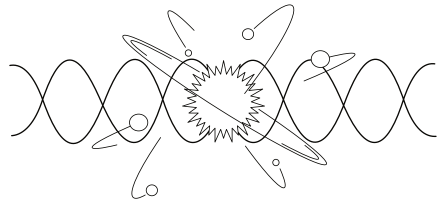
In our Physics 1 class we studied classical mechanics and had one bonus lesson on relativity (which is a pretty important concept in astrophysics). In Physics 2 we'll be covering a wide variety of topics!

CLASSICAL MECHANICS



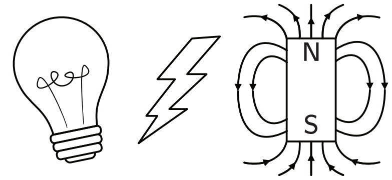
- [x] The study of how everyday objects move and behave

QUANTUM MECHANICS



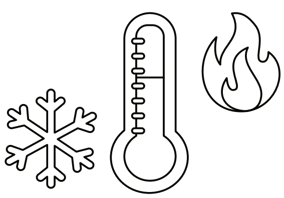
- [ ] The study of how very small particles behave

ELECTROMAGNETISM



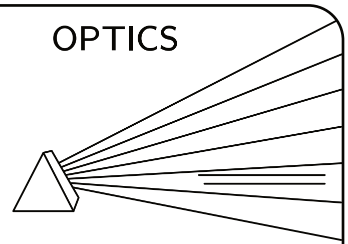
- [ ] The study of electric and magnetic fields

THERMODYNAMICS



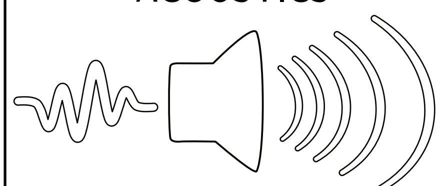
- [ ] The study of heat, energy, and entropy

OPTICS



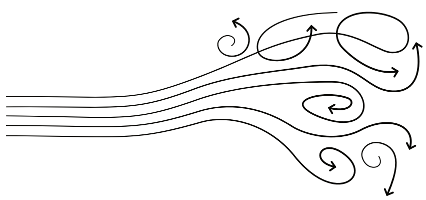
- [ ] The study of the behavior and properties of light

ACOUSTICS



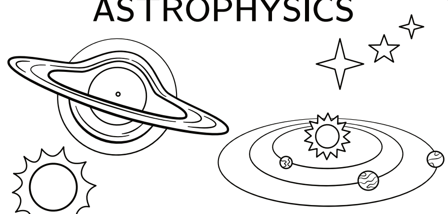
- [ ] The study of mechanical waves such as sound

FLUID DYNAMICS



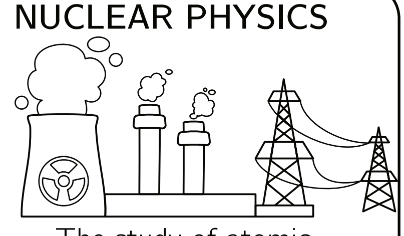
- [ ] The study of the flow of liquids and gases

ASTROPHYSICS



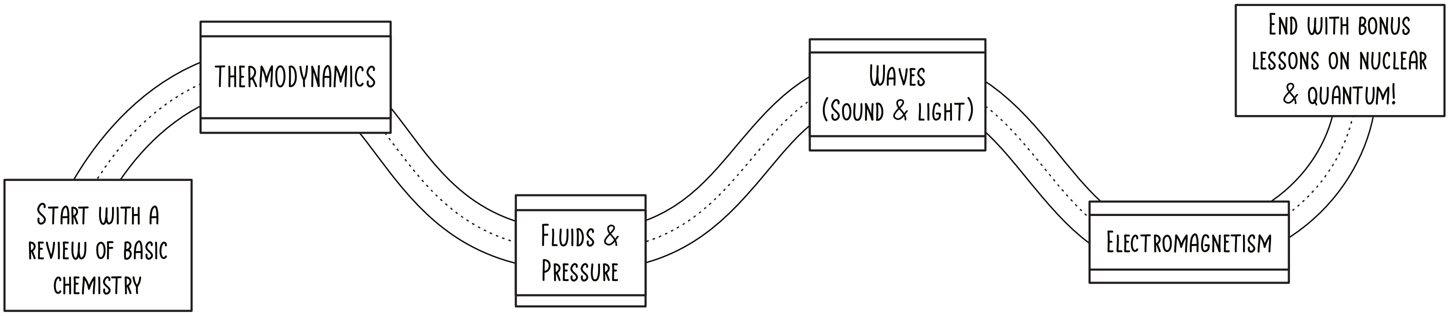
- [x] Physics in outer space! How stars, black holes, and solar systems work

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.

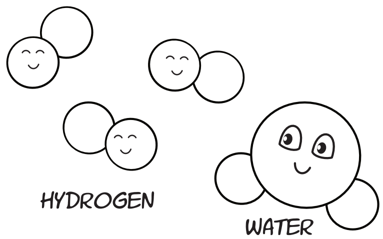
MY PLAN FOR WATCHING THE LESSONS AND USING THE NOTES:

MY PLAN FOR DOING THE PRACTICE PROBLEMS:

MY PLAN FOR COMPLETING THE LABS OR HANDS-ON ACTIVITIES:

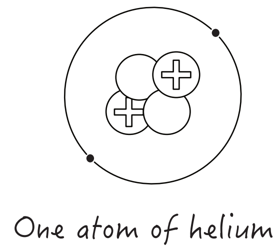
The chemistry you need for physics!

MOLECULE



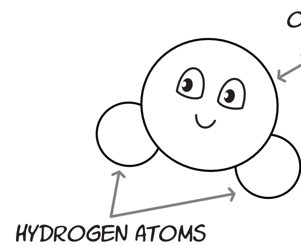
The smallest fundamental unit of a substance, often formed by two or more atoms

ATOM



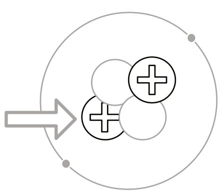
The smallest unit of an element

COMPOUND



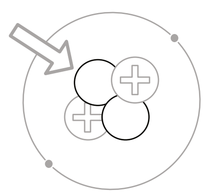
A molecule or substance made of two or more elements bonded together

PROTON



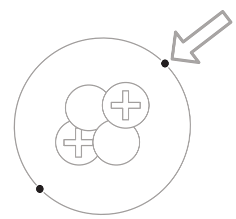
Positively charged particle in the nucleus of an atom

NEUTRON



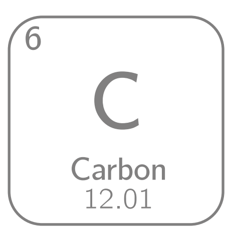
A particle with no charge in the nucleus of an atom

ELECTRON



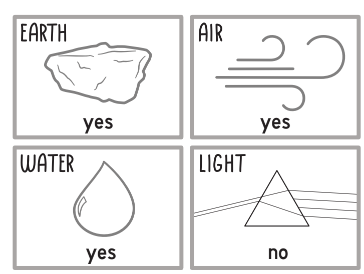
A negatively charged particle that orbits the nucleus of an atom

ELEMENT



A substance that cannot be broken down by chemical reactions

MATTER



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

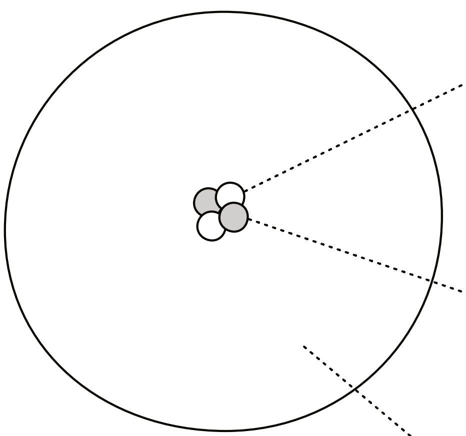
What's the Matter?

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:



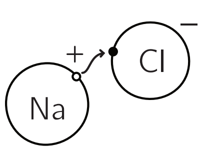
+ charge
PROTONS – positive charge and a mass of about 1 atomic mass unit. Located in the nucleus.

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

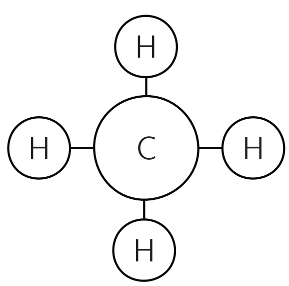
– charge
ELECTRONS – negative charge and almost no mass. Super tiny! Located in a cloud around the nucleus.

TYPES OF CHEMICAL BONDS

Electrons transferred from one atom to another

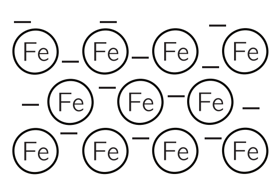


Makes + and – ions!

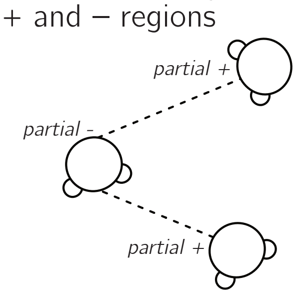


Share electrons between atoms

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

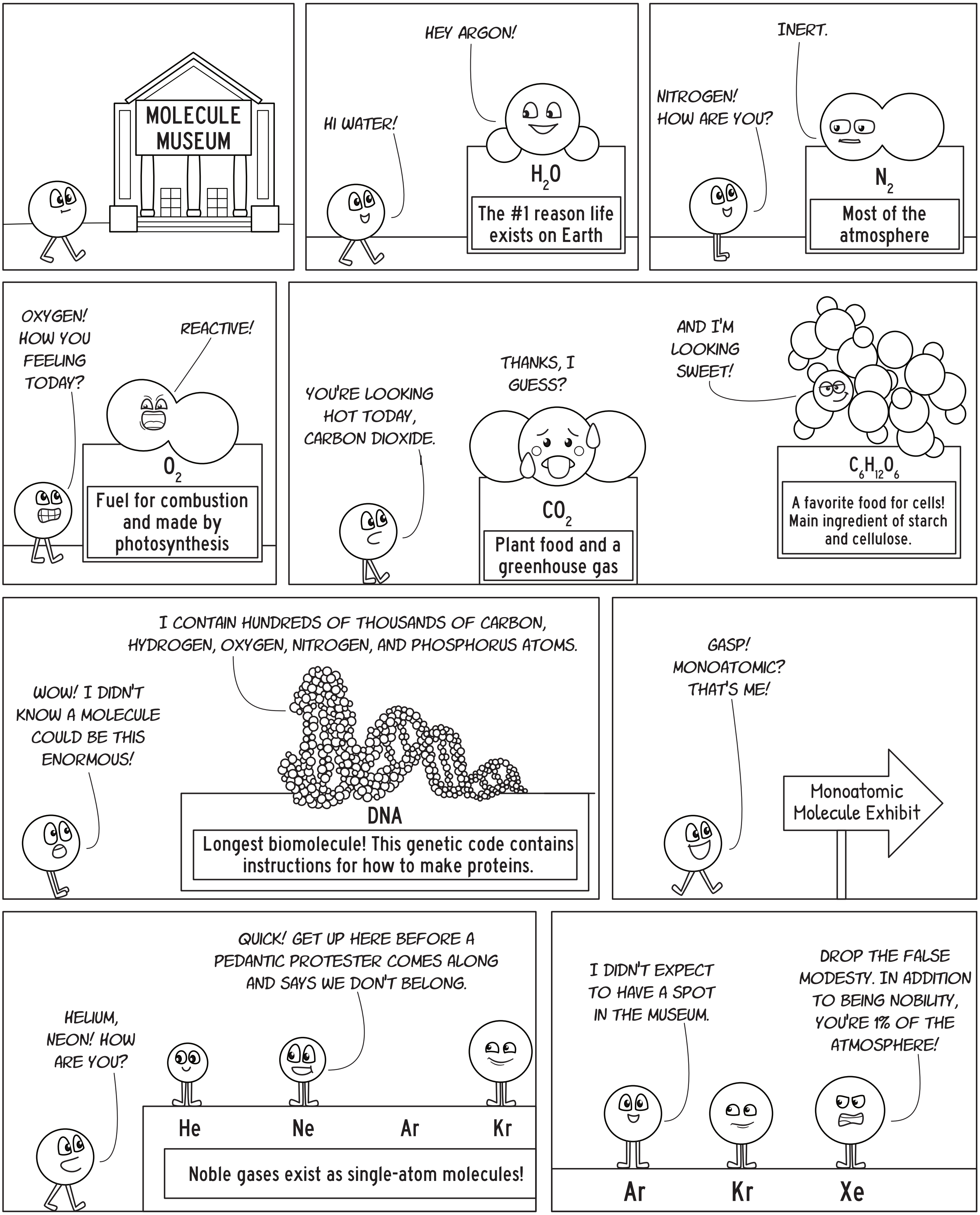


Weak attraction between partially + and – regions



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

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

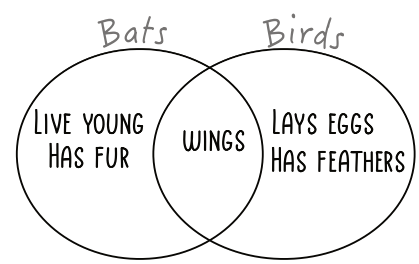
10. Which of the following is not composed of atoms?
    A. Water
    B. Rock
    C. Sunlight
    D. Plastic

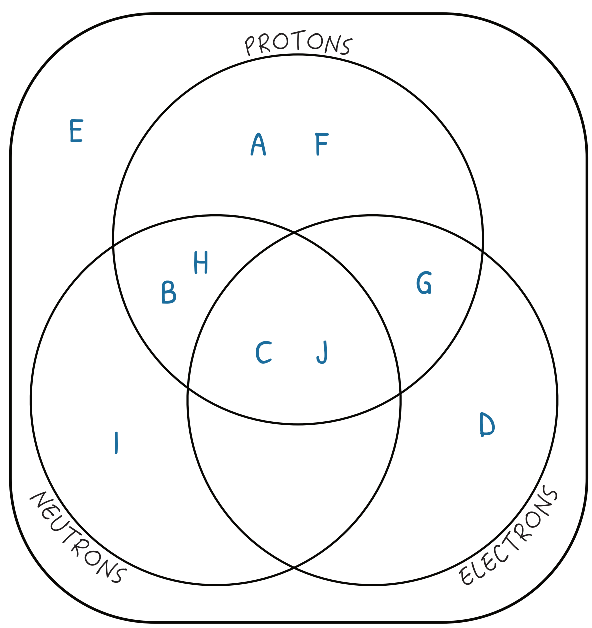
11. Bonds between atoms primarily involve:
    A. Sharing or transferring protons
    B. Sharing or transferring neutrons.
    C. Sharing or transferring electrons.
    D. Sharing or transferring photons.

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

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

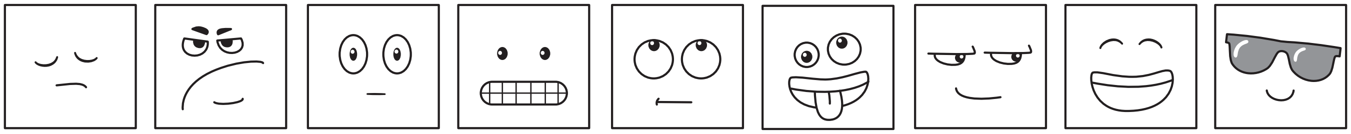




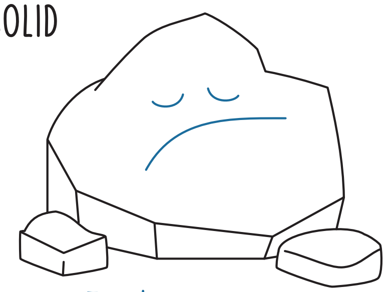
Elemental

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

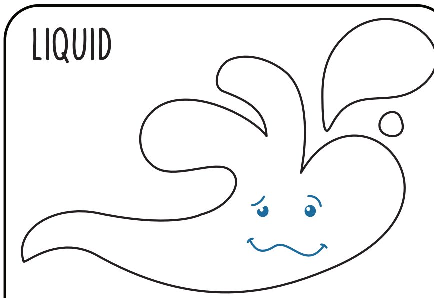


SHAPE: Fixed

VOLUME: Fixed

ENERGY LEVEL:

LIQUID

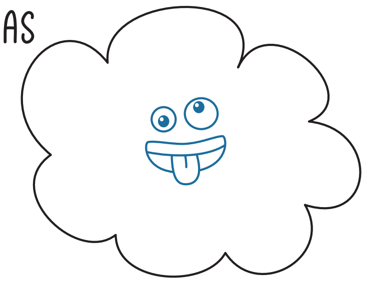


SHAPE: Flexible

VOLUME: Fixed

ENERGY LEVEL:

GAS



SHAPE: Flexible

VOLUME: Flexible

ENERGY LEVEL:

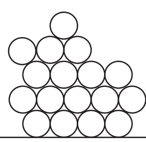
THE ENERGY OF MOVING PARTICLES IS CALLED KINETIC ENERGY.

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

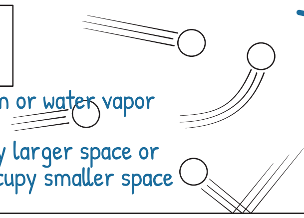
Can be in crystal structure (regular pattern) or not (amorphous)



Gas

Ex. Air, helium, steam or water vapor

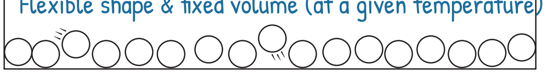
Can expand to occupy larger space or be compressed to occupy smaller space



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

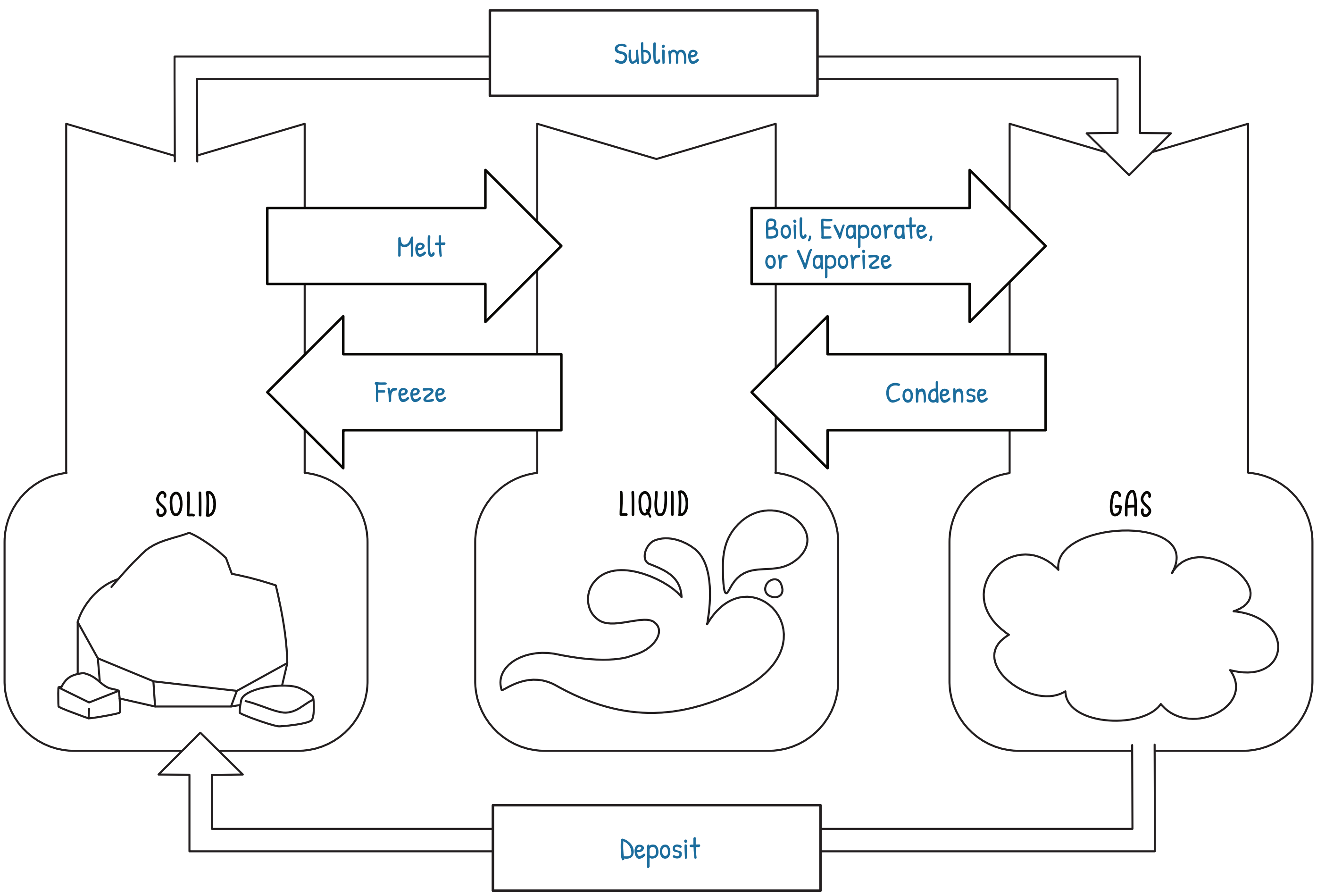
8. What happens to particles when a substance changes from solid to liquid?
   A. They move closer together and more slowly
   B. They spread out and move slower
   C. They move closer together and faster
   D. They spread out and move faster

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.*

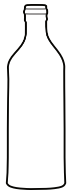
    Note: one of the arrows will have three words.

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

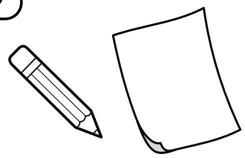


FUN PHYSICS TRICKS

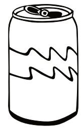
MATERIALS



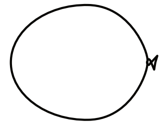
1 bottle with a narrow neck



Drawing supplies and paper

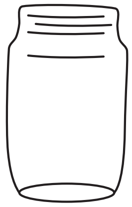


An empty aluminum can

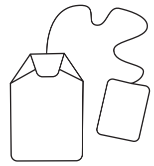


1 balloon or a short length of plastic pipe

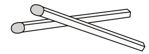
A coin



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

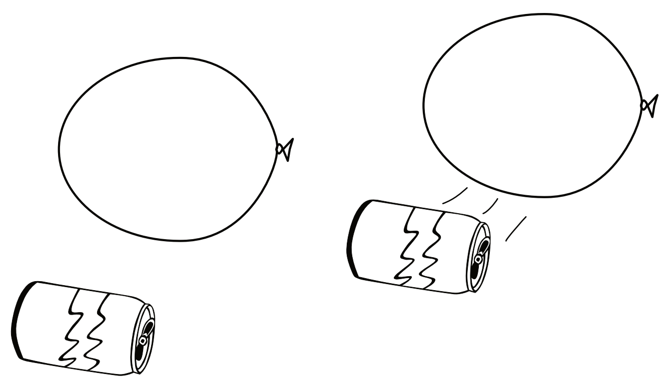
Can you move an empty aluminum can across a table without blowing on it or touching it?

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.

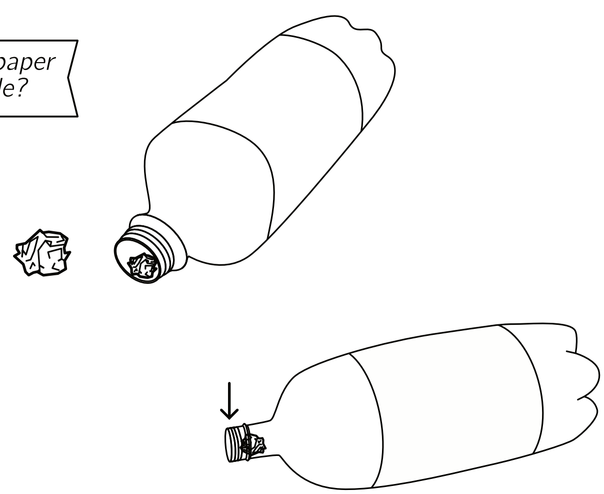
2 Paper Wad Challenge

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.

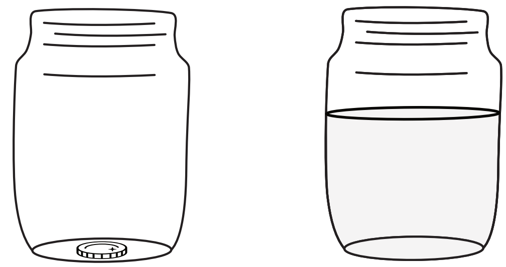
2. Challenge a friend to get the paper into the bottle by blowing on it.

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.

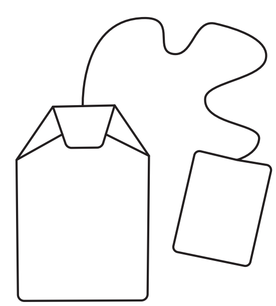
3. Place the image about 10 cm behind the glass. It should look about the same.

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?



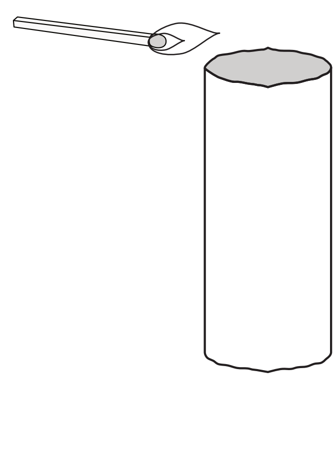
This activity must be done with adult supervision!

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

☆☆☆☆☆

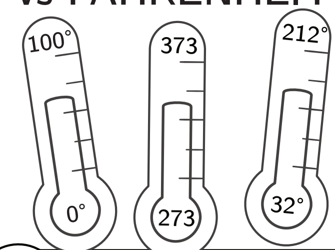
Tips for next time (optional): ____________________

Something you noticed or wondered about: ____________________

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

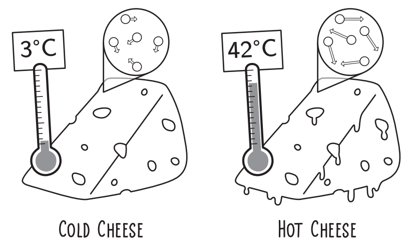
____

CELSIUS vs KELVIN vs FAHRENHEIT



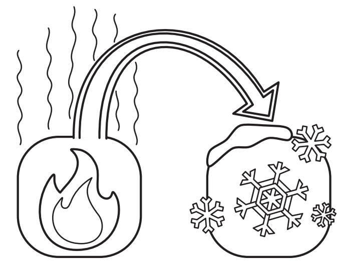
K °C °F
Three different systems for measuring temperature

TEMPERATURE



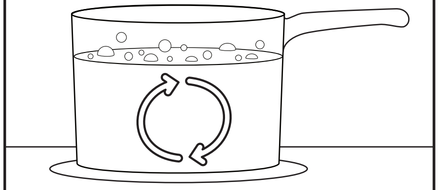
A measure of the average kinetic energy of the particles in a system.

HEAT



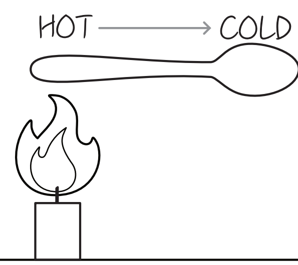
cal or J
Energy moving from one object to another because of a difference in temperature.

CONVECTION



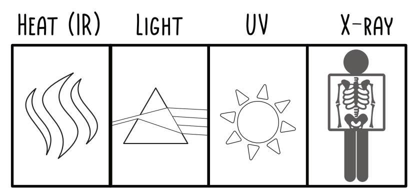
Heat transfer by the movement of fluids (gas or liquid)

CONDUCTION



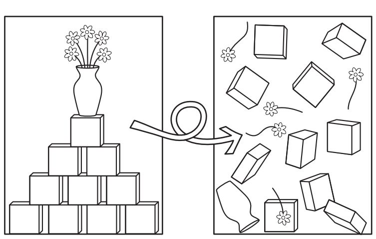
The movement of heat or electricity through a material.

RADIATION



Energy transmitted by electromagnetic waves

ENTROPY

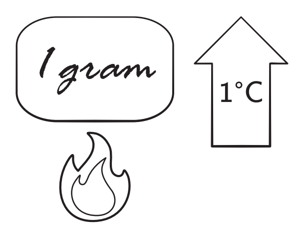


S
A measure of the disorder or randomness in a system

INTERNAL ENERGY

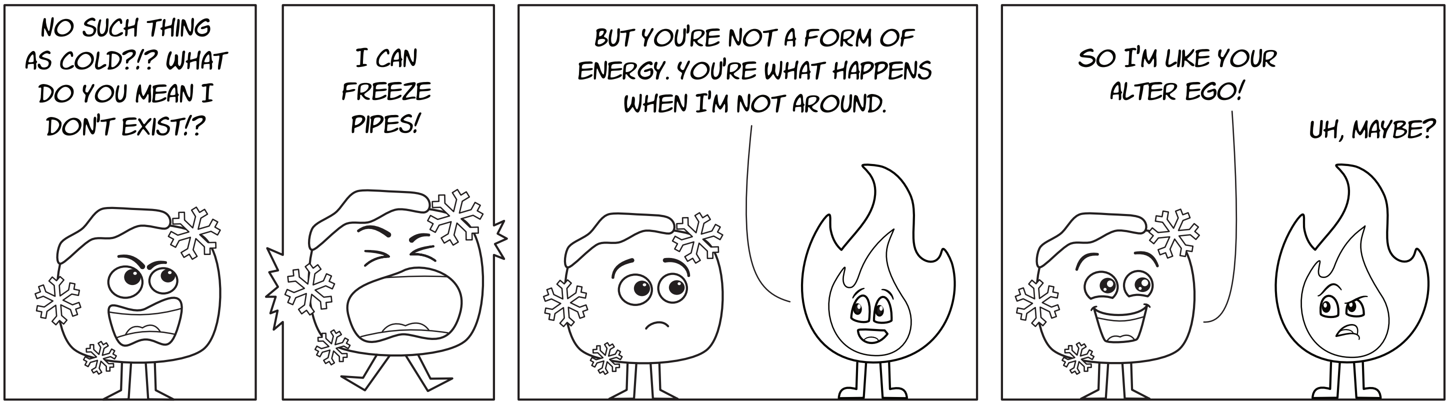
The total kinetic and potential energy of the particles in a system.

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)

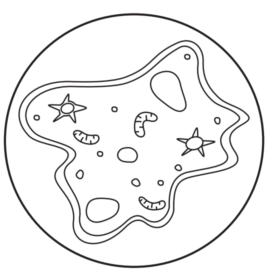
Used primarily in United States.

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

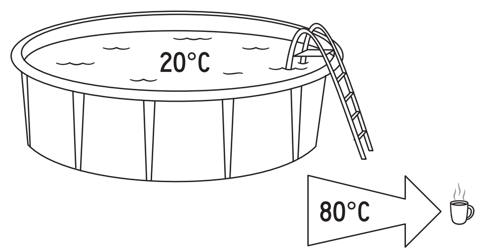


Consider an amoeba that can survive in water as long as the temperature stays ABOVE 15° C (59° F).

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)

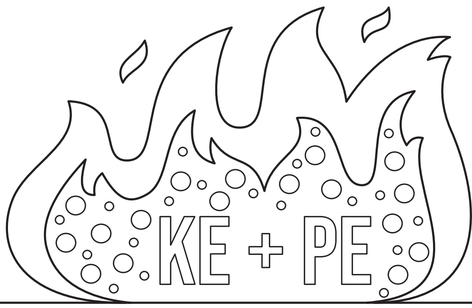


WHICH CONTAINER WOULD KEEP THE AMOEBA WARM THE LONGEST AND WHY? The swimming pool would stay warmer longer because it takes longer to change the temperature of a large body of water than a smaller one. The internal energy of an object is the energy from the movement and interactions of the molecules. 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

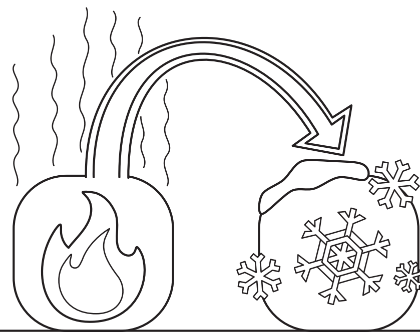
LABEL EACH CARD WITH THE CORRECT TERM AND DEFINITION, THEN DESCRIBE THEIR SIMILARITIES AND DIFFERENCES.

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.

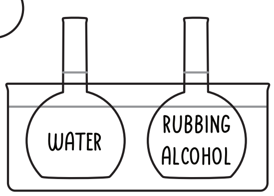
SOMETHING SIMILAR: Both measured in Joules.

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

THERMAL EXPANSION

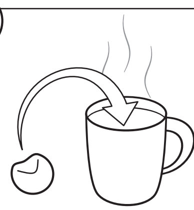
Record what happens in each case below. Is it what you expected?

1



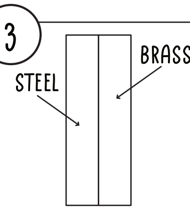
COLD FLASKS OF FLUID ARE PLACED IN A HOT WATER BATH.

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

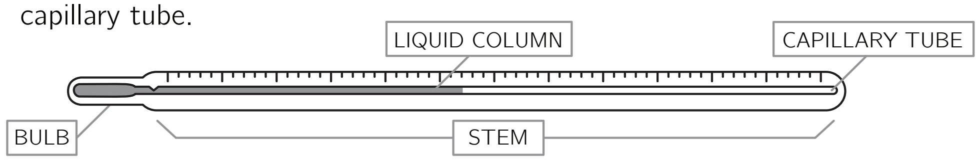
Ping pong ball inflates

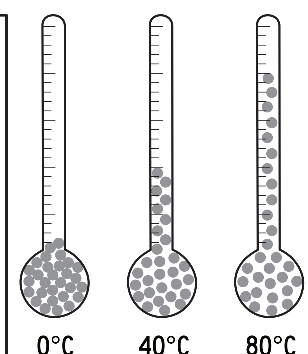
Strip of metal bends because brass expands more than steel

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

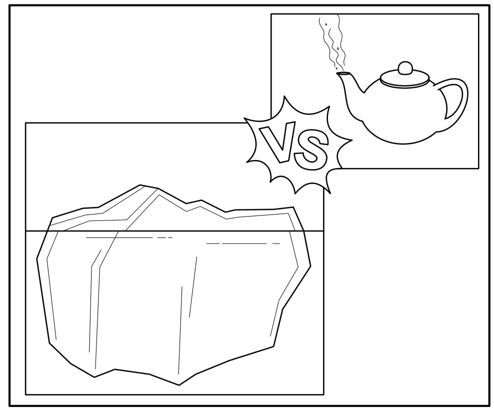
1. List 3 examples of thermal expansion that occur in every day life?

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?

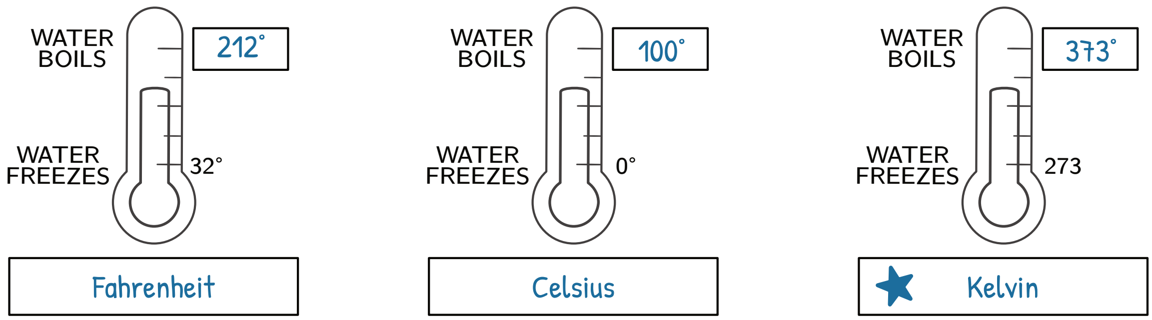
A. The kinetic energy of an object
B. The movement of energy from one object to another
C. The energy arising from the position and interactions of the molecules within an object

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

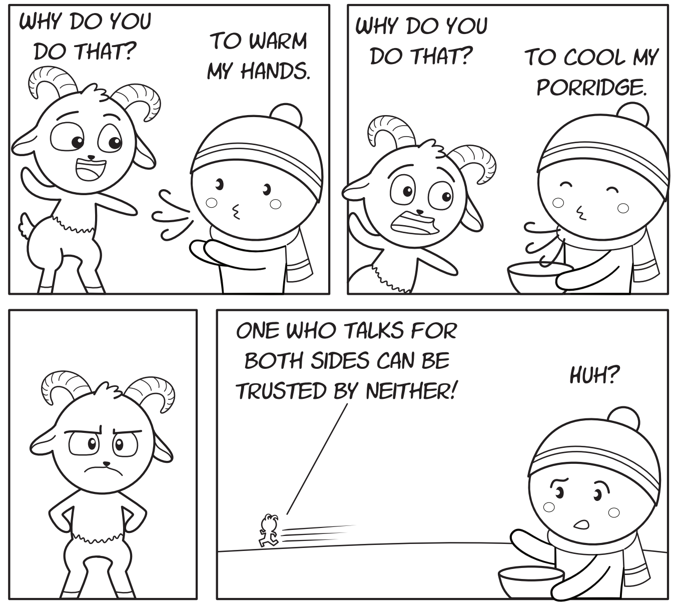
Heat Transfer

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!

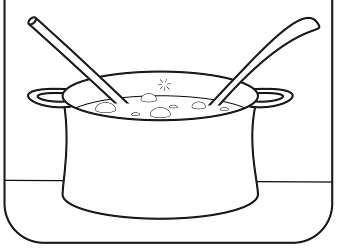
In actuality, the temperature of the man's breath was always the same. How can you explain the fact that the same breath can be used both to cool and warm something?

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).



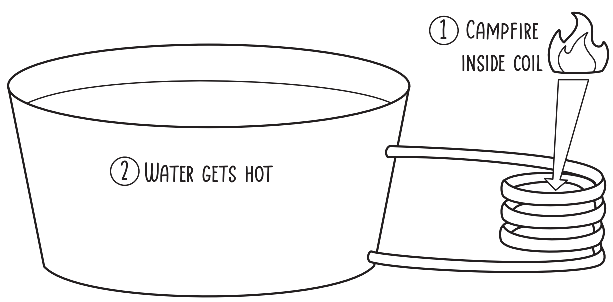
*What is your prediction for each situation below? Check the box you agree with, then describe how the heat is being **transferred**.*

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



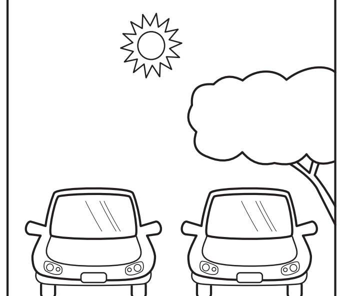
- [ ] *Both spoons are hot*
- [x] *Metal spoon is hot, wooden spoon is cool*
- [ ] *Wooden spoon is hot, metal spoon is cool*
- [ ] *Both spoons are cool*

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!

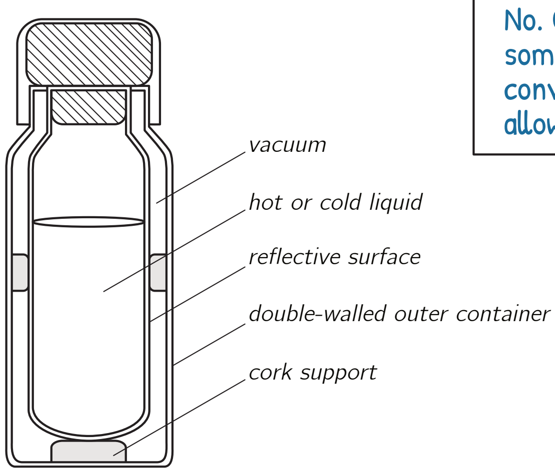
FIND 3 EXAMPLES OF THERMAL CONDUCTORS IN YOUR HOME:

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.

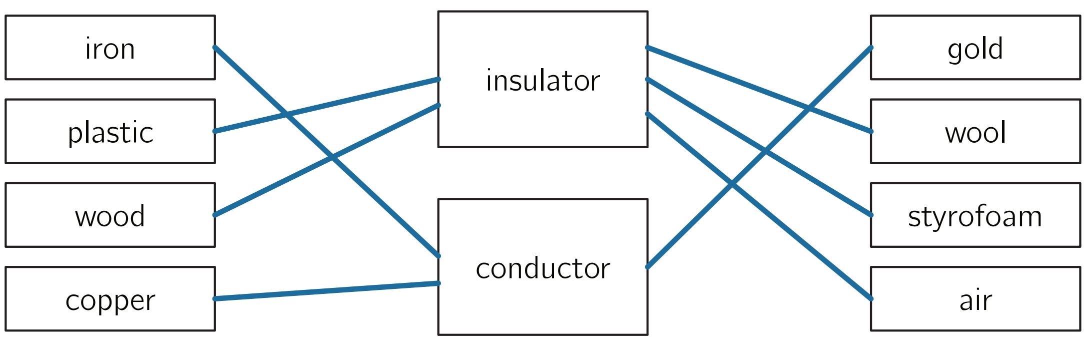
   Metal feel colder than wood at the same temperature because metals are better conductors of heat. When Emily touches the metal railing, it conducts heat away from her skin more efficiently than the wooden post. The higher heat transfer means the metal feel colder, even though both are at the same temperature.

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?

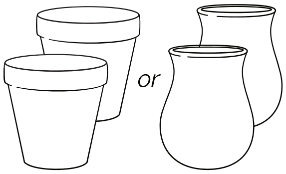
A substance is a good thermal conductor if it allows heat to flow easily through it. This is often due to its atomic or molecular structure, which allows energetic particles to quickly transfer their energy to neighboring particles.

(11) Why do insulators prevent the transfer of heat?

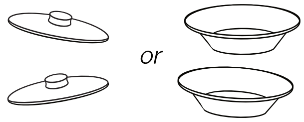
Insulators have a structure that restricts the flow of heat. Their atoms or molecules do not transfer energy as effectively as conductors, so they slow down or prevent the transfer of heat.

MAKE A FRIDGE FROM CLAY AND SAND

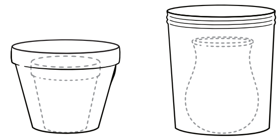
MATERIALS



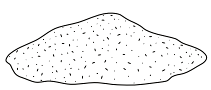
2 small clay pots or vases



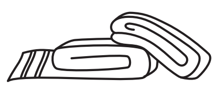
2 metal lids or aluminum pie tins that can cover the top of the clay pots



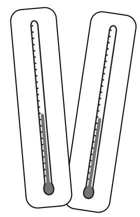
2 buckets or clay pots that are larger than the small clay pots



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.

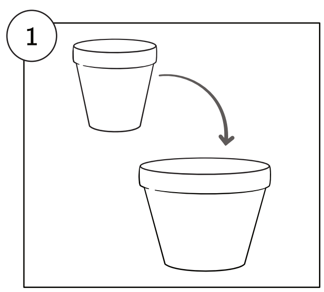
2. Fill the space between the small pots and the larger containers with sand. Label one setup "wet" and the other one "dry."

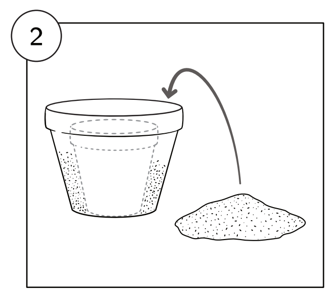
3. Pour water into the sand of the pot labeled as "wet" until the sand is completely moist. Be careful not to pour water into the inner pot. Leave the sand in the "dry" pot as is.

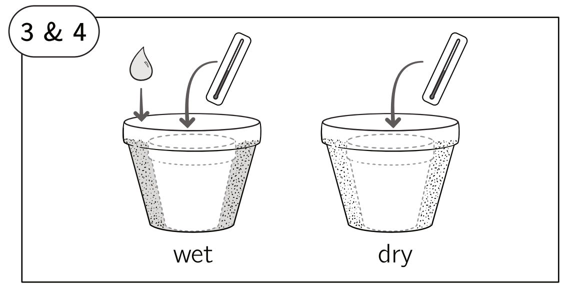
4. Place a thermometer inside each clay pot and take a temperature reading. Then cover both of the clay pots with metal lids.

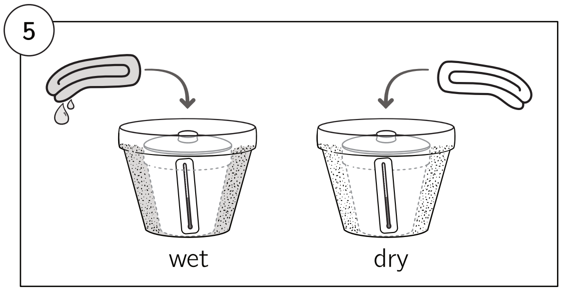
5. Get one of the towels completely wet and ring out excess water. Place it over the clay pot that has wet sand. Place the other towel over the dry clay pot.

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.





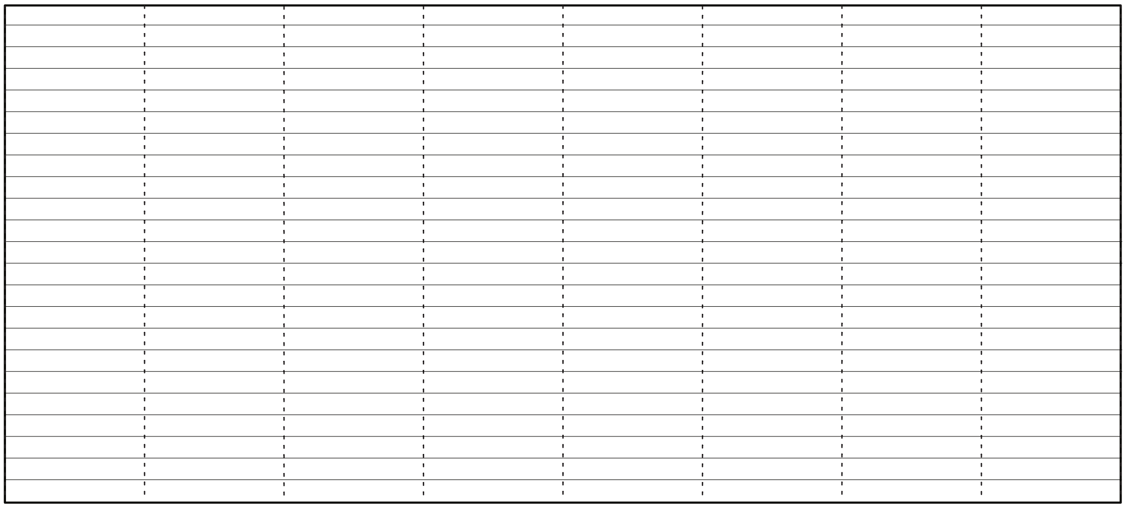




When water evaporates, it absorbs heat from its surroundings. This principle is used in many cooling methods such as sweating, swamp coolers, misters, cooling towers in industrial plants, and "pot in pot" refrigerators or Zeer pots.

A Cool Experiment

Label temperature on the Y axis

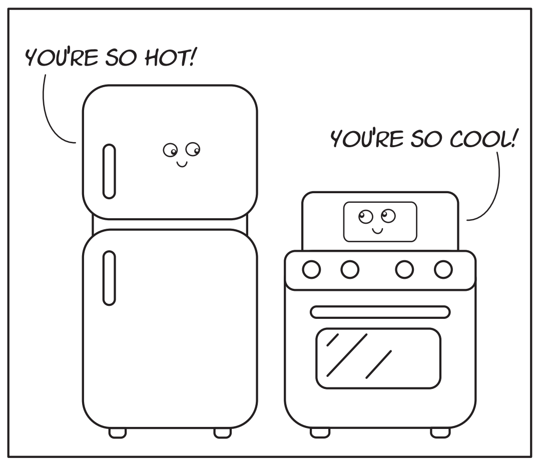


Use a different color to record for the data for each pot.

- ☐ 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.

____

____

____

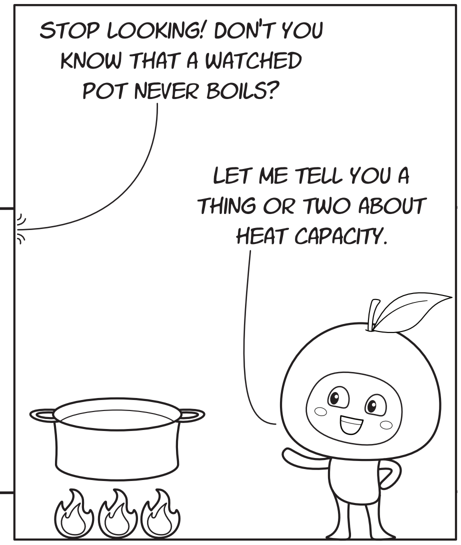
What could be changed to improve the clay pot fridge? Could it preserve food and keep the internal temperature near 3 to 5 °C or 40° F? Why or why not?

____

____

____

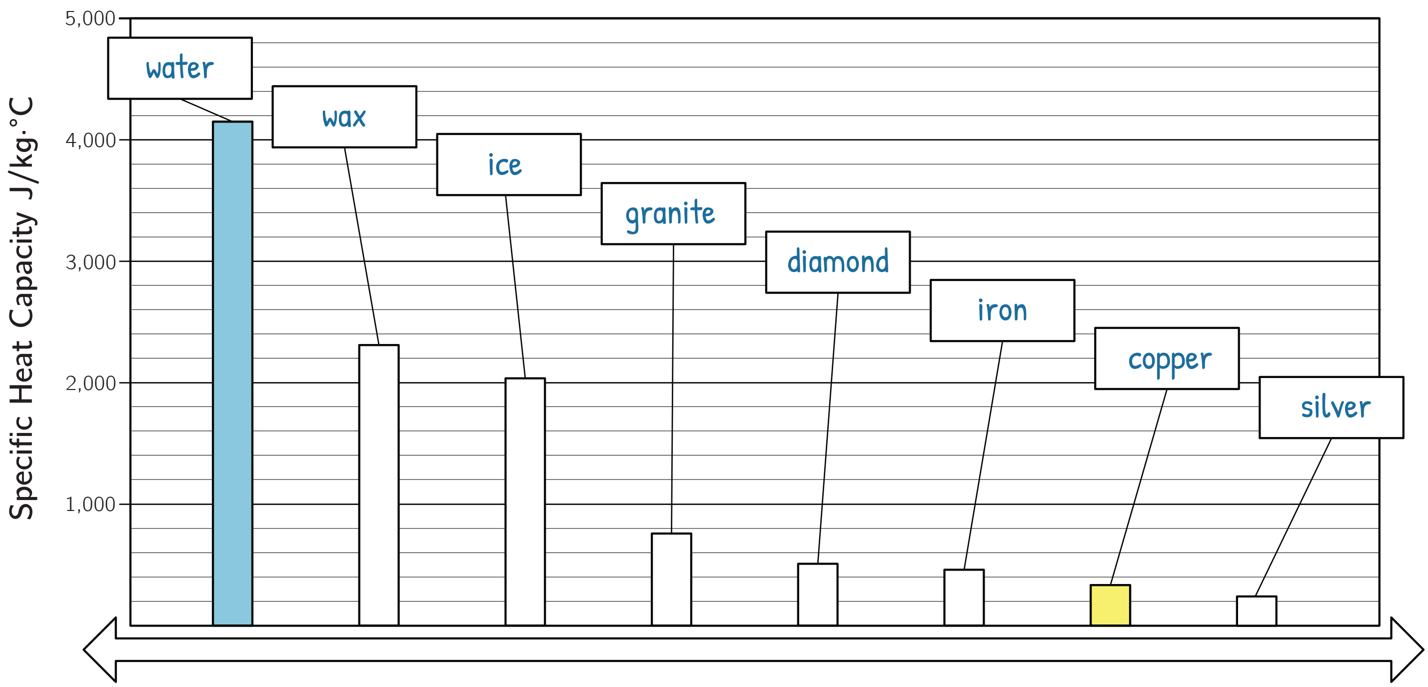
Specific Heat Capacity



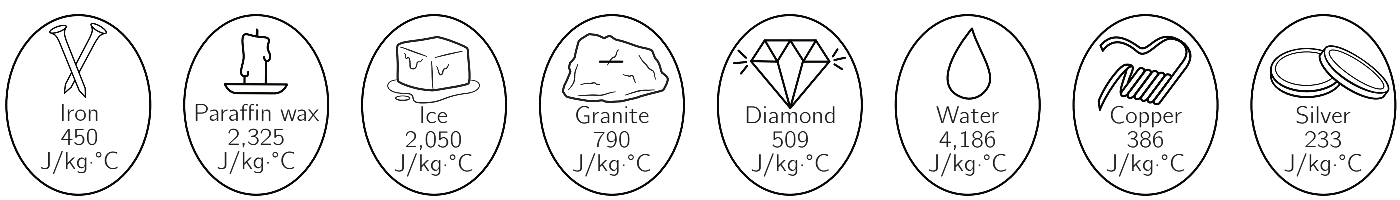
Fill in the blanks:

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?

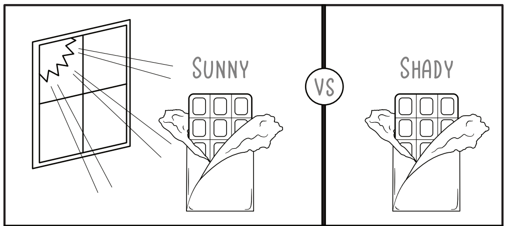
Intermolecular forces *are the forces that hold molecules together.*

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

SCIENCE MOM

Change of Phase

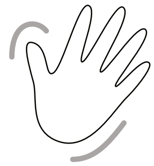
Do melting & vaporization ABSORB or RELEASE energy? *Consider these questions before answering:*



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?

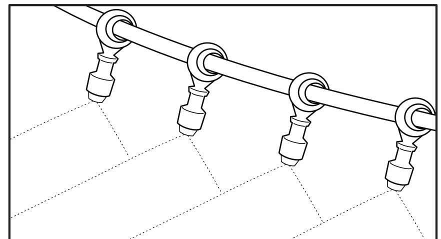
Melting = ABSORB. The chocolate in the sunny location melts as it is receives heat energy (in the form of radiation) from the Sun.



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.

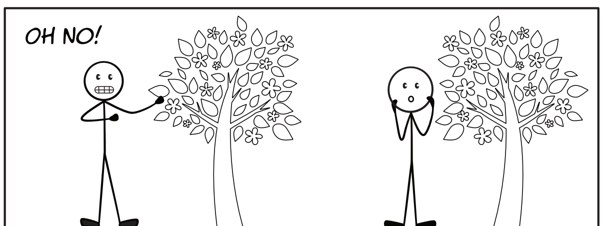


Misters spray super small water droplets into the air, which then evaporate.

Why do the misters cool the area underneath?

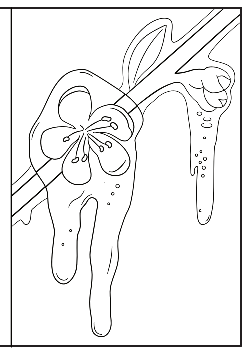
Evaporative = ABSORB. As the water evaporates it absorbs heat from the surroundings. Evaporative cooling!

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.



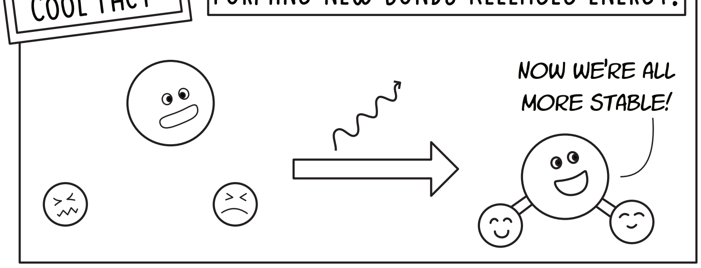
Deja's trees have flowers after the frost. Bob's trees lose all of their blossoms.

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?

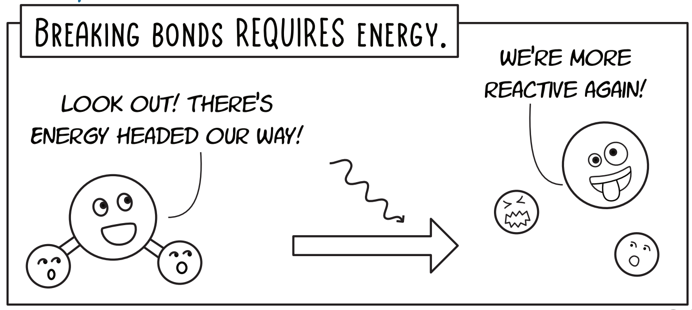
When water changes from liquid to solid (freezes), it releases heat. This released heat is absorbed by the surrounding environment. Even though the water on the plants is turning into ice, the process of freezing actually releases enough heat to keep the plants at a temperature just above freezing. This 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:

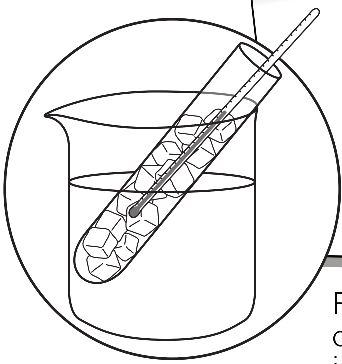
FORMING NEW BONDS RELEASES ENERGY.



BREAKING BONDS REQUIRES ENERGY.



Change of Phase



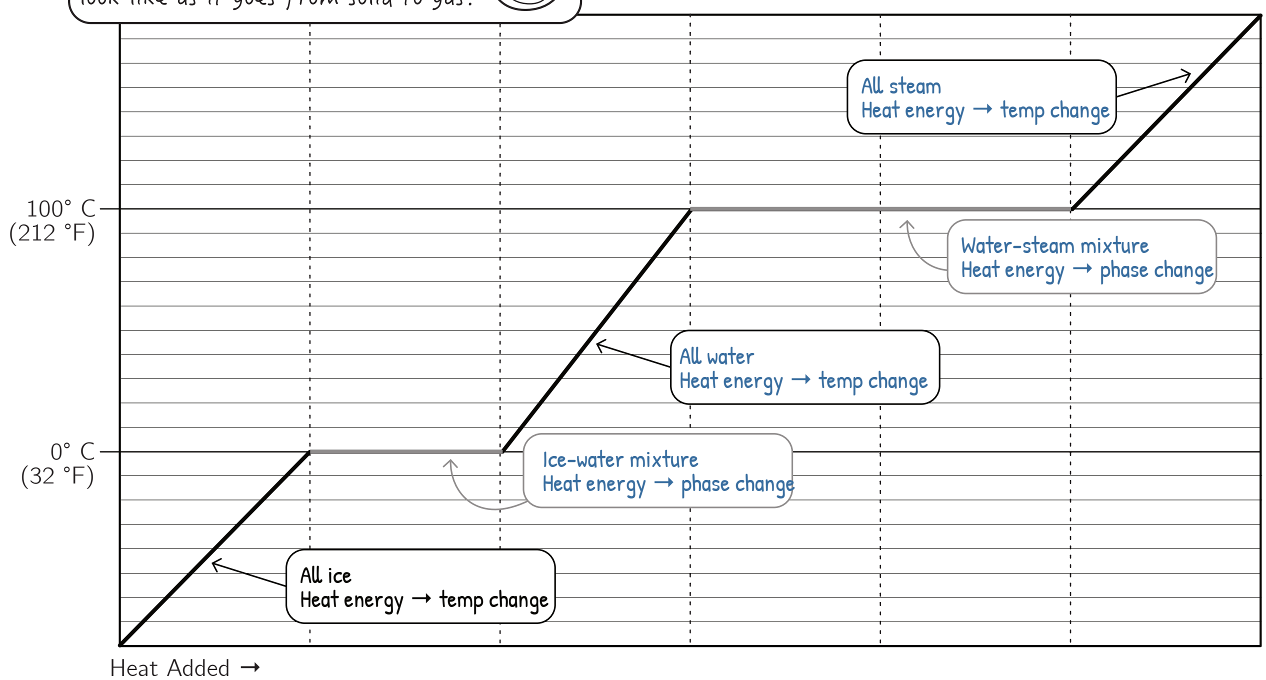
Frozen water is placed in a glass tube along with a thermometer then heated until it melts and then boils into gas.

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.

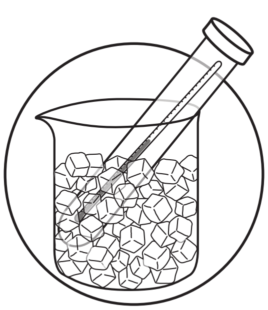
HEATING CURVE

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

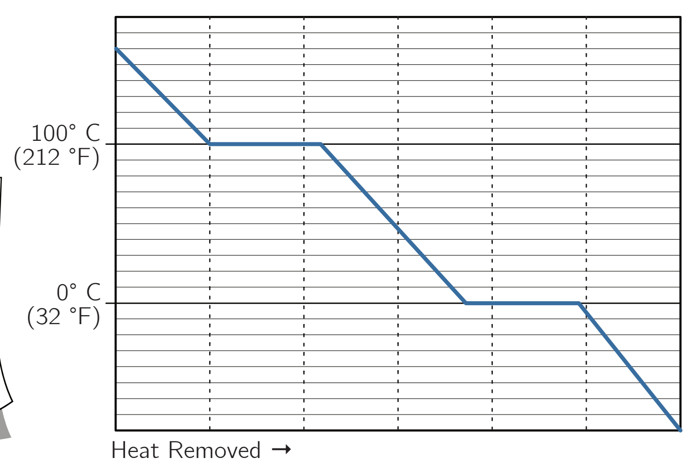


COOLING CURVE

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

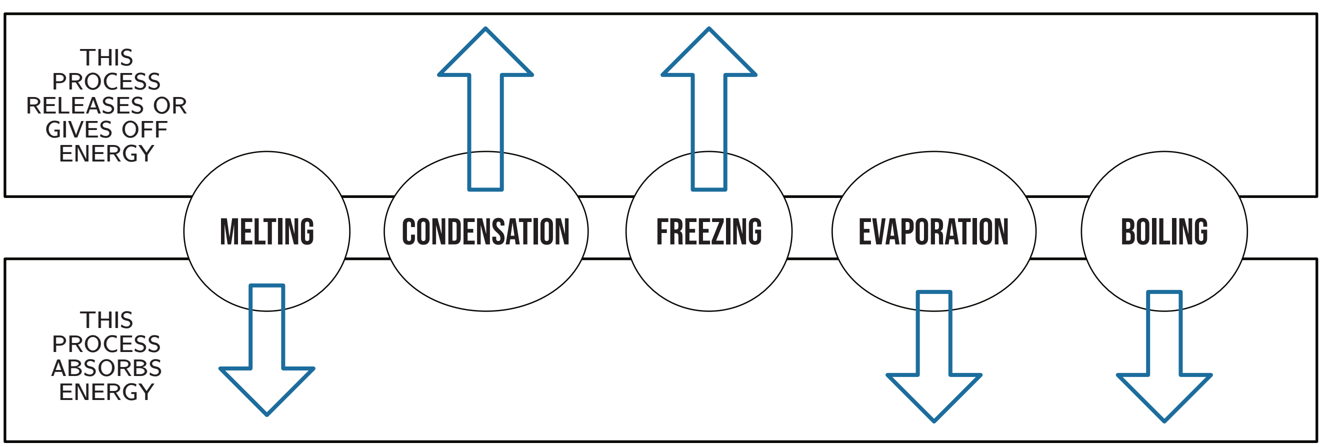
1. When water is boiling, it is undergoing which phase change?
   A. Melting
   B. Freezing
   C. Vaporization
   D. Condensation

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**.



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).

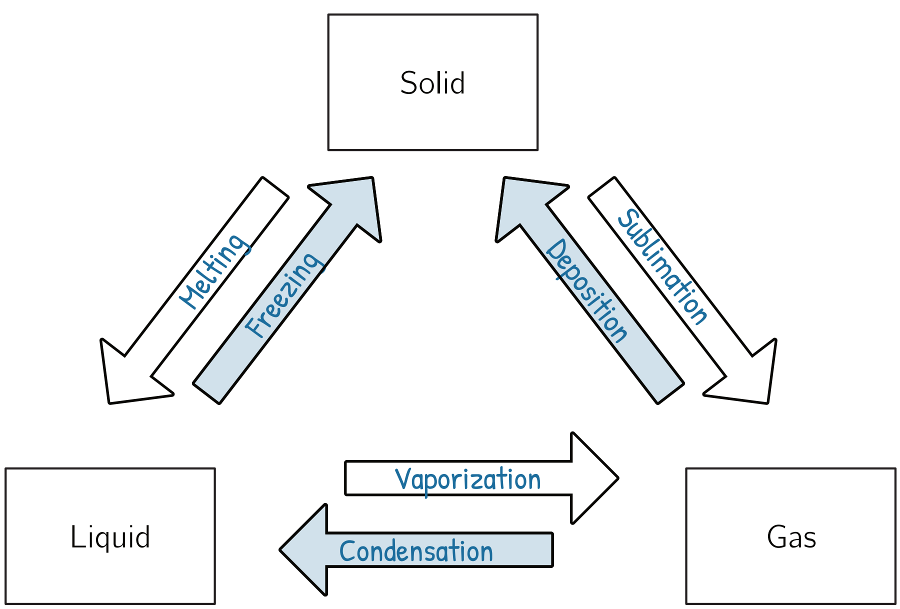
7. What is the difference between vaporization and condensation when considering heat transfer?

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.

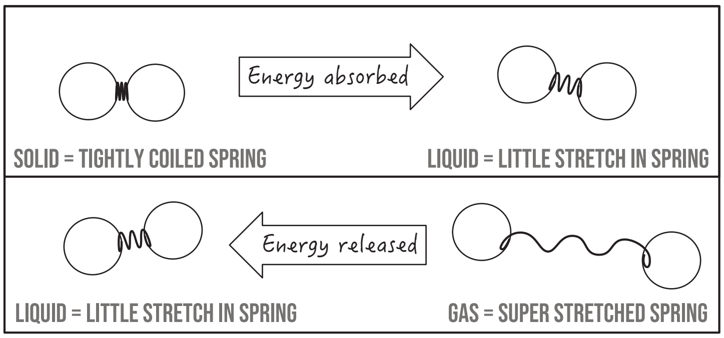


Thermodynamics

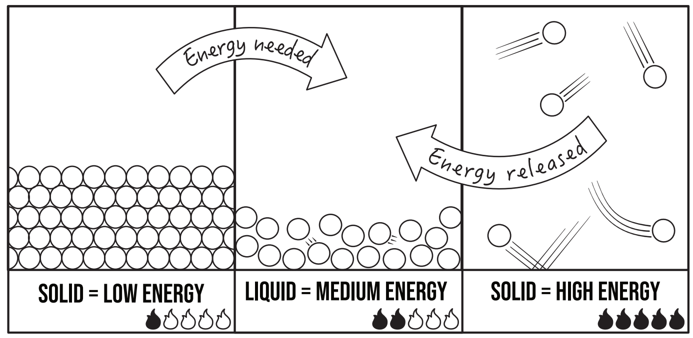
Review: Bob has water condensing on the outside of his fish tank and wants to know if the condensation is warming up or cooling down the tank. In other words, does condensation absorb or release heat? How would you explain the answer to Bob?

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

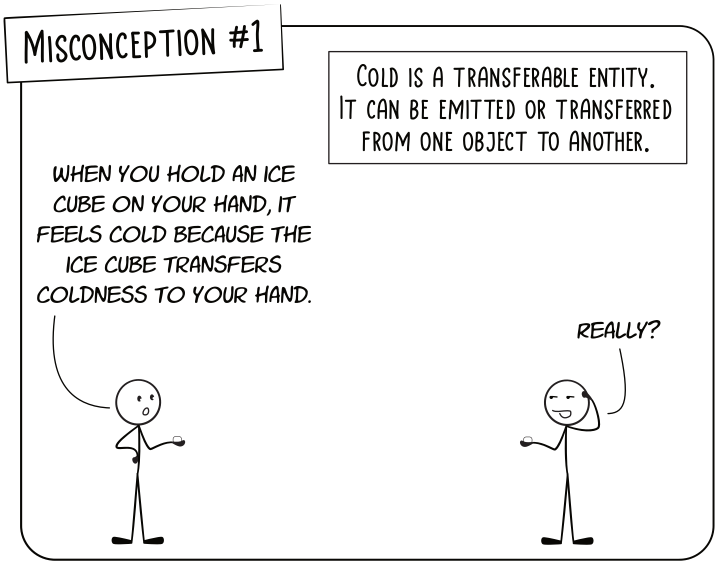
Diagrams or pictures will vary. Something with particles and something to show their motion/movement would be great!

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

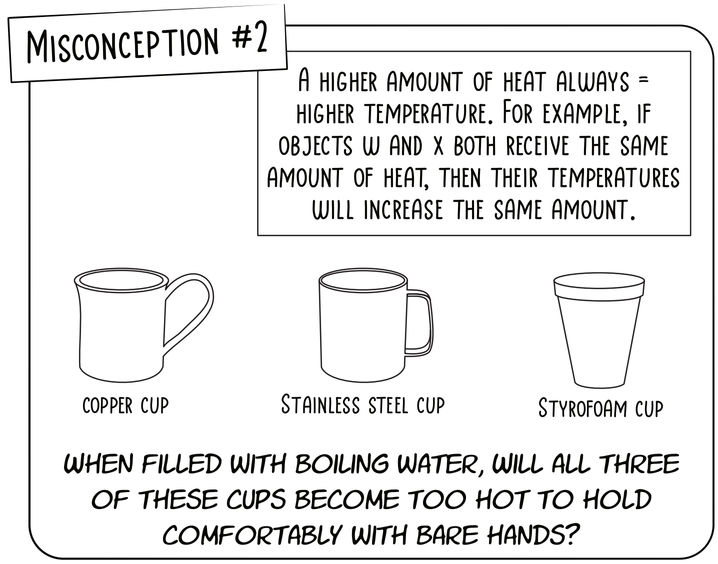
Below are two common misconceptions about thermodynamics, along with an example that seems to support each of them. Correct each statement and explain what is happening with the example.



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.



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

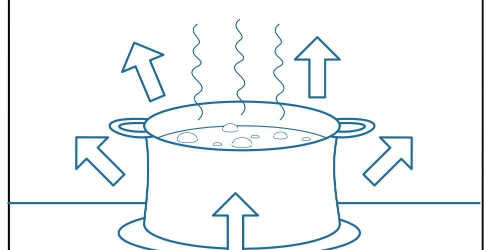
Much of what we've learned in this unit can be summarized in the three laws of thermodynamics.

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.



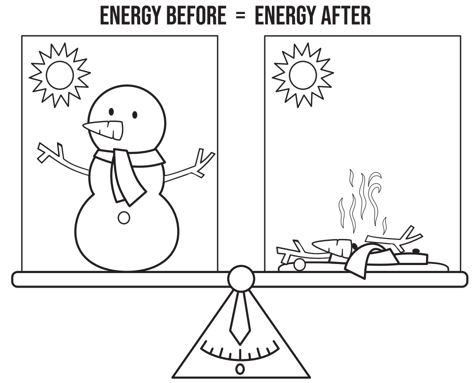
1st law: Electric energy is transformed into heat in the stovetop.

2nd 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.



$\Delta U = Q - W$

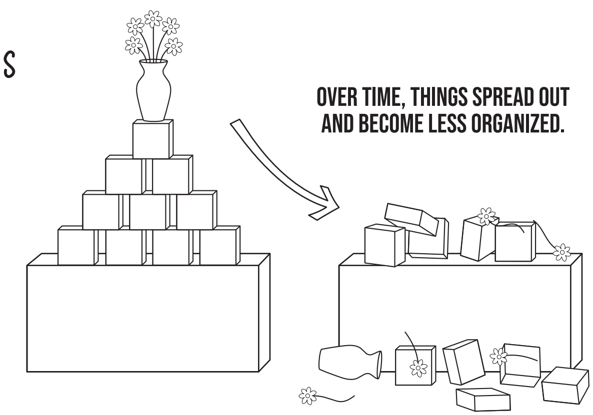
The change in the internal energy of a system is equal to the heat added or lost to the system and the work done by the system on its surroundings.

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.

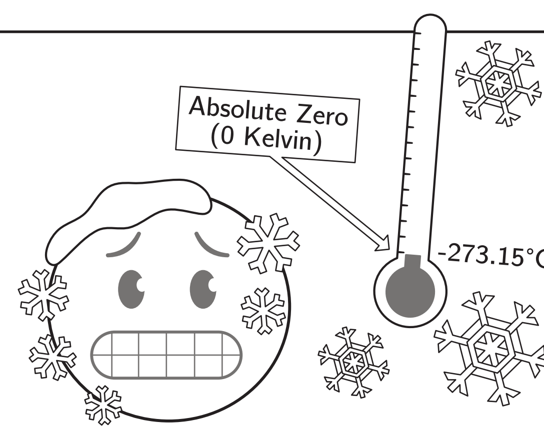
Third Law of Thermodynamics

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

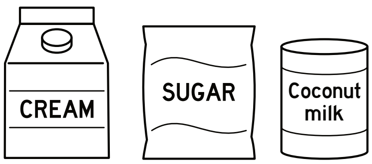
5. If you leave a hot cup of coffee in a cold room, what will happen according to the second law of thermodynamics?
   A. The coffee will get hotter.
   B. The temperature of the coffee and the room will equalize.
   C. The room will become hotter than the coffee.
   D. Nothing; the temperature will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

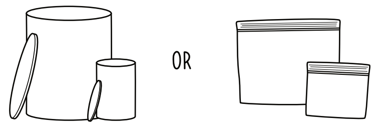
7. If energy is conserved in a closed system, what does this imply?
   A. The total energy in the system will increase over time.
   B. The energy can change forms but the total amount remains constant.
   C. Energy flows from cold objects to hot objects.
   D. Marmoset.

MAKE YOUR OWN ICE CREAM

MATERIALS



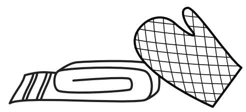
Ingredients for ice cream
(For a dairy-based dessert, use sugar, cream, and desired flavorings. For a dairy-free dessert, use coconut milk, dates, and cocoa powder.)



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

Ice

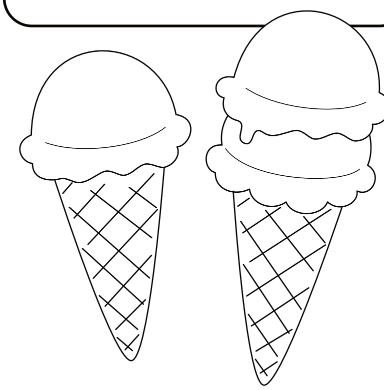
Rock salt



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!

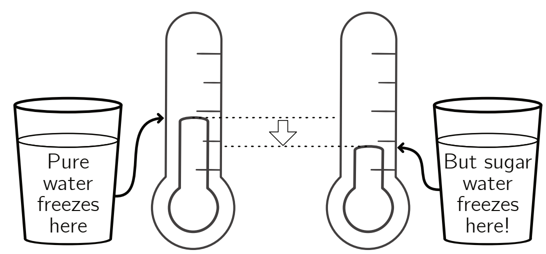


Pre-lab Questions:

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

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!

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

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.

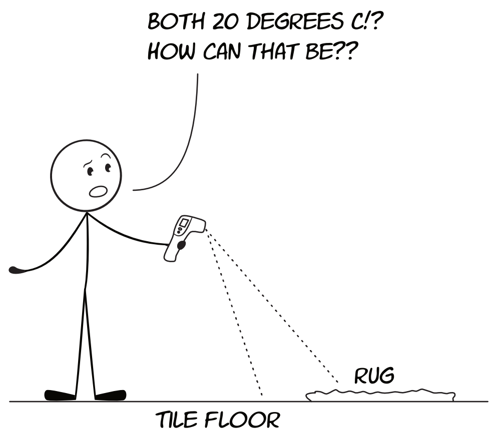
HEAT: The energy that flows from one object to another due to a difference in their temperatures. Heat is measured in calories or joules.

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

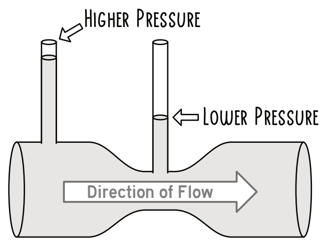
13. Which phase change below releases heat?
    A. Evaporation
    B. Sublimation
    C. Melting
    D. Freezing

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

Unit 2: Fluids and Pressure

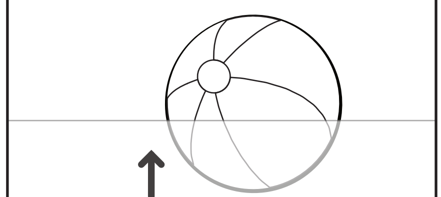
Liquids and gases are both fluids!

BERNOULLI'S PRINCIPLE



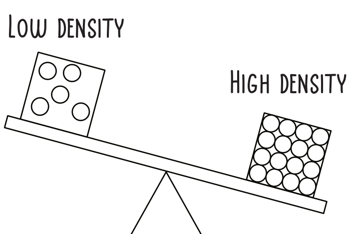
As the speed of a fluid increases, the pressure decreases

BUOYANCY



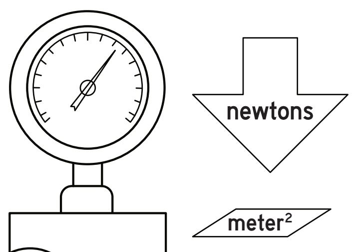
$\vec{F}_b = -\rho g V$ The upward force exerted by a fluid on an object

DENSITY



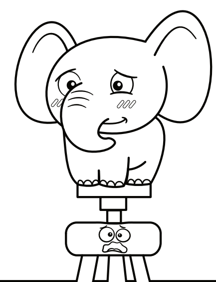
$\rho = \frac{m}{V}$ How compact something is or how much mass per unit of volume

PASCALS



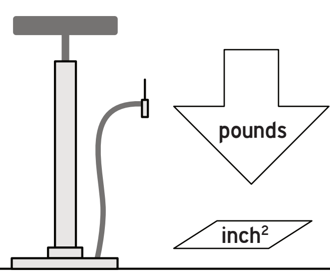
Pa A measure of pressure: newtons per square meter

PRESSURE



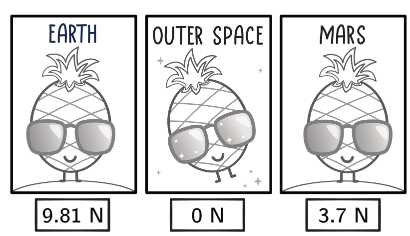
$P = \frac{F}{A}$ The amount of perpendicular force applied per unit of area

PSI



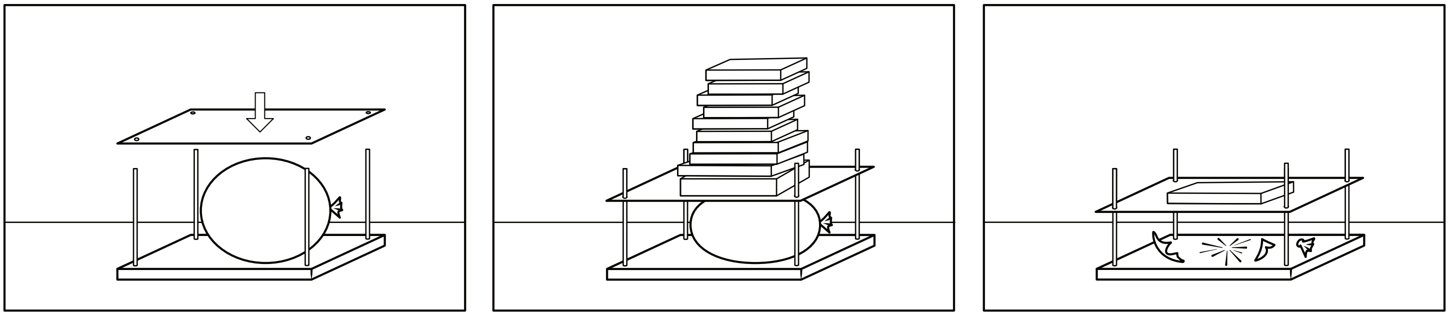
A measure of pressure: pounds per square inch

WEIGHT



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

Pressure



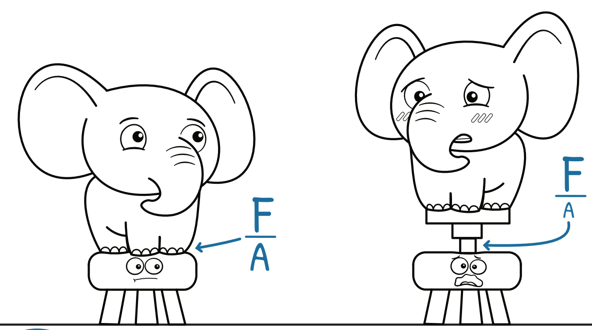
A balloon can support the weight of 10 books before popping. But if a pin is placed on the bottom of the press, then the balloon pops under the weight of one book. Why?

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

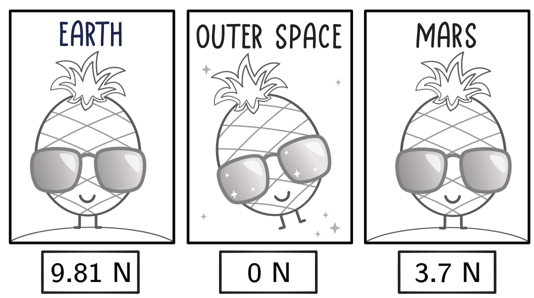
LABEL EACH CARD WITH THE CORRECT TERM AND DEFINITION, THEN DESCRIBE THEIR SIMILARITIES AND DIFFERENCES.

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:

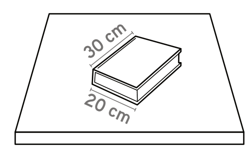
$$1.75 \text{ PSI} \ \frac{6.895 \text{ kPa}}{1 \text{ PSI}} = 12.07 \text{ kPa} \qquad 12.07 \text{ kPa} \cdot \frac{1 \text{ atm}}{101.3 \text{ kPa}} = 0.119 \text{ atm}$$

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?

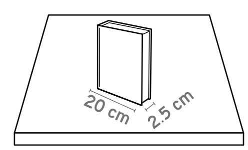


Pressure = Force / Area. To calculate the force the book is exerting on the table in pascals, we need to be sure we have the correct units of newtons/m^2.

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
1,000 Pa = 1 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:

Flows easily: has low viscosity

Resistance to flow: has high viscosity

Behaves in ways that don't match the typical definition of a fluid

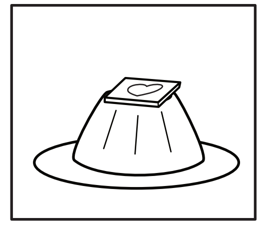
Practice Problems – Pressure & Fluids

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 m². How much pressure (in pascals) is the book applying on the gelatin dessert?

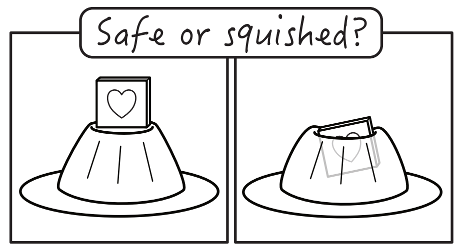


$\frac{12\ \text{N}}{0.04\ \text{m}^2} = 300\ \text{Pa}$

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 m².



$\frac{12\ \text{N}}{0.003\ \text{m}^2} = 4{,}000\ \text{Pa}$

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 m², 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.

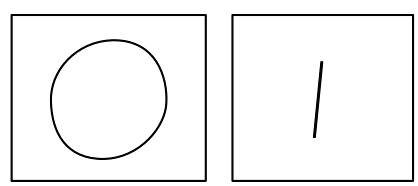
    The same weight applied to a smaller area of contact will result in greater pressure.

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

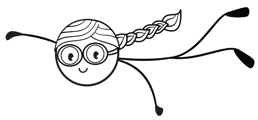
    Skater pressure : $\frac{\text{force}}{\text{area}} = \frac{110 \text{ lb}}{1.5 \text{ in}^2} \approx 73.3 \text{ PSI}$

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

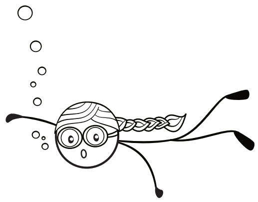
Going for a Swim

Think about it:

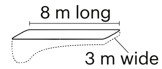
At surface:
Ears don't pop



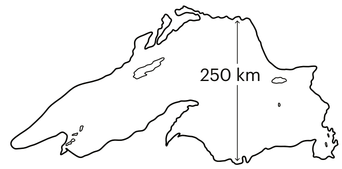
8 feet deep:
Ears pop



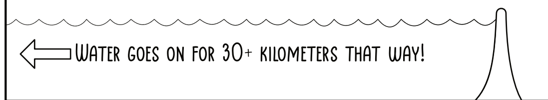
Backyard pool:
48 cubic meters



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?

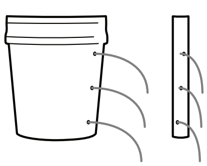
Answers will vary, but students might know from experience that the feeling of increased pressure from being a certain depth underwater is the same regardless of how large the pool or lake is.

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.

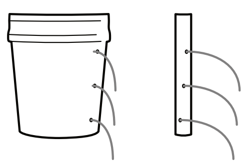
Holes are drilled in a 5 gallon bucket and a narrow piece of pipe. The holes are the same diameter and depth. Which of these drawings matches your prediction for how the water will flow out?

A



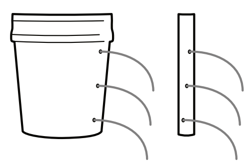
Stronger spouts from bucket but same from all holes. Hole position doesn't matter but container size does.

B



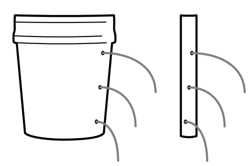
Stronger spouts from pipe but same from all holes. Hole position doesn't matter but container size does.

C



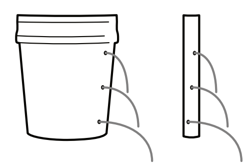
Same-sized spouts from all of the holes. Position and container shape make no difference.

D



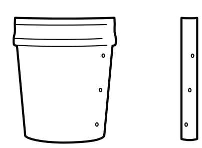
Stronger spouts from top but same pattern from bucket and pipe. Hole position matters, not container size.

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

$P_{(fluid)} = \rho g h$

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

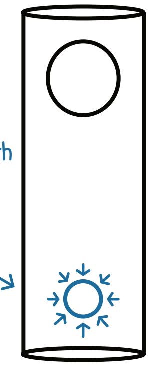
A CONFINED FLUID APPLIES PRESSURE EVENLY IN EVERY DIRECTION.

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

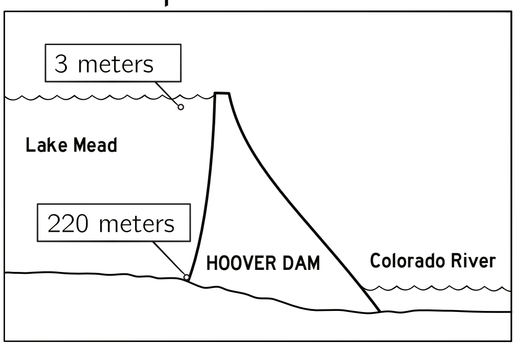
Pressure increases with depth! In any liquid, the deeper you go , the higher the pressure.

WHAT SHAPE WOULD A BALLOON HAVE DEEP UNDER WATER?

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



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.

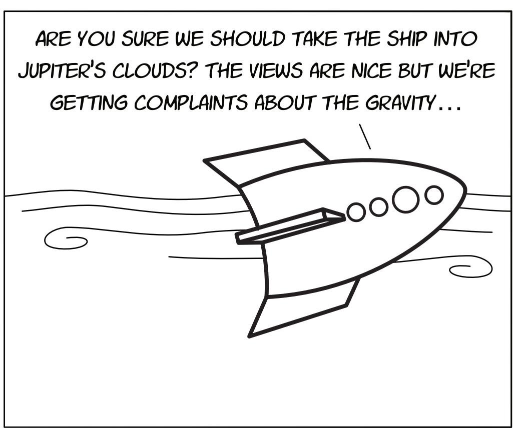
Pressure = ρgh (density · gravity · depth)

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?

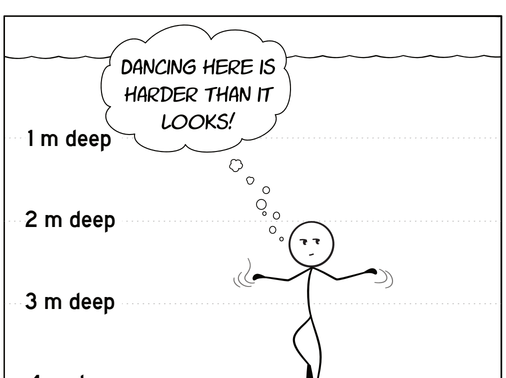
Pressure = ρgh (density · gravity · depth)

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

To find the depth, use P=ρgh 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)

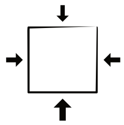


Bob is performing an underwater dance while standing on the bottom of a swimming pool. Calculate the water pressure at Bob's head (2 m deep) and his feet (4 m deep).

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

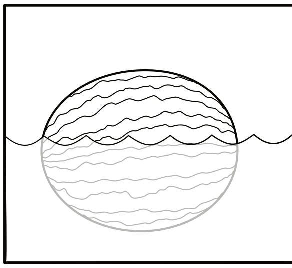


Because pressure increases with depth, the pressure against the bottom of an object in a fluid will always be greater than the pressure against the sides or top.
This net upward force is called the **buoyant force**.

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.

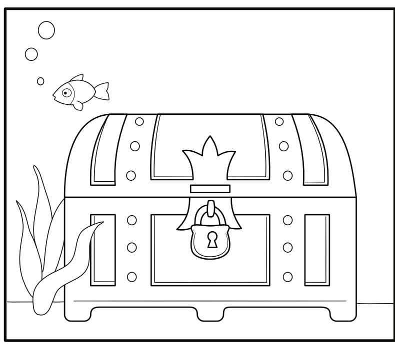
WHAT IS THE BUOYANT FORCE ON THE WATERMELON?

58 N

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

Equal because the watermelon is floating. a floating object always displaces a volume of water (or any fluid) whose weight is equal to its own weight.

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 4,660 NEWTONS?

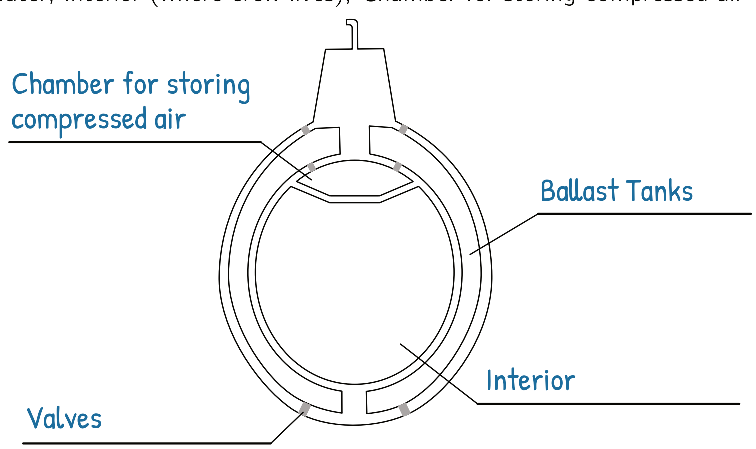
More. If the weight of the chest were equal or less than the buoyant force, then it would be suspended in water or floating.

WHY DOES THE WATERMELON FLOAT WHILE THE TREASURE CHEST SINKS?

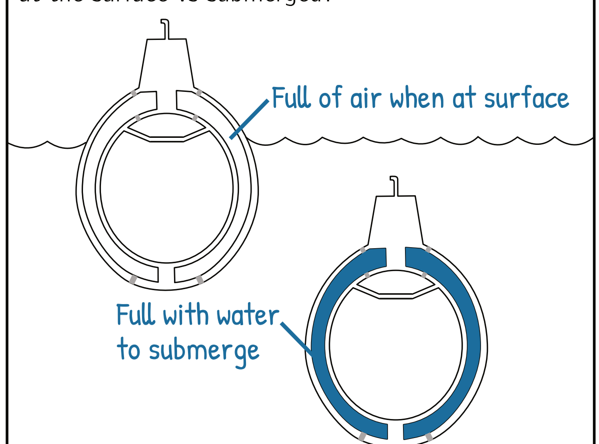
The chest weighs more than the weight of the water it displaces so the chest weighs more than 4,600 N (1,034 pounds). This is true of all objects that sink. Floating objects have a weight equal to the weight of the water they displace. So the weight of the watermelon weight must be equal to 58 N (13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

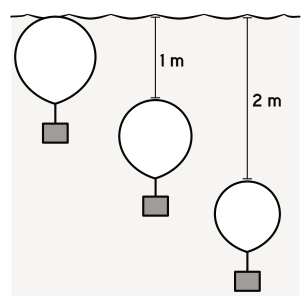
1. How does the volume of a completely submerged object compare with the volume of the water displaced?
   A. The submerged object has more volume than the water displaced.
   B. $\boxed{\text{The submerged object has the same volume as the water displaced.}}$
   C. The submerged object has less volume 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. $\boxed{\text{The floating object has the same weight as the water displaced.}}$
   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 feels like it lost the weight of the water that was 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.

(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?

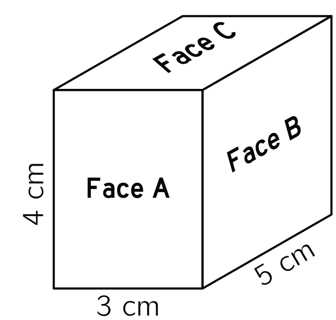
The water level remains unchanged. An ice cube displaces its weight of liquid water. When the ice cube melts, its volume matches exactly the water that it displaced when it was solid.

(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)

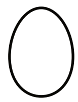
WATER PRESSURE at 2 m deep = 1,000 kg/m^3 · 9.8 m/s^2 · 2 m = 19,600 pascals (19.6 kPa)

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

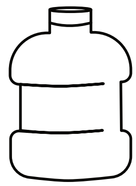
The water exerts more pressure than honey at these depths. But we still wouldn't recommend swimming in honey.

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.

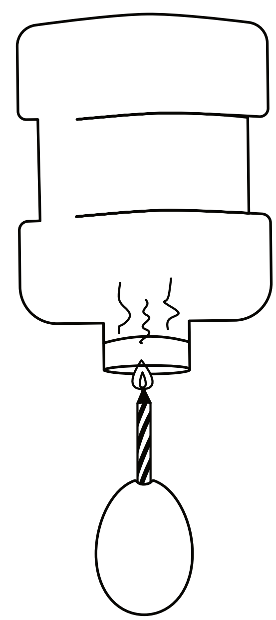
A small candle

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?

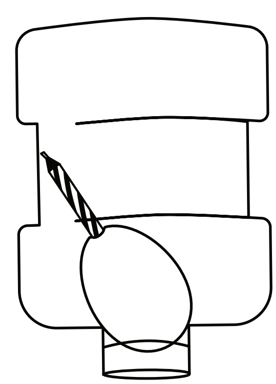


INSTRUCTIONS:

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:

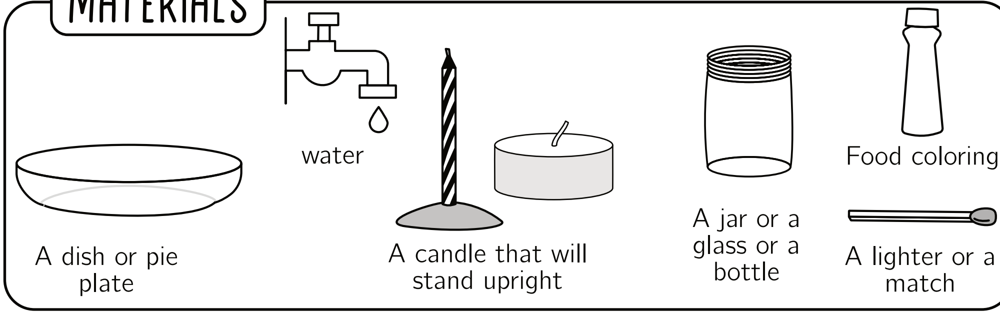
The hot flame heats up the air inside the bottle causing the air to expand as its molecules get excited. Without the heat of the flame, the air molecules cool quickly. Normally, other air would rush in to fill the bottle as the cooler air inside contracts, but the egg blocks the opening. The pressure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

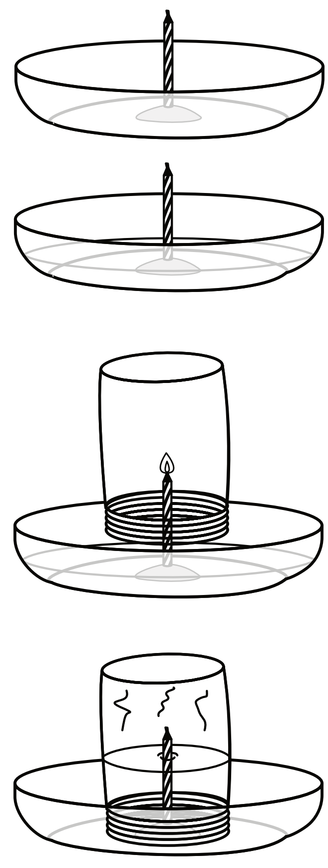
MATERIALS



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.

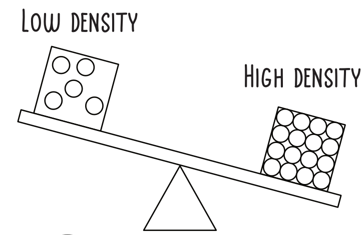
Did it work? If not, then write about what might have gone wrong. If so, then write some advice that would help another student carry out this demonstration.

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

DENSITY



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

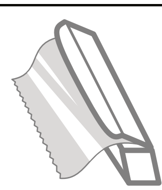
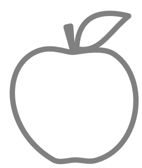
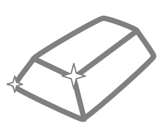
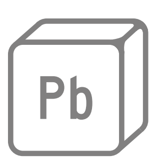
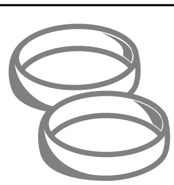
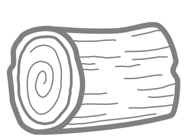
2. 250 milliliters of olive oil weighs 215 grams. What is the density of olive oil?

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

so 215g/250cm³ = 0.86 g/cm³

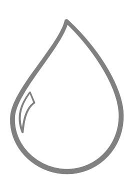
Will it sink or float?

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

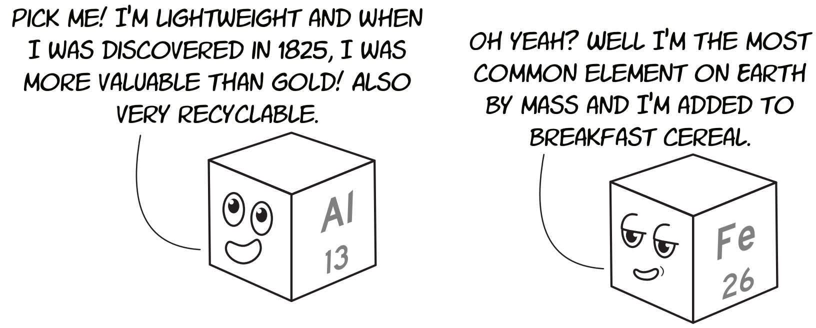


Density of water at 4 °C is 1,000 kg/m³
Density of honey is 1,400 kg/m³
Density of mercury is 13,590 kg/m³

Buoyancy

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

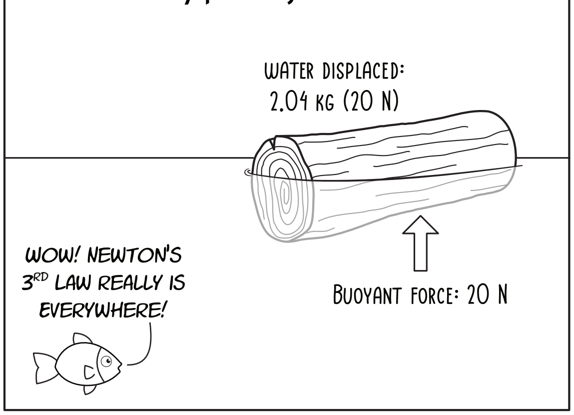
Their buoyancy will be the same! They both displace 1 cubic meter(1,000 kg) of water so they will both experience a buoyant force of 1,000kg·9.81 m/s² = 9,810 N



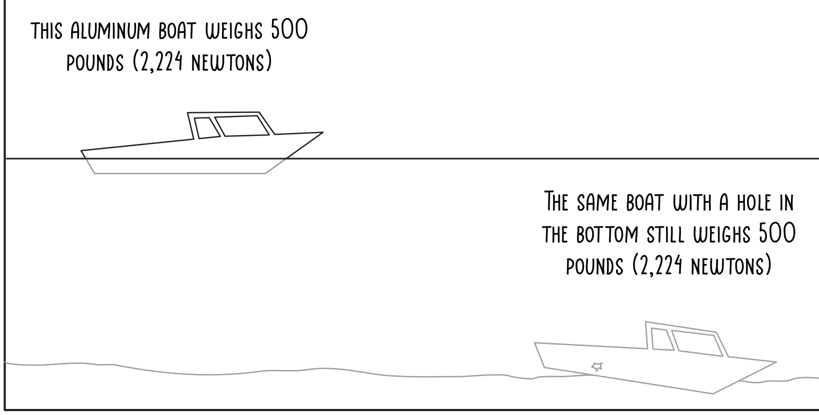
MISCONCEPTION ALERT!

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!



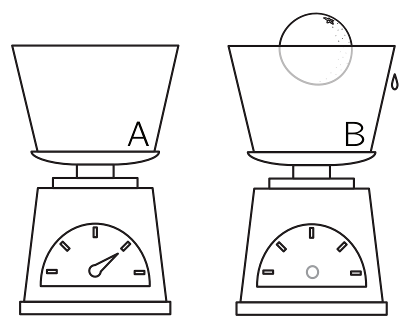
Weight or density alone won't tell you if an object will sink or float!



Use the floatation principle to answer the following questions:

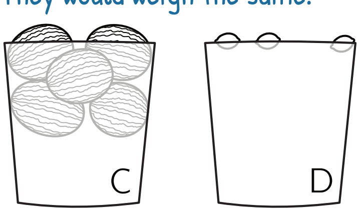
1. A container **full to the brim** with water weighs 30 newtons (A). How much would the container weigh after a grapefruit is placed in the water (B)? *Note: adding the fruit will cause water to spill over the edge.*

   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.

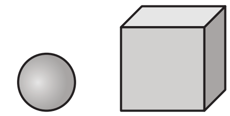


FLOATATION PRINCIPLE:

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.

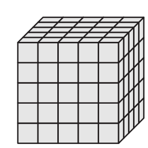
gold	water	ice	wood	air
MOST DENSE				LEAST DENSE

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?

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

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.

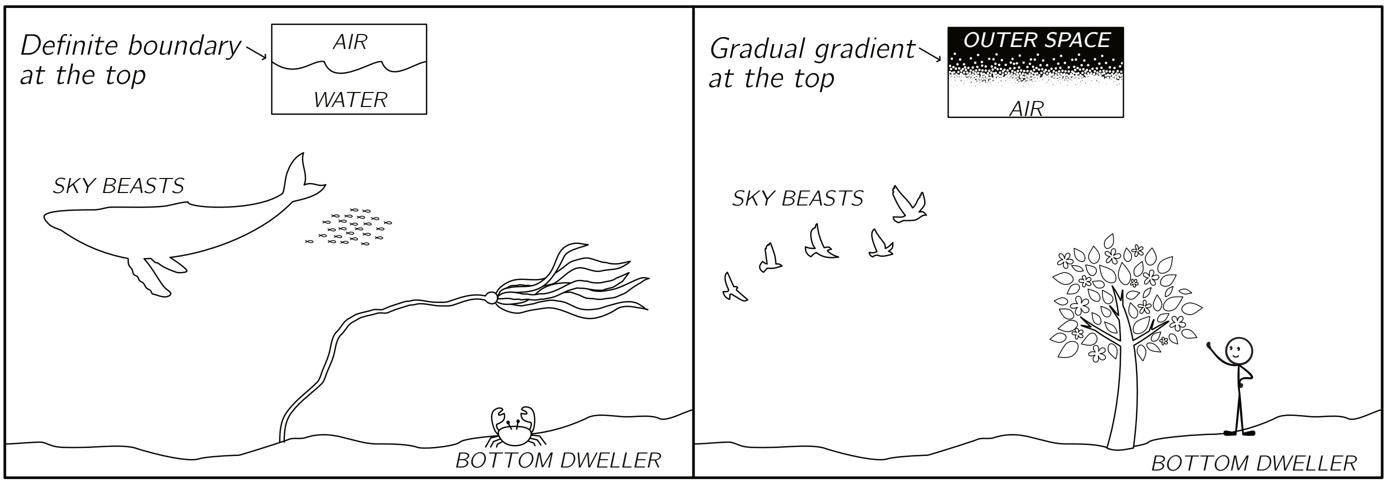
An Ocean of Air

Fill in the blanks:

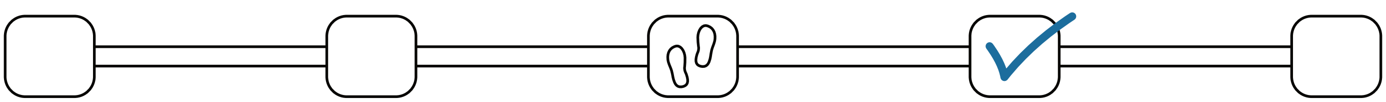
expand	pressure	fluids	decreasing	increasing

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 | 5x bigger ✓ | 10x bigger

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

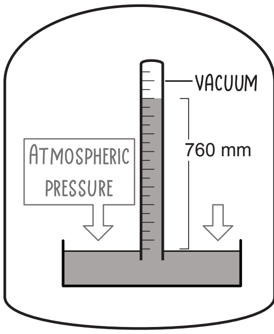
Answers will vary! Brief explanations are:

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.

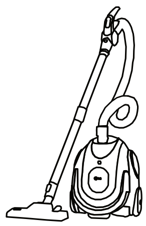
Magdeburg sphere: If air is pumped out, the atmospheric pressure on the spheres is so strong, they can't be pulled apart!

An Ocean of Air



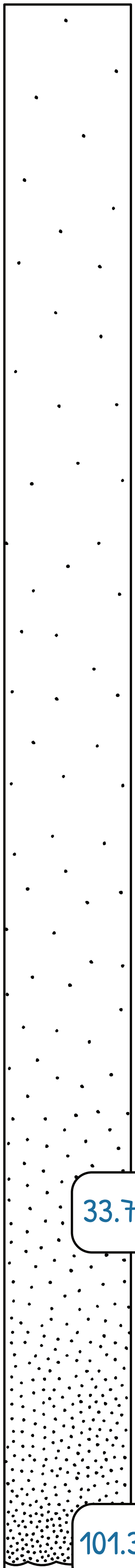
Italian physicist Evangelista Torricelli believed that air had weight and could apply pressure to support a column of water. To test this idea, he filled a glass tube with mercury and inverted it into a dish that was also filled with mercury. This groundbreaking experiment in 1693 led to the development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

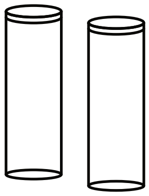
R *is the ideal gas constant (8.314 J/(mol·K)*

T *should be in degrees kelvin.*

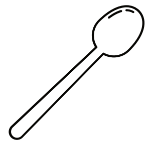
Once moles are found, use the average molar mass of air to convert to kilograms. (multiply the value of ***n*** *by 0.029 kg/mol)*

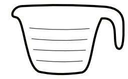
OPTION 1: DENSITY COLUMN

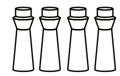
MATERIALS


2 tall narrow clear containers

Several liquids of different densities OR sugar and water


Spoon


Measuring cup


Food coloring (optional)

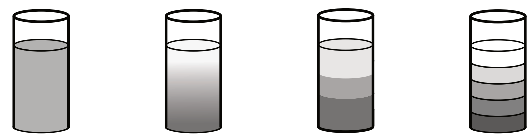
GOALS

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

Pre-lab Questions:

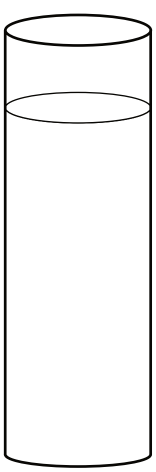
① What is density? Describe it in your own words:

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?

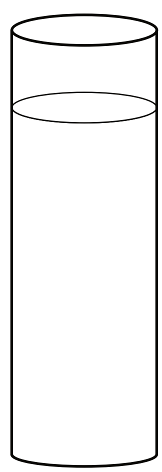


Draw and explain your prediction for when the liquids are layered from *most dense* on bottom to *least dense* on top (container 1). Also make a prediction for what you expect to see when they are layered from *least dense* on bottom to *most dense* on top (container 2).

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?

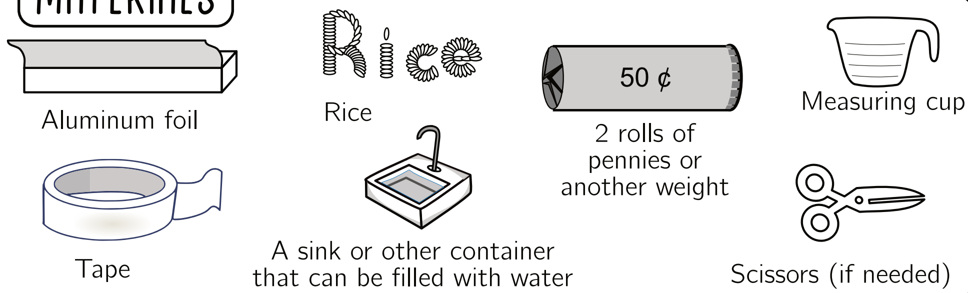
Did your observations match your predictions?

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

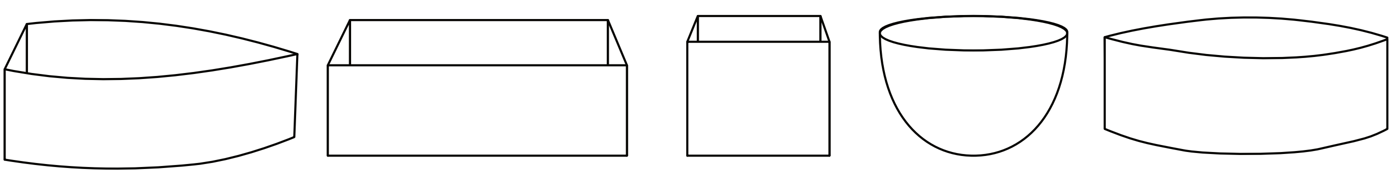
Pre-lab Question:

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.

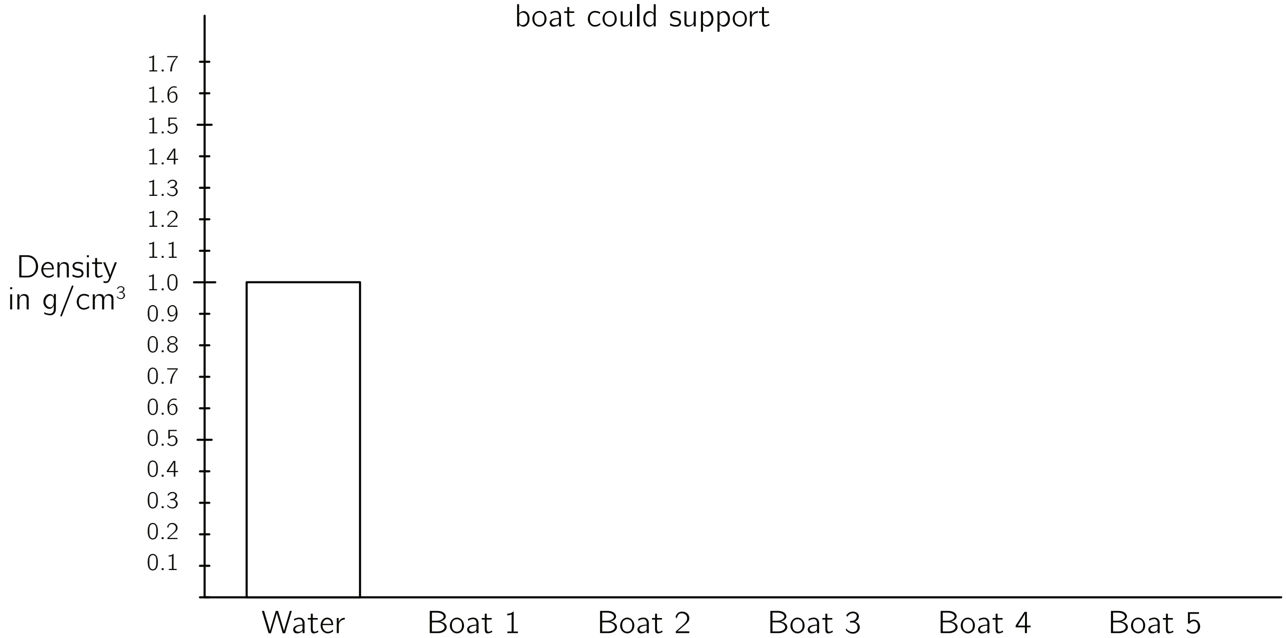
1. Use aluminum foil and tape to construct five small boat hulls. Each boat should have a different size and shape (e.g. boxy, pointed, wide, or triangular). Check to make sure your boats do not leak. Each boat should be strong enough to keep its shape when filled with rice.



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				

The maximum density each boat could support



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?

____

____

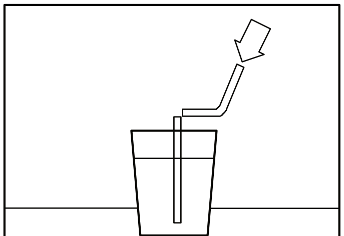
How do you think the results would have turned out differently if you had used a different liquid than water?

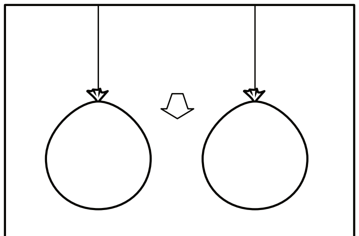
____

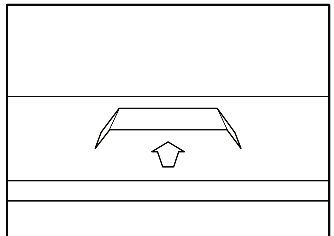
____

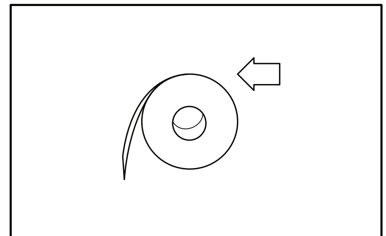
Fluids in Motion

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

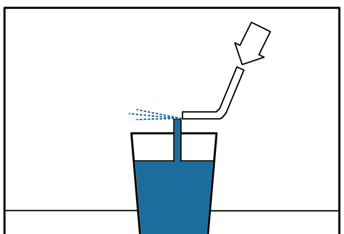

BLOWING AIR BETWEEN TWO BALLOONS HANGING FROM STRING

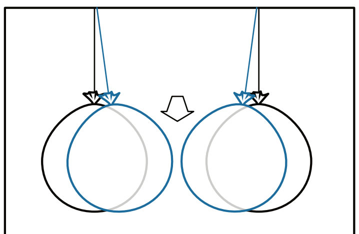

BLOWING AIR UNDER A BENT INDEX CARD RESTING ON A TABLE

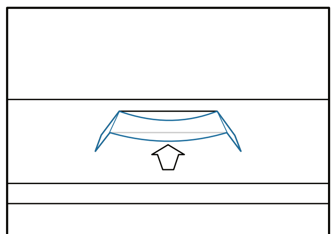

BLOWING AIR OVER THE TOP OF A ROLL OF TOILET PAPER

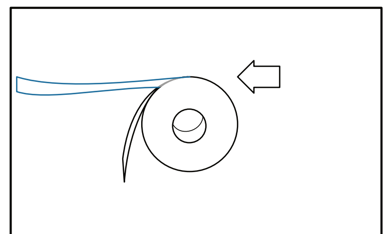
Predictions will vary

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


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

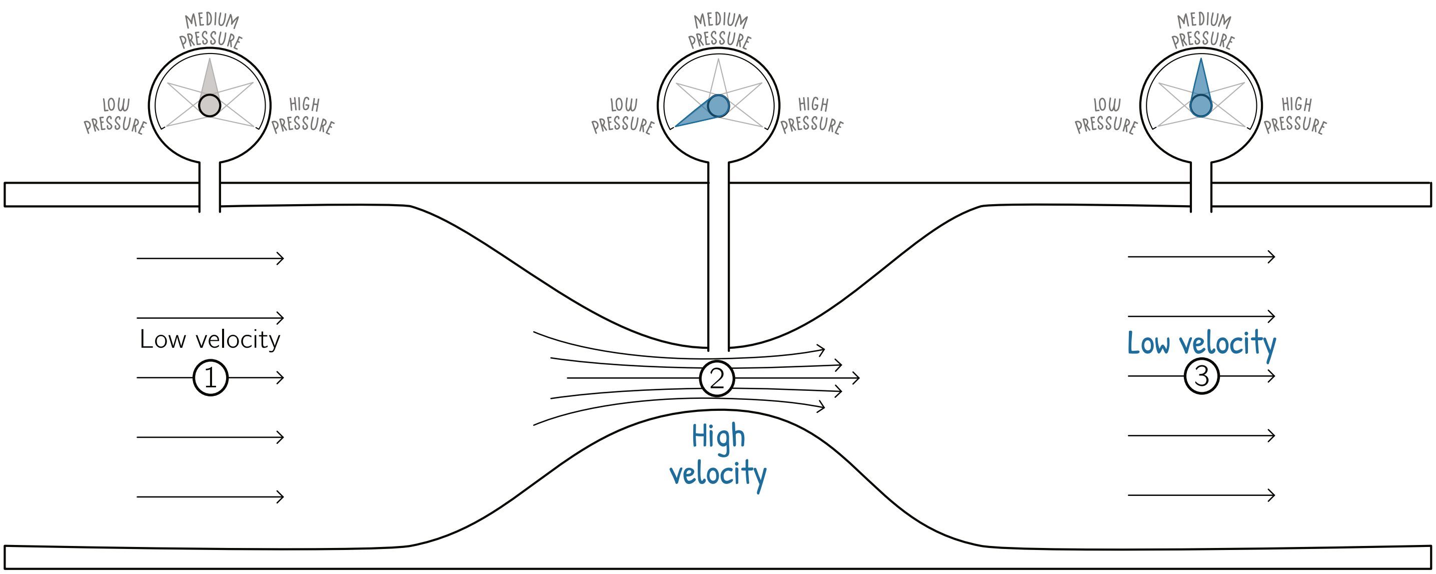
Water goes up and out from the straw!

The balloons move closer together

The card pulls down toward the table

The paper lifts up!

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

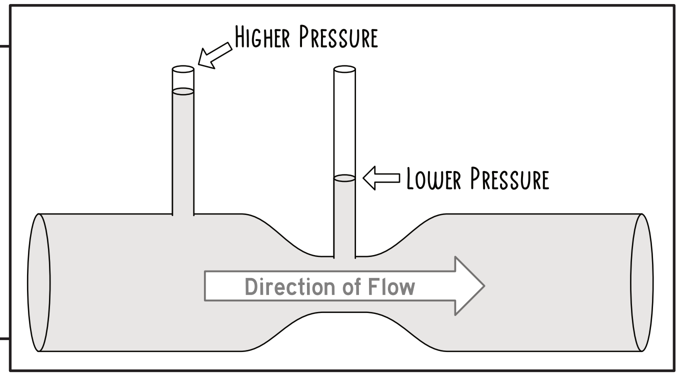


Fluids in Motion

Bernoulli's Principle

As the velocity of a fluid increases,

the pressure decreases.



Laminar Flow

Fluid moves smoothly in parallel layers with minimal mixing.

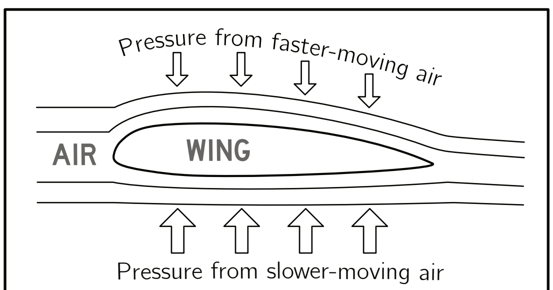
- Predictable
- Less friction or energy loss due to drag
- Movement of objects through fluids are more efficient with laminar flow

Turbulent Flow

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

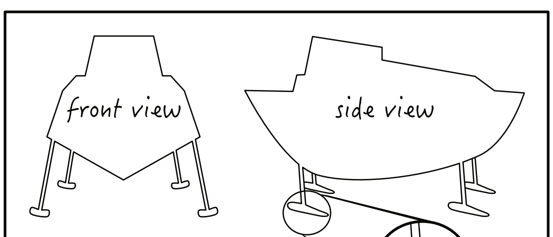
- Unpredictable
- Usually occurs at high velocities or in fluids with low viscosity (ie air)
- Enhances heat transfer and mixing

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

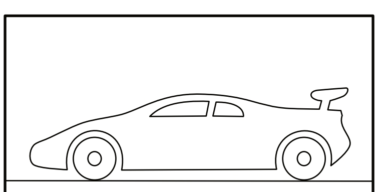
Airplane wing: the curved edge (airfoil) causes air to move faster over the top. As speed increases, lift increases.



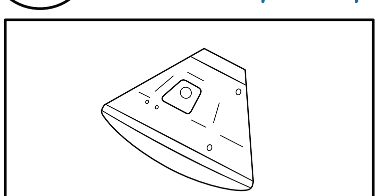
HYDROFOIL

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.



SPOILER



REENTRY CAPSULE

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

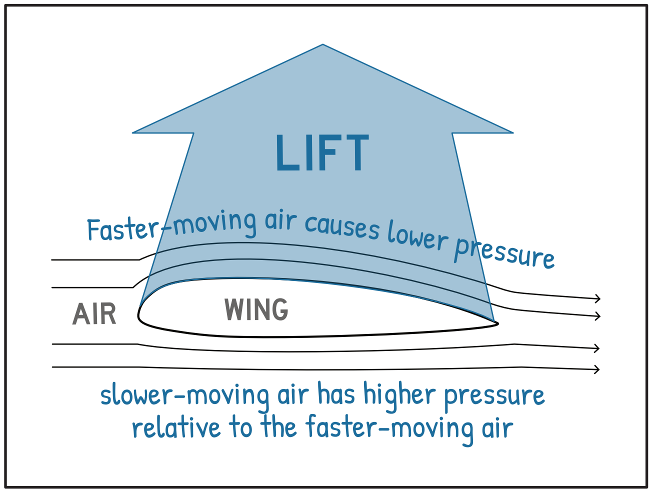
It's the combined result of the Bernoulli effect and hot air rising that pulls the curtain inward

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?

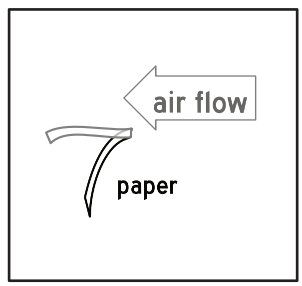
   The wing is curved more on the top and flatter on the bottom, which makes air travel faster over the top surface than the bottom. The faster-moving air has lower pressure and this difference in pressure produces lift. The angle of attack (the angle between the wing and the oncoming air) also contributes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

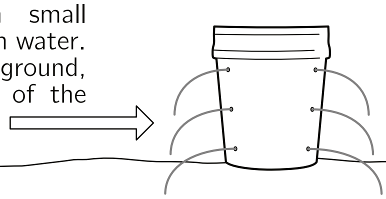
    Faster-moving fluid = lower pressure

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.



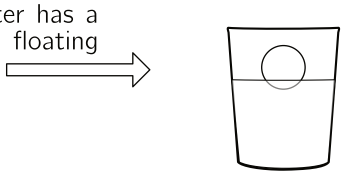
What will happen when the bucket is dropped?

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?

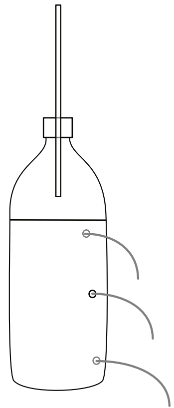
What do you predict will happen and why?

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.

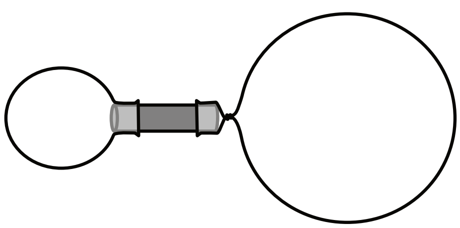


What will happen when the straw is lowered into the bottle?

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?

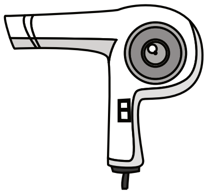
Because the only force acting on them is gravity, and gravity is a non-contact force. Everything inside a freefalling system moves at the same rate.

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?

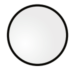
Because it is displacing more than 200,000 tons of water, and therefore experiences a buoyant force that is more than its weight.

PING PONG LAUNCH

MATERIALS



Blow Dryer



Ping Pong Ball

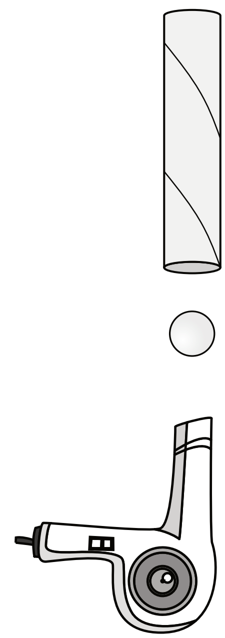
Paper towel tube or toilet paper tube

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:

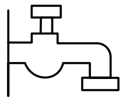
The ping pong ball stays in place because the net forces are balanced. The flowing air pushes against the ball, while gravity pulls the ball. The atmospheric pressure pushes against the ball while a lower pressure from the fast moving air pushes with less force from below the ball. As the blow dryer 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.

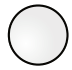
Would this demonstration work with a leaf blower that can blow air much faster than a blow dryer? If so, explain why. If not, what might go wrong?

A BALL ON A STRING

MATERIALS


Tape or a glue gun


Faucet


Ping Pong Ball


String

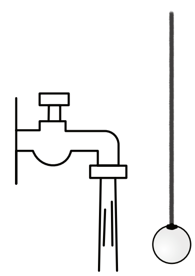
GOALS

- 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)

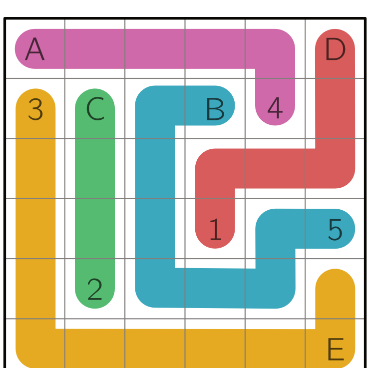
FLUID: Gas or liquid - something that can flow and does not have a fixed shape.

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.

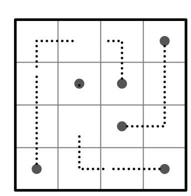
PSI: Pounds per square inch.

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



Fluids & Pressure Assessment

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

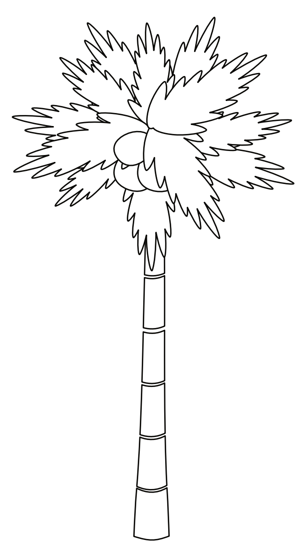
12. Which statement best describes why fish are able to float at different depths in water?
    A. Fish change their volume by inflating or deflating air bladders, adjusting their density
    B. Fish constantly swim upward to stay afloat
    C. The water's density changes to accommodate the fish
   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

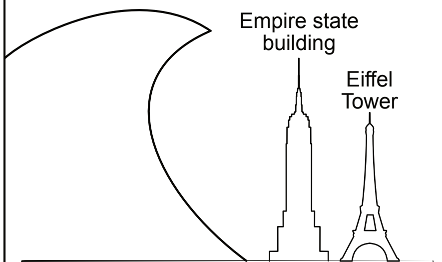
16. Why does a diver feel more pressure as they dive deeper?
    A. Because water temperature decreases with depth, increasing pressure
    B. Because the volume of water above the diver increases, increasing pressure
    C. Because the density of water increases with depth
    D. Because of increased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



Making Waves

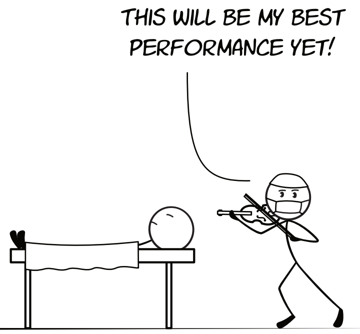
FACT OR FICTION? *Write your verdict below each statement:*

The largest recorded ocean wave had a height more than 1,000 ft above sea level.



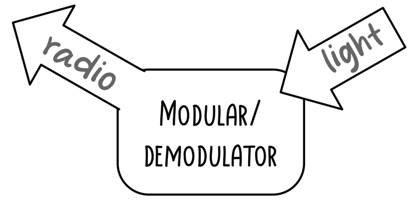
Fact - It was caused by the 1958 Lituya Bay earthquake. This megatsunami washed out trees 524 m (1,719 ft) above the entrance of the bay!

It's possible to do brain surgery using only sound.



Fact - But it can't be done with a violin. It's called High-Intensity Focused Ultrasound (HIFU).

Most modern homes contain a machine that converts light into radio waves.

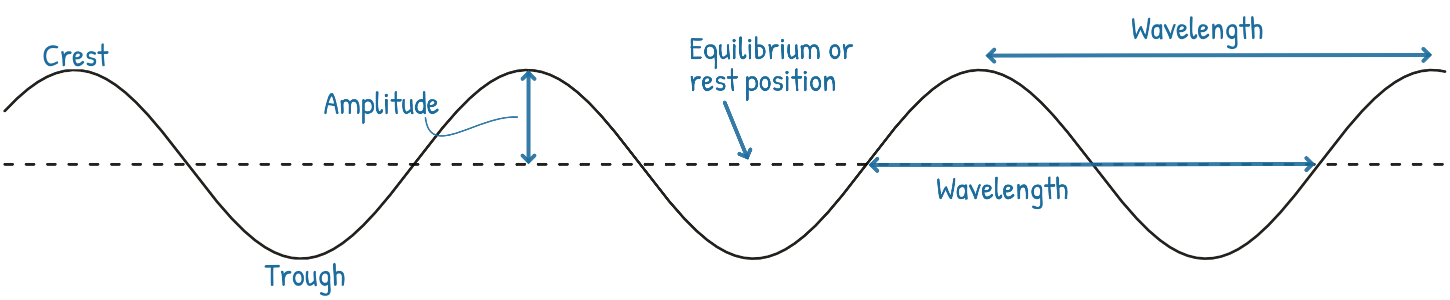


Fact - It's called a modem! Most high speed internet comes from converting information in light (via a fiberoptic cable) into radio waves (wifi).

Fill in the blanks:

energy	*disturbance*	*medium*	*transmitted*

A wave is a disturbance that transfers energy from one place to another without transferring matter. Some waves, such as sound, require a medium. This means they can only travel or be transmitted through physical materials such as air, water, or rock.

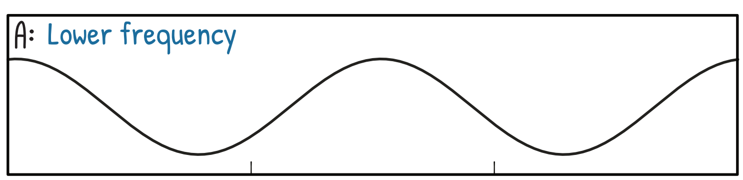


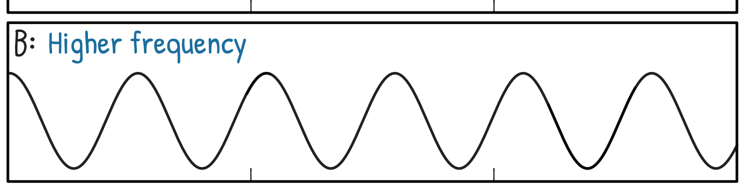
Amplitude: From rest to crest! How HIGH a wave is.

Wavelength: From crest to crest or trough to trough. A measure of how WIDE a wave is.

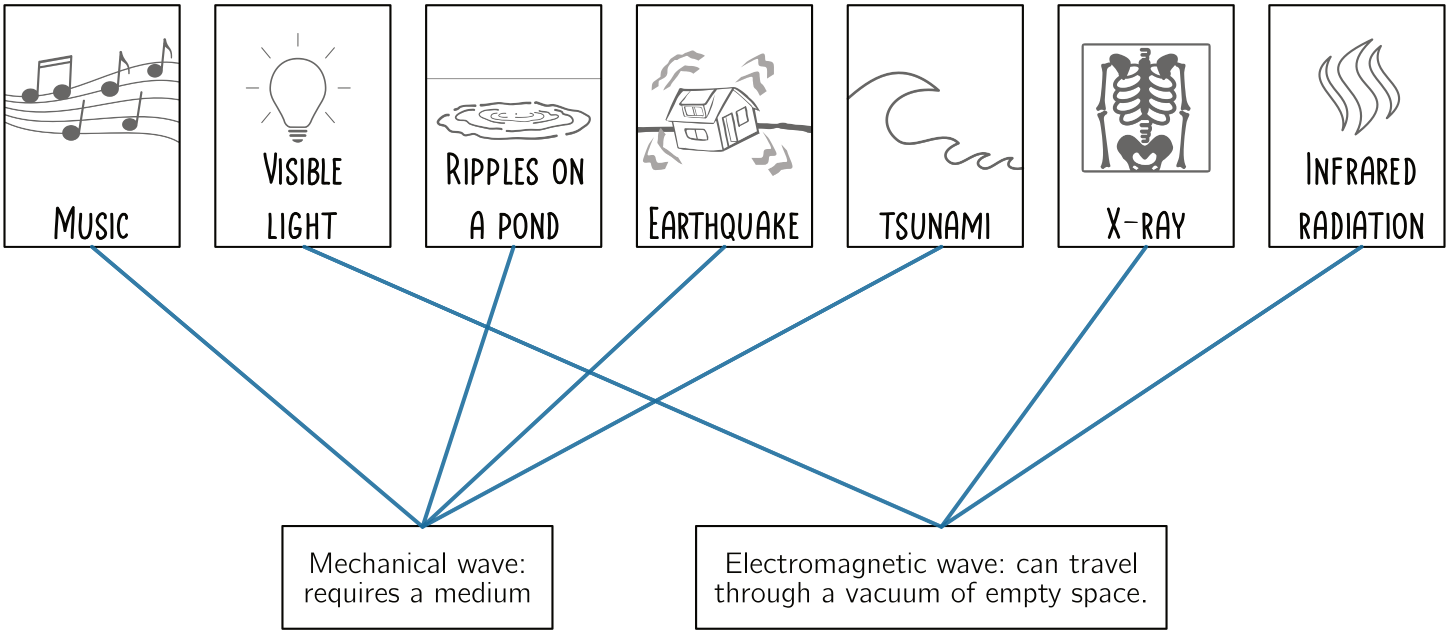
Frequency: The number of crests/troughs (or oscillations) that happen in a certain amount of time. How FAST the wave is.

The images below show how many oscillations occur in 3 seconds.
ave has a higher frequency?



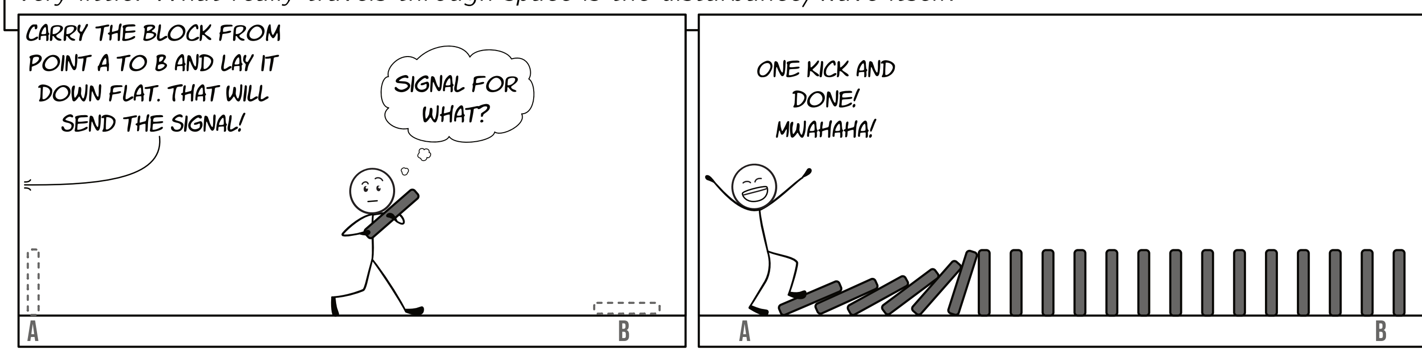


Draw lines to categorize each of these as either a mechanical or electromagnetic wave:

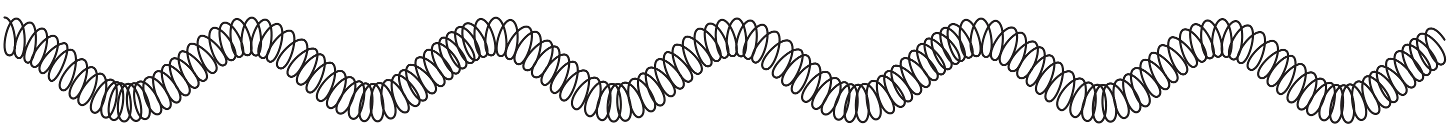


THINK ABOUT IT:

There are 2 primary ways to send energy or information from one place to another: by transporting physical matter or by creating a disturbance or wave that travels through space. With a wave, any matter involved moves very little. What really travels through space is the disturbance/wave itself.

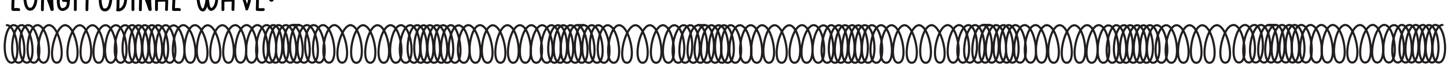


Transverse Wave:



The motion is at a right angle to the direction of the wave speed. Ex. String vibrations, electromagnetic waves, earthquake (secondary or s-waves)

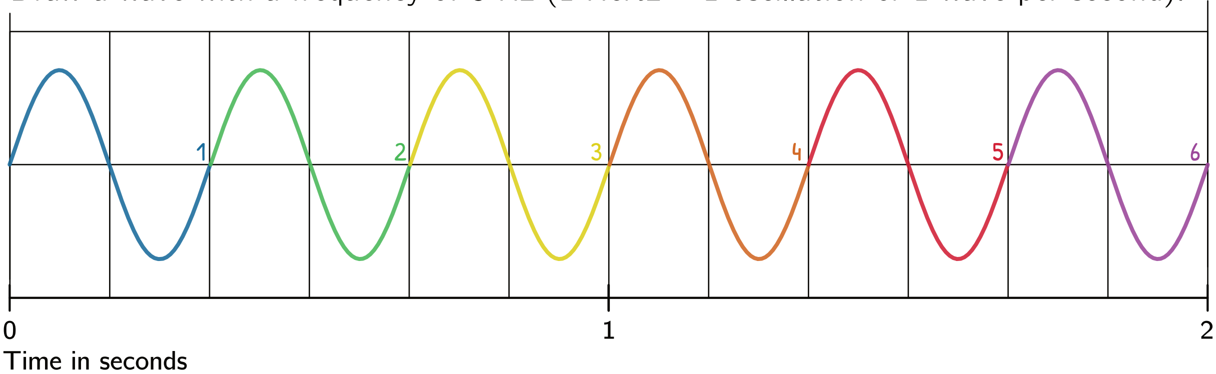
Longitudinal Wave:



The motion is in the same direction that the wave travels. Ex. Sound, sonar, pressure waves, earthquake (primary or p-waves)

Practice Problems – Making Waves

① Draw a wave with a frequency of 3 Hz (1 Hertz = 1 oscillation or 1 wave per second).



② Explain the difference between a mechanical wave and an electromagnetic wave and give an example of each.

A mechanical wave must travel through a physical matter (a medium). It travels fastest through solids and slower through gases. Examples: sound, ocean wave, earthquake

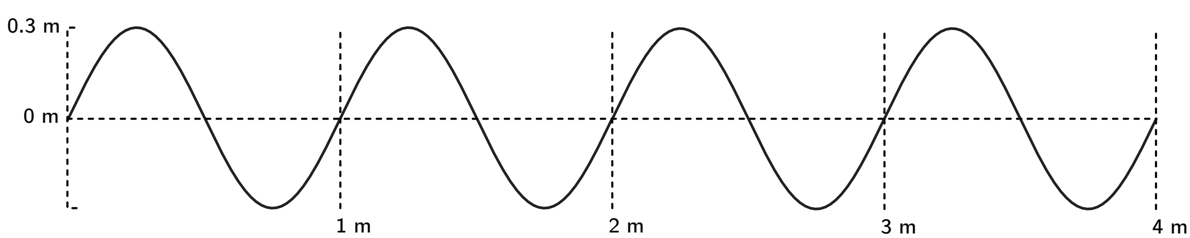
An electromagnetic wave travels at the speed of light and can travel through a vacuum of empty space. Examples: radio waves, microwaves, infrared, visible light, UV light, x-rays, gamma rays

③ A wave represented in the diagram below travels 4 meters in 2 seconds. Answer the following questions about the wave:

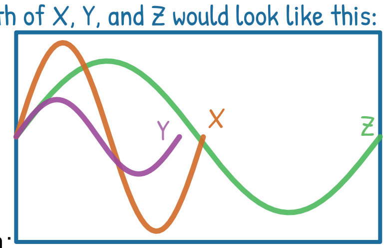
A. What is the wavelength in meters? 1 meter

B. What is the amplitude? 0.3 m

C. What is the speed of the wave in meters per second? 4 m in 2 sec = 2 m/s



One wavelength of X, Y, and Z would look like this:



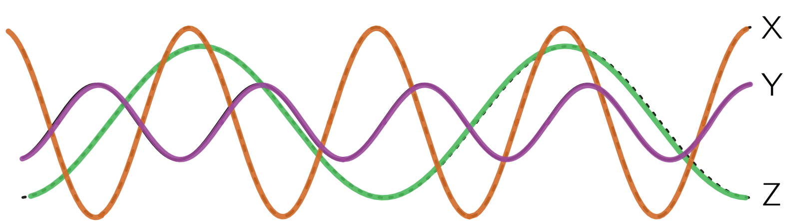
④ Three waves labeled X, Y, and Z are shown below.

A. Rank curves X, Y, and Z below from smallest to largest amplitude:

amplitude of Y < amplitude of Z < amplitude of X

B. Rank curves X, Y, and Z below from smallest to largest wavelength:

wavelength of Y < wavelength of X < wavelength of Z



Practice Problems – Making Waves

5. Are earthquake waves mechanical or electromagnetic? Explain.

   Earthquake waves are mechanical. They are a movement of physical matter.

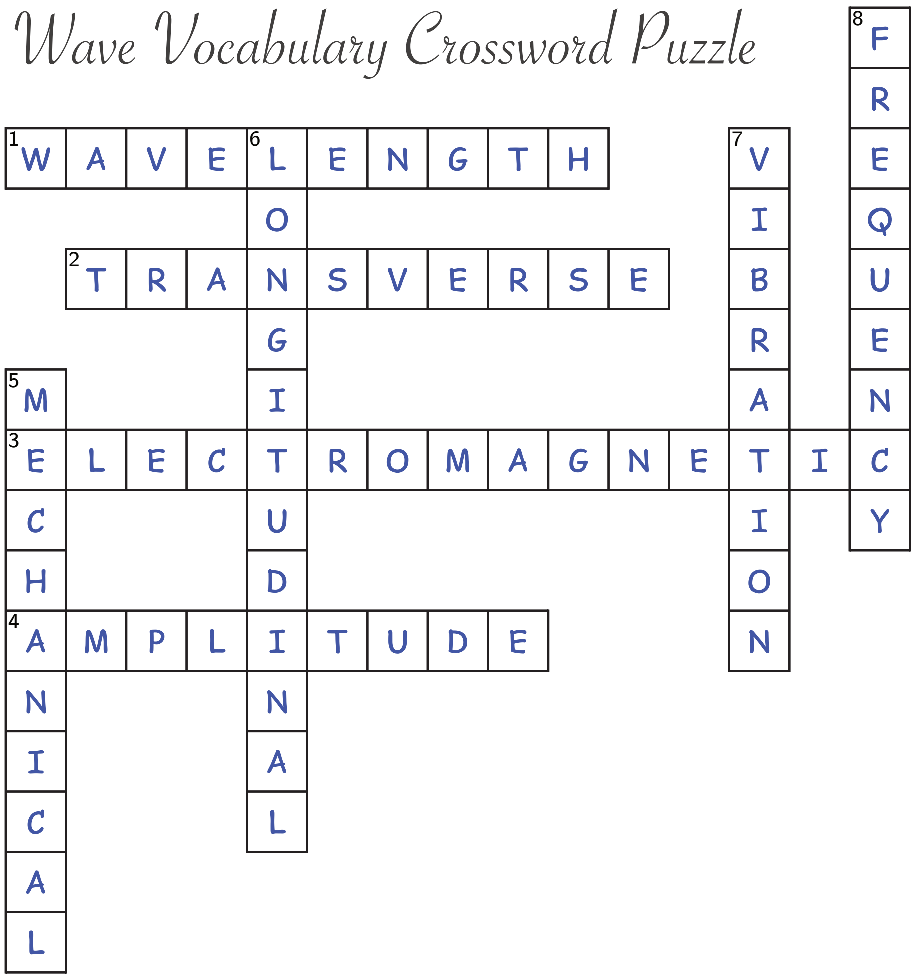
6. What wave has motion that moves in the same direction the wave travels?

   Longitudinal wave

7. What type of wave has motion that moves perpendicular to the direction the wave travels?

   Transverse wave

Wave Vocabulary Crossword Puzzle



Horizontal Words

1. The distance between crests of the wave
2. A wave that moves perpendicular to the direction of the wave speed
3. The type of wave that can travel through a vacuum of empty space
4. The distance from rest to the top of the wave (the distance from crest to peak)

Vertical Words

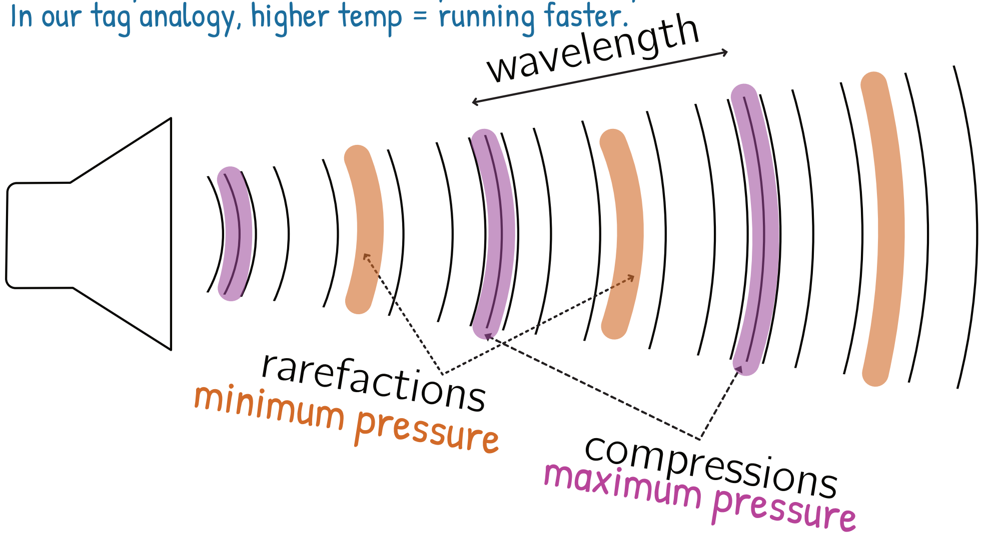
5. A type of energy-carrying wave that always travels through material matter
6. A wave that moves along the same direction as the wave speed.
7. An oscillation, a wiggle repeated over time
8. How often a wave repeats itself.

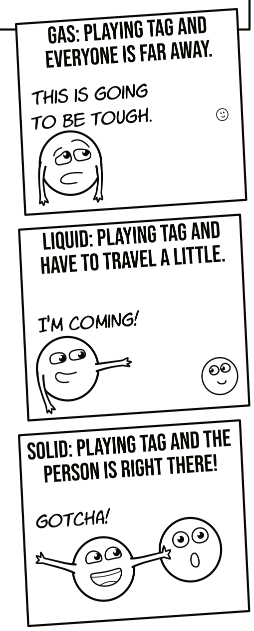
Good Vibrations

Fill in the blanks! Options for words include density, longitudinal, temperature, transverse

Sound is a longitudinal wave created by a vibrating source. These waves or compressions travel at varying speeds depending on the density or temperature of the medium.

When temperature increases in any medium, the speed of sound increases.
In our tag analogy, higher temp = running faster.





Humans have a specific range of sound frequencies they can hear, typically between 20 hertz and 20,000 hertz. This range varies and tends to decrease with age. Frequencies below 20 Hz are called **infrasound** or **infra-sonic** and are too low for human ears to detect. Frequencies too high for human hearing are called **ultrasound**.

20 Hz | Human vocal range: 85-1,100 Hz | 20,000 Hz

Infra-sonic | Human hearing range (20-20,000 Hz) | Ultrasound

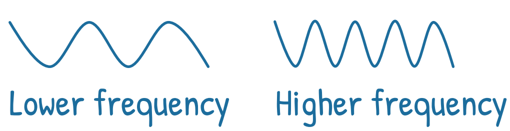
Which 3 animals have these hearing ranges? Bat, cat, dog, dolphin, elephant, snake, or whale?

Dolphin (150-150,000 Hz)

Dog (15-50,000 Hz)

Elephant (5-12,000 Hz)

PITCH: Determined by the FREQUENCY of the wave.



VOLUME: Determined by the AMPLITUDE of the wave

$$\lambda = v/f$$

meters

meters/second

hertz: one (cycle) per second

Wavelength (Greek letter lambda (λ) is equal to the speed (v) of a wave divided by its frequency (f).

Bats emit ultrasonic sounds at 40 kHz to navigate and locate prey. If the speed of sound in air is approximately 340 m/s, what is the wavelength of these ultrasonic sounds?

Using the wavelength equation λ = v / f, where v = 340 m/s and f = 40 kHz (or 40 x 10^3 Hz).

$$\lambda = \frac{340\text{m/s}}{40{,}000\text{Hz}} = 0.0085\text{m}$$

Note that the hertz is the reciprocal of the second (Hz = s^{-1}), so the hertz and seconds cancel each other out.

So, the wavelength of the bats' ultrasonic sounds is 0.0085 meters, or 8.5 millimeters.

If the wavelength of a WiFi signal is 0.12 meters and the speed of electromagnetic waves is 3 x 10^8 meters per second, what frequency band is the WiFi signal using?

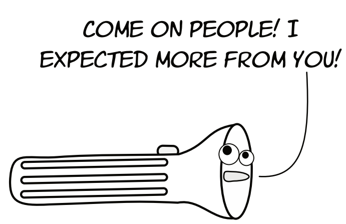
The wavelength equation λ = v / f can be rearranged to solve for frequency (f=v/λ)

$$f = \frac{3\times10^8 \text{ m/s}}{0.12 \text{ m}} = 2.5\times10^9 \text{ Hz (or 2.5 GHz)}$$

So, the frequency of the WiFi signal is 2.5 gigahertz.

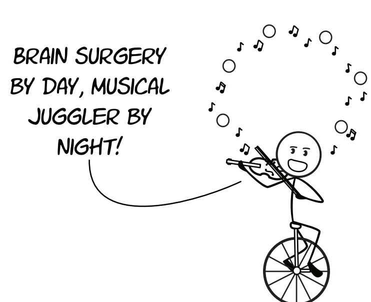
FACT OR FICTION? *Write your verdict below each statement:*

10 million people talking at once would barely produce enough energy to operate a flashlight.



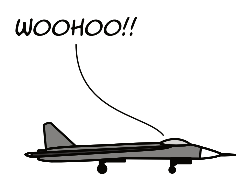
FACT – Sound is relatively low in energy.

Sound can make objects levitate in the air.



FACT – While acoustic levitation wouldn't be possible with a violin and juggling balls, a subwoofer can easily levitate small pieces of styrofoam.

The first sonic boom in history happened on Oct 14, 1947 when Chuck Yeager flew a Bell X-1 jet at an altitude of 45,000 ft.



FICTION – Whips can create sonic booms and have been around for hundreds of years.

Practice Problems – Good Vibrations

1. How does the speed of sound change in a gas as temperature increases?

The speed of sound increases as temperature rises because the molecules are moving at a faster rate. This allows them to transfer energy between each other more effectively.

2. How are microwaves different than sound waves?

A. Sound waves are longitudinal waves while microwaves are transverse waves
B. Sound waves are transverse waves while microwaves are longitudinal waves
C. Sound waves can travel through a vacuum of empty space but microwaves can't
D. Microwaves always have larger amplitude than sound waves

3. What formula is useful for determining the relationship between the frequency, wavelength, and speed of a wave?

A. $\lambda = v / f$
B. $f = v / \lambda$
C. $\lambda = f \cdot v$
D. $f = \lambda \cdot v$

The equation where wavelength (λ) is equal to the speed or velocity (v) of a wave divided by its frequency (f) can be written as:

$\lambda = v / f$ (wavelength = $\frac{\text{speed of wave}}{\text{frequency}}$)

$f = v / \lambda$ (frequency = $\frac{\text{speed of wave}}{\text{wavelength}}$)

$v = f \cdot \lambda$ (speed of wave = frequency · wavelength)

4. Which form of water would sound travel the fastest through?

A. Ice
B. Liquid water
C. Steam
D. Sound would travel at the same speed through water no matter what state it was in.

Sound moves faster through solid materials because the atoms are closer together

5. The larger the amplitude, the ________ the sound will be.

A. Quieter
B. Louder
C. Sound waves with different amplitudes will have same volume

In general, greater amplitude = louder volume.

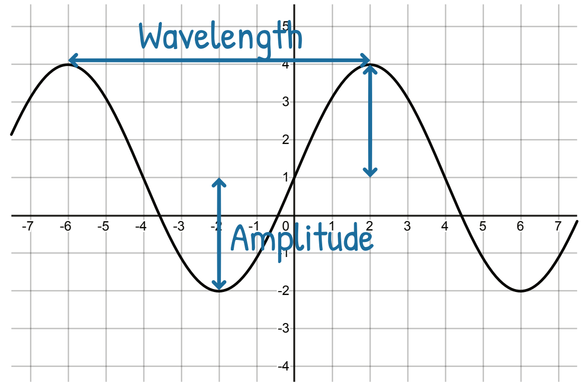
6. The pitch of a sound is primarily determined by the:

A. Amplitude
B. Frequency
C. Wavelength

The higher the frequency, the higher the pitch.

Practice Problems – Good Vibrations

(7) Find the amplitude and wavelength of the graph on the right. (For units, count the number of squares)



Amplitude: 3

Wavelength: 8

(8) A lightning bolt strikes, and it takes 6 seconds before you can hear the thunder from the lightning strike. Approximately how far away was the lightning strike from your location?

The speed of sound is about 340 m/s, so in 6 seconds it travels about

6 s × 340 m/s = 2040 m or roughly 2 km.

(9) Explain how a sound is produced when you strike a drum.

When you strike a drum, the drum head (membrane) vibrates back and forth. This vibration causes the surrounding air molecules to vibrate, creating alternating regions of high and low pressure, which propagate as sound waves.

(10) The longer a guitar string is, the:

A. Higher its pitch
B. Lower its pitch
C. Louder its sound
D. Softer its sound

A longer string has a longer wavelength and a shorter frequency, so the pitch will be lower.

(11) Plucking a guitar string harder will do what to the sound wave it creates?

A. Increase the wavelength
B. Increase the frequency
C. Increase the amplitude
D. All of the above

Changing the frequency would change the wavelength and the pitch of the note. The increased volume corresponds to an increased amplitude.

MAKE YOUR OWN INSTRUMENT

MATERIALS (will vary depending on what type of instrument you make)

Panpipes

- ▫ scissors
- ▫ duct tape
- ▫ 8 pieces of pipe OR 8 straws cut to different lengths

Straw Flute or Trombone

- ▫ scissors
- ▫ 2 straws* or 1 straw and a piece of paper and tape

**If using 2 straws, one straw needs to be able to slide inside of the other.*

Rubber Band Banjo

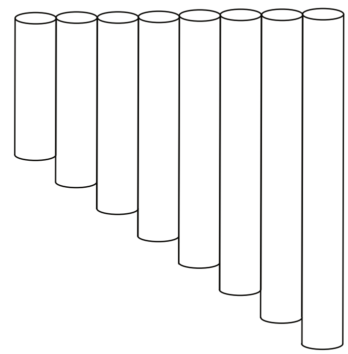
- ▫ scissors
- ▫ rubber bands
- ▫ stapler or tape
- ▫ a cardboard container (an empty tissue box works well)

Bucket Drums

- ▫ buckets or metal cooking pots of several different sizes
- ▫ a wooden spoon or mallet

INSTRUCTIONS for Panpipes:

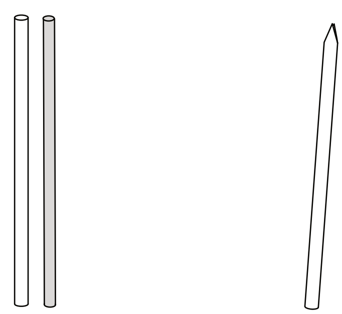
1. Cut the straws or pipes to different lengths.* For better sound quality, cap the bottoms by covering them securely with tape or (in the case of actual pipe) capping them with pipe fittings.
2. Use glue or tape to secure the tubes together in a straight line.
3. Blow over the top of each tube and listen to the pitch of the notes.
4. Optional: cover the bottoms of each tube with tape or paper and see how that changes the sound.

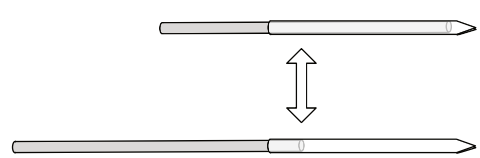


**The pitch depends on both the width and the length. But straw pipes cut to the following lengths in centimeters will usually produce a nice set of tunes: 9.5, 10, 11.5, 13, 14.5, 15.5, 17, and 19.5 cm. Err on the side of cutting too long because it's easier to trim a pipe shorter than to make it longer.*

INSTRUCTIONS for Straw Flute or Straw Trombone:

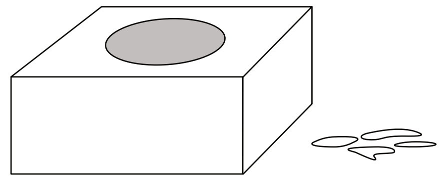
1. Blow into a straw and observe the sound made.
2. Flatten one end of the straw and then use scissors to trim that end to a point.
3. Place the flattened end of the straw in your mouth and blow again. Observe the sound made.
4. The flute is now complete. To make a Trombone, you may want to trim your straw flute with scissors to be shorter in length. Whether trimmed or not, make your trombone by fitting a smaller straw inside the straw flute OR make a cylindrical tube of paper that fits inside or just over the straw flute. Adjust the length by sliding the paper forward and back and observe how the sound changes.

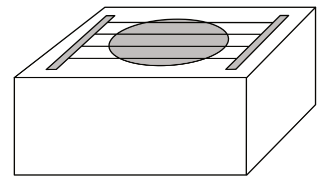




INSTRUCTIONS for Rubber Band Banjo:

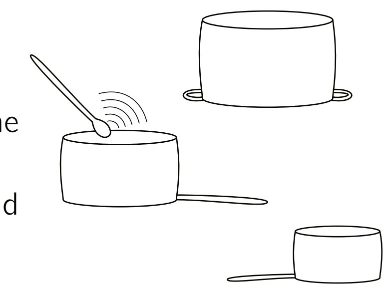
1. Find a container made of cardboard or another material that can be used to amplify the sound of the rubber bands. An empty tissue box or cereal box with a hole cut in one end works well.
2. Stretch rubber bands over the opening of the container. Depending on the size of your rubber bands and container, you might be able to stretch them over or you may need to cut them with scissors and secure them to the box with a stapler. Placing a popsicle stick or pencil under the rubber bands at each end may help improve the sound.
3. Experiment with the placement of the rubber bands. Stretch them differently or change the sizes to get





INSTRUCTIONS for Bucket Drums:

1. Gather bucket-shaped objects of different sizes such as cans or pots.
2. Using a wooden spoon or an actual mallet, tap the buckets and notice the pitch of the sound made.
3. Arrange the bucket drums from highest to lowest pitch. Can you find shapes that correspond to pitches so you can play a song?



Questions to consider and explore:

There are 3 main types of instruments: wind, string, and percussion. Why does a note of the same pitch sound different when played on a violin versus a trumpet? How can someone tell the difference between a middle C being played on a flute vs a harp vs a xylophone?

The short answer: harmonics! When an instrument is played the pitch we hear is actually a blend of different vibrations that overlap together. Different instruments produce different harmonics.

What happens to the pitch of a stringed instrument when you shorten the string?

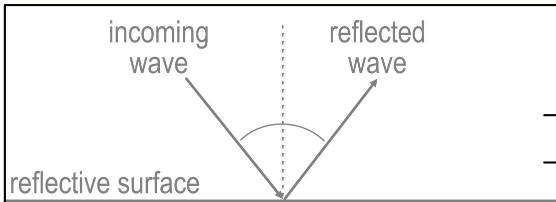
When the string is shortened the pitch increases (gets higher). If the string is shortened by ½ the pitch will be one octave higher.

In the instrument(s) you made, what part of the instrument vibrated and created sound waves?

Answers will vary depending on the instrument: for a drum or percussion instrument it will be whatever was hit. For the rubber band banjo, the rubber bands vibrate. For the straw flute/trombone, it's the angled pieces of straw. For the panpipes, it's the air that is going in and then out of the tube.

Resonance & Decibels

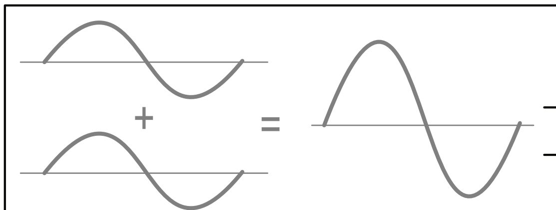
Interesting things happen when waves collide with objects or with other waves. When two waves collides, they don't destroy each other! Instead they pass *through* each other.



Reflection

When a wave strikes a reflective surface it bounces back at the same angle. This is true for both mechanical waves like sound and EM waves such as light.

Ex. echoes, sonar, light bouncing off mirrors

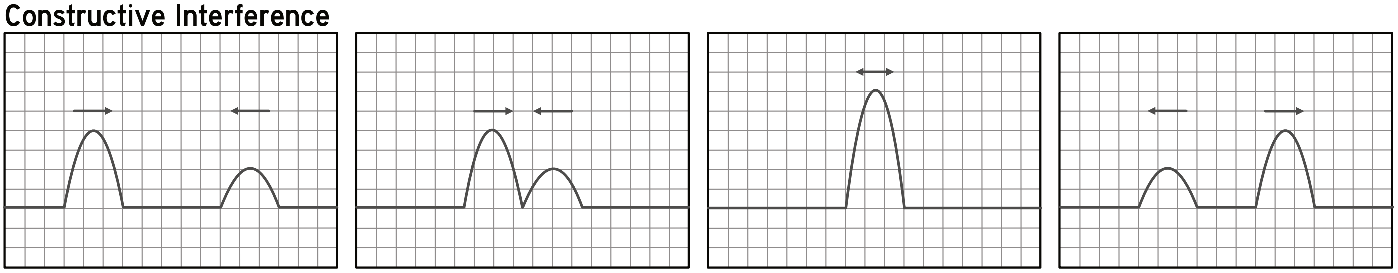


Superposition/Interference

Waves pass through each other and the combined forces change how particles move. When the waves are at the same position their AMPLITUDES are ADDED together.

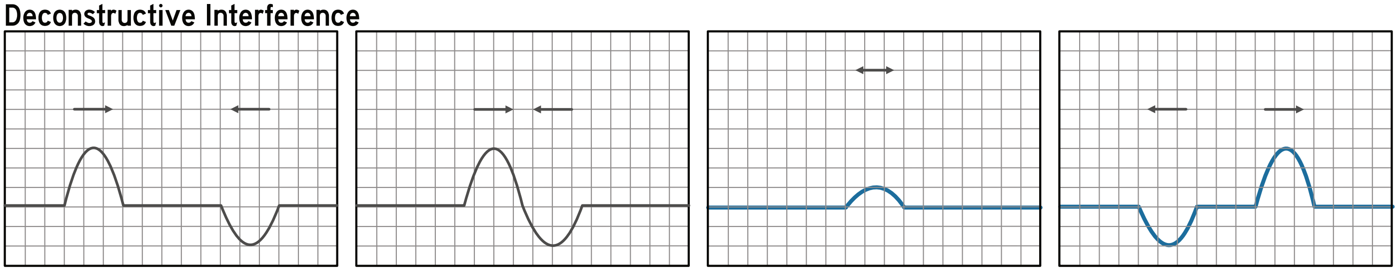
Ex. Rogue or sneaker waves in ocean, noise cancelling headphones, a dead spot with no WiFi, hot spot in a microwave

Constructive Interference

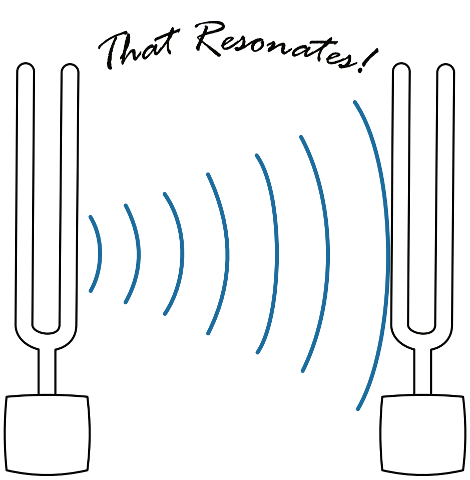


Two pulses with positive amplitude are moving towards each other. When they overlap, the resulting amplitude increases significantly. After passing through each other they return to their original shape and size.

Deconstructive Interference



Two pulses with opposite amplitude are moving towards each other. Draw the resulting amplitude when they overlap and after the waves pass each other. (After passing, these waves will also return to their original shape and size.)



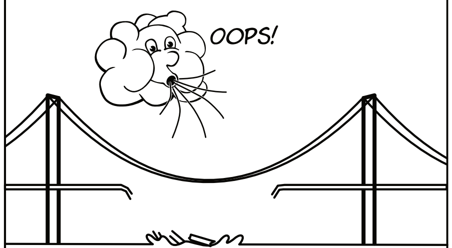
Natural frequency: All objects have a frequency they vibrate to in the absence of outside force. It's the frequency at which the object or system can store and transfer energy most easily.

Resonance: When a wave (periodic force) transfers energy to an object at its natural frequency, this results in large amplitudes!

If 2 tuning forks have the same frequency, the sound from one can cause the other to vibrate!

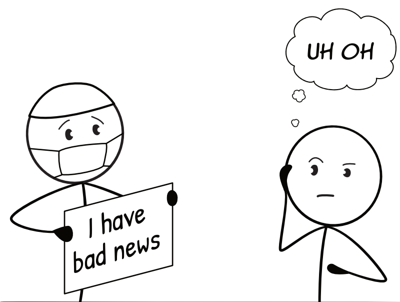
FACT OR FICTION? *Write your verdict below each statement:*

In 1940, a mile-long bridge collapsed because of a moderate wind.



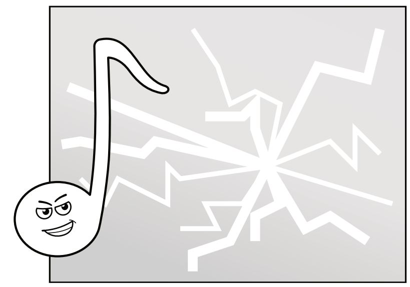
FACT- Tacoma Narrows

A broken eardrum will result in permanent hearing loss.



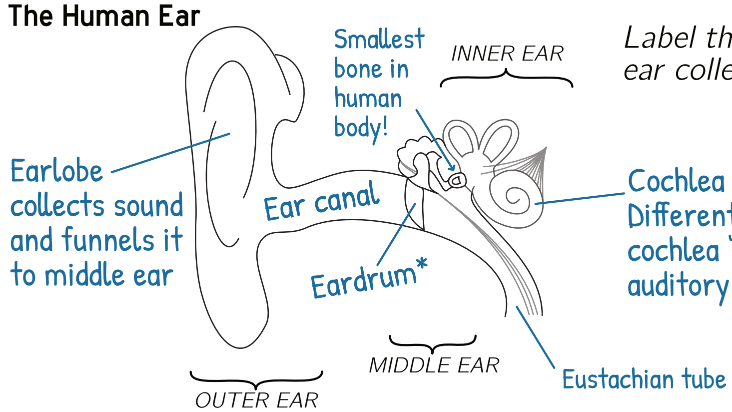
FICTION - Most ruptured eardrums heal within a few weeks

If you sing loudly enough, you can break glass using just your voice!



FACT- With crystal cups or glasses using resonance!

The Human Ear



Label the earlobe, eardrum, and cochlea. Which parts of the ear collect, transfer, and sort or interpret sound waves?

Cochlea is filled with fluid that vibrates small hairs. Different hairs vibrate at different frequencies so the cochlea 'sorts' the sound. This sends signals to the auditory nerve cells connected to the brain.

*The eardrum and 3 bones (hammer, anvil, and stirrup) transfer the vibrations of the collected sound waves to the inner ear.

The Decibel Scale

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190

- 0: Threshold of audible sound
- 10: Normal breathing
- 30: A quiet whisper
- 60: Normal talking volume
- 80: Noisy restaurant
- 110: Chainsaw
- 120: Siren
- 140: Jet Engine
- 180: Krakatoa 1883 eruption
- 190: Loudest possible sound

Color the decibel scale above to show the range of decibels associated with the following:

GREEN: Safe. Little or no risk of hearing loss.

YELLOW: Caution. Sustained exposure will result in permanent hearing loss.

RED: Danger. Short term exposure causes pain and hearing loss.

FILL IN THE BLANKS:

10 100 1,000 logarithmic

The decibel scale is a logarithmic scale, which means that an increase of 10 dB changes the sound intensity by a factor of 10. An increase of 20 dB changes the sound intensity by a factor of 100, and an increase of 30 dB means the sound is 1,000 times more intense!

Practice Problems – Resonance and Decibels

1. Bob is standing 100 meters away from a large wall with a stopwatch. He bangs a pair of cymbals together and records the time until he hears an echo. Today he hears the echo in 0.6 seconds. What is the speed of sound through the air today?

   $\text{Speed} = \frac{\text{distance}}{\text{time}}$ $\text{Speed of sound} = \frac{2 \cdot 100\text{ m}}{0.6\text{ s}}$ Speed of sound today = 333 m/s

   *Multiply by 2 because we need the total distance the sound traveled (to the wall and back)

2. The speed of a wave depends on:
   A. The medium through which it is traveling
   B. The wavelength. Shorter wavelengths travel faster than longer wavelengths.
   C. The frequency. Higher frequency waves travel at higher speeds.

   The speed depends on the medium. The same sound (same wavelength and frequency) will travel faster in a solid and slower in a gas.

3. Which of these has a bigger impact on the frequency of a wave?
   A. The medium through which it travels
   B. The source producing the wave

4. Which of the following are examples of resonance?
   A. The 1850 collapse of the Angers Bridge in France
   B. A child pumping their legs to move higher on a swing
   C. The balance wheel in a mechanical clock
   D. All of the above
   E. None of the above

5. What does the decibel scale measure?
   A. The pitch of a sound
   B. The frequency of a sound
   C. The intensity of a sound
   D. The duration of a sound

   The decibel scale measures the intensity or loudness of a sound.

6. Prolonged exposure to sounds above which decibel level can lead to hearing loss?
   A. 50 decibels
   B. 60 decibels
   C. 85 decibels
   D. 100 decibels

   Sounds of 85 decibels can cause hearing loss if someone is exposed to them for more than 8 hours at a time

Practice Problems – Resonance and Decibels

7. What is the approximate threshold of human hearing? Or in other words, what is the quietest sound a human can hear?

   0 decibels is the threshold of human hearing

8. On the decibel scale, a sound that is 30 decibels is _____ times more intense than a sound that is 20 decibels.

   A. 2 times

   B. 5 times

   C. 10 times

   D. 100 times

9. What statement about resonance is true?

   A. When resonance happens, more energy is being added to the object or system

   B. Tuning forks vibrate in the presence of any sound

   C. When an oscillating force is applied at a frequency that matches the natural frequency of an object, this vibration will cause the system to vibrate at a lower amplitude

   D. Objects must be completely still for resonance to occur.

   An oscillating force that matches the natural frequency of an object will cause it to vibrate at HIGHER amplitude

10. Give two examples of situations where you might encounter superposition or interference in everyday life. One example should be for constructive interference. The other example should be deconstructive interference.

    Answers will vary but here are some possible examples:

    Constructive interference:

    A hot spot in a microwave

    Rogue or "sneaker" waves in the ocean that travel far further up a beach than typical waves

    A place in a room where sounds are louder

    Deconstructive interference:

    Noise cancelling headphones

    A dead spot for a wifi signal

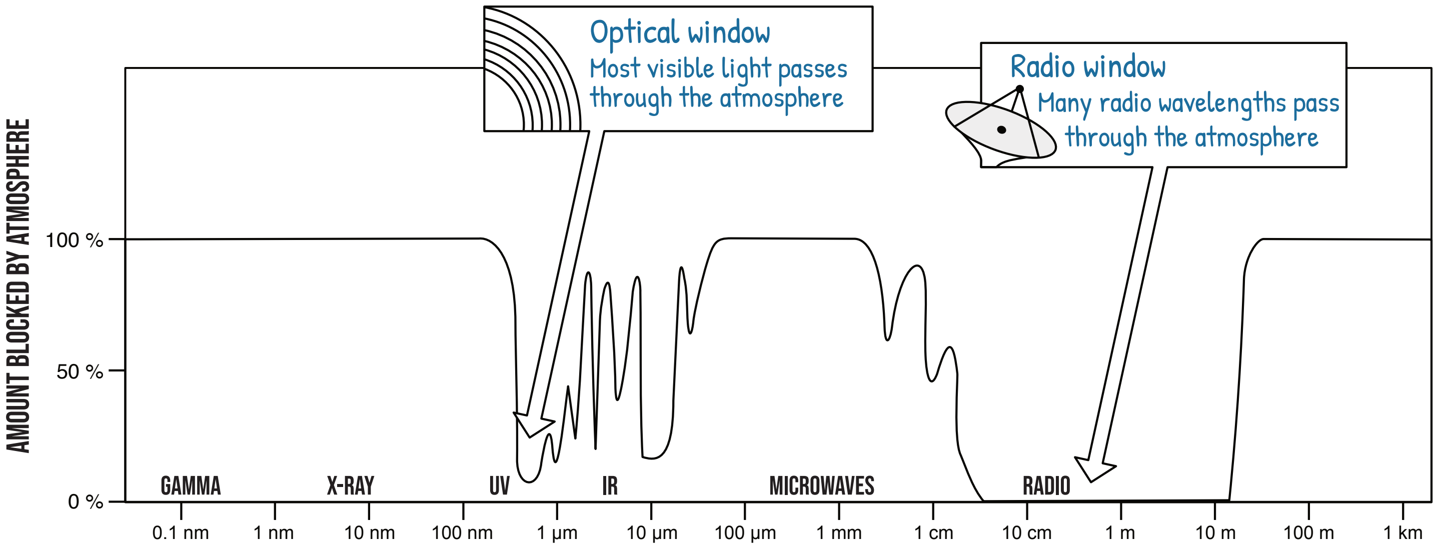
    A place in a room where sounds are muffled or quieter

The Electromagnetic Spectrum

Fill in the blanks:

visible | wavelengths | eyes | radiation | radio | gamma

The electromagnetic spectrum is the full range of electromagnetic radiation organized by frequency or wavelength. Radio waves have wavelengths longer than a football field. The shortest wavelengths are found in gamma waves, which have a wavelengths as small as the width of an atomic nuclei. Human eyes can only perceive a narrow band of radiation with wavelengths from 400 to 700 nm. This radiation is called visible light.



Why are these waves called electromagnetic?

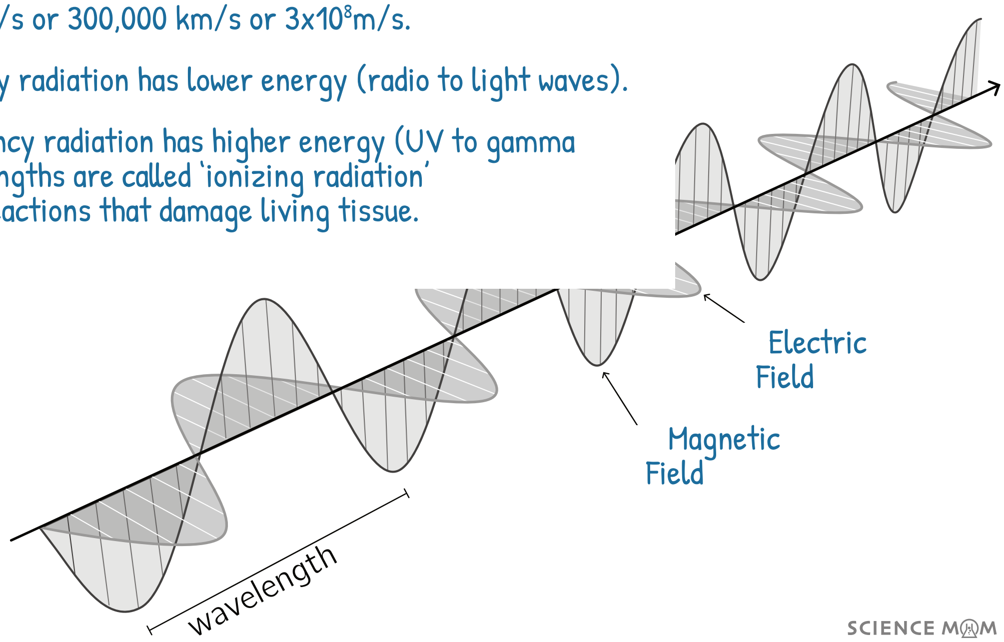
They have both electric and magnetic fields that oscillate at right angles to each other.

EM radiation has both particle-wave properties. It can be described as a stream of particles without mass (photons) traveling in a wave like pattern at the speed of light.

Speed in a vacuum is 186,000 miles/s or 300,000 km/s or 3×10^8 m/s.

Longer wavelength/lower frequency radiation has lower energy (radio to light waves).

Shorter wavelength/higher frequency radiation has higher energy (UV to gamma rays). These higher-energy wavelengths are called 'ionizing radiation' because they can cause chemical reactions that damage living tissue.



Match each definition and example with the correct term:

When a wave strikes a reflective surface it bounces back at the same angle.

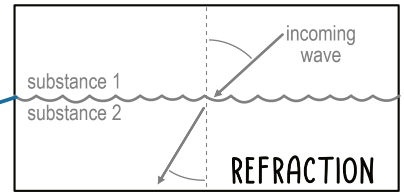
Ex: echoes, mirrors

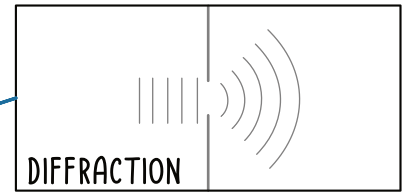
The apparent speed of a wave changes as it moves from one medium to another.

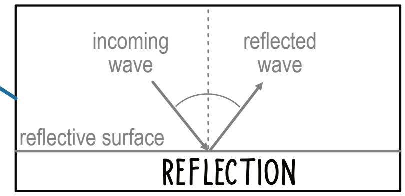
Ex: underwater objects look distorted, rainbows

A wave spreads out around obstacles.

Ex: hearing someone on other side of door, light shining through a pinhole

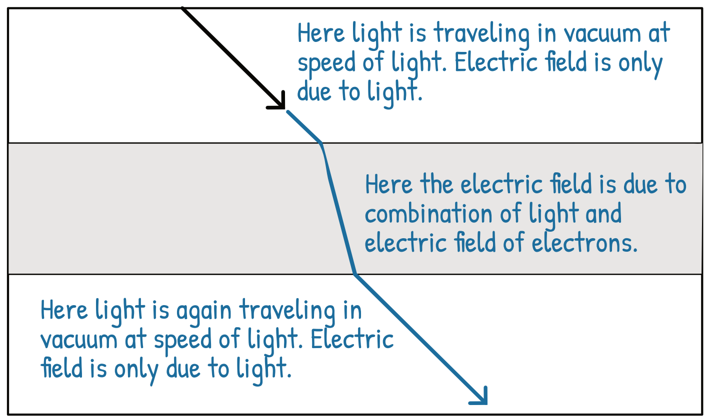




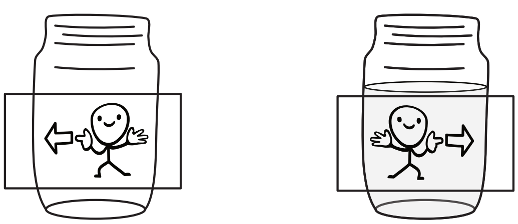


What path does light take through glass?

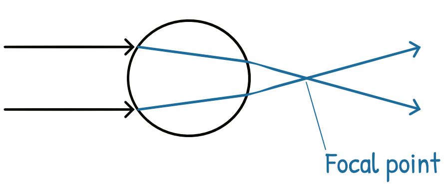
It bends or refracts! The angle of the light changes and so does the apparent speed. Remember light behaves as both a particle and a wave. As it moves through materials that have atoms, there are interactions between the electrons and the electric field of the light. The interference of these two waves change the light wave while it is in the material. The amount and angle of diffraction are predictable for different materials. This is the main principle behind why magnifying glasses, eye glasses, and telescopes work.



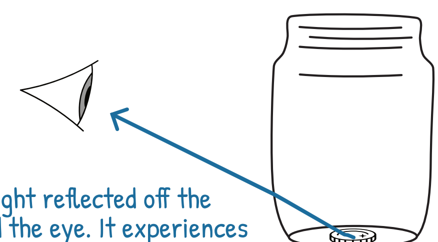
The image reverser - how it works!



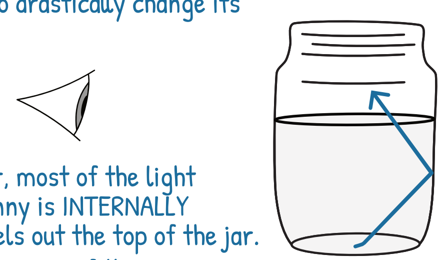
In the water-filled jar, light refracts so that it forms a focal point on the other side of the jar. This is what causes the reversal. If the image is in front of the focal point, it will not be reversed; it will just appear smaller.



The disappearing coin trick - how it works!



In the air-filled jar, light reflected off the penny travels toward the eye. It experiences some refraction when moving from glass to air, but not enough to drastically change its overall direction.



In the water-filled jar, most of the light reflecting off the penny is INTERNALLY REFLECTED and travels out the top of the jar. Note that this only happens if there is an "air-glass-water-glass-air" setup between the coin and the viewer. If the coin is wet, it will be visible just like it was in the glass full of air!

Practice Problems – The Electromagnetic Spectrum

1. **"Microwaves are just another color that humans can't see."**
Do you agree with this statement? Why or why not?
An argument for agreeing:
All wavelengths of the electromagnetic spectrum travel at the speed of light and are made of photons. Most humans can see the wavelengths of light from red to blue (400–700nm), but certain insects can see shorter wavelengths (UV) and longer wavelengths (IR).
An argument for disagreeing:
The word color should only be used to refer to the visible spectrum of light (400 to 700 nm). Microwaves have much longer wavelengths than visible light.

2. Rank the following from shortest wavelength to longest wavelength. Then label which one is most energetic and which has the least amount of energy. EM wavelengths: *gamma, infrared, microwave, radio, ultraviolet, visible light, x-ray.*

gamma	x-ray	ultraviolet	visible light	infrared	microwave	radio
SHORTEST WAVELENGTH Most energetic						*LONGEST WAVELENGTH* Least energetic

3. X-rays are used in medicine because:
   - A. They can easily pass through soft tissues but not through bones
   - B. They are completely safe and have no side effects
   - C. They are easily visible to the human eye
   - D. They provide warmth and help with healing

4. Which of the following are made of photons traveling at the speed of light in a vacuum?
   - A. s-waves in an earthquake
   - B. Microwaves
   - C. Green light
   - D. Radio waves
   - E. Infrared light (heat) emitted from a sleeping marmoset
   - F. The sound of middle C (a frequency of 261.62 hertz)

All forms of EM radiation are made of photons and travel at the speed of light in a vacuum. Earthquake waves and sound are mechanical waves.

5. The Sun emits all of the following. Which wavelengths are blocked by Earth's atmosphere?
   - A. Red light
   - B. Microwaves
   - C. X-rays
   - D. Gamma rays
   - E. Radio waves

All colors of visible light and radio waves pass through the atmosphere. The majority of the other EM wavelengths are blocked by Earth's atmosphere.

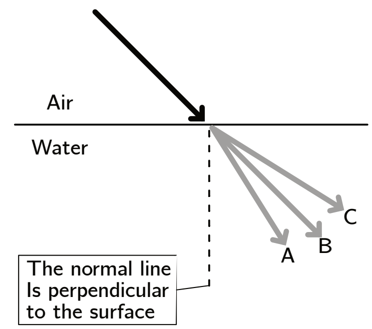
Practice Problems – The Electromagnetic Spectrum

6. A remote control uses a pulse of electromagnetic radiation of 940 nanometers to turn on a television screen. This wavelength is invisible to human eyes but picked up by a cell phone camera. What type of electromagnetic radiation is used by this remote control?
   A. Ultraviolet
   B. X-ray
   C. Infrared
   D. Microwave
   E. Radio

7. What type of wave is a radio wave?
   A. Sound wave
   B. Light wave

To hear a song on the radio, the receiver in the radio has to convert the radio waves (which are light waves) into sound. The radio broadcast is either an FM (frequency modulated) or AM (amplitude modulated) electromagnetic wave. Since it is a light wave (not a sound wave!) it travels very fast and over long distances.

8. How would light bend when it travels from air to water?
   A. It would bend toward the normal line (line A)
   B. It would not bend (line B)
   C. It would bend away from the normal line (line C)
   D. All of these options (the light would spread out in a cone)
   E. None of these options

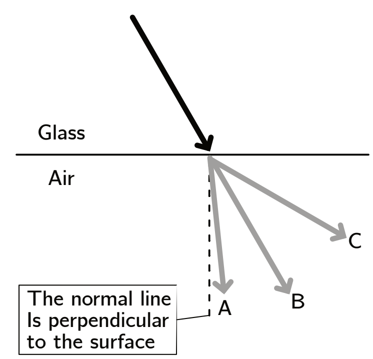


When light travels from a less dense to a more dense material, it bends toward the normal line and the apparent speed decreases

9. When driving on a highway, Bob sees a mirage. It looks like there is a puddle of water in the middle of the highway. But as Bob continues driving the puddle moves. No matter how fast or slow Bob drives, the puddle is always about 100 meters in front of the car. This mirage is primarily caused by:
   A. Reflection
   B. Refraction
   C. Water on the road quickly evaporating and then condensing

Difference in air temperature causes light from the sky at the horizon to bend and appear on the road. This refracted light is the cause of the "puddle"

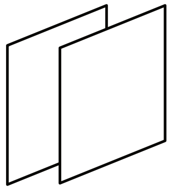
10. How would light bend when it travels from glass to air?
    A. It would bend toward the normal line (line A)
    B. It would not bend (line B)
    C. It would bend away from the normal line (line C)
    D. All of these options (the light would spread out in a cone)
    E. None of these options



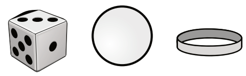
When light travels from a more dense to a less dense material, it bends away from the normal line and the apparent speed increases

TABLETOP KALEIDOSCOPE

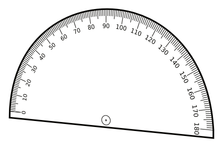
MATERIALS



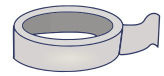
2 flat mirrors *



A small object to place in front of the mirror such as a pebble, ring, dice, or small figurine



Protractor



Tape

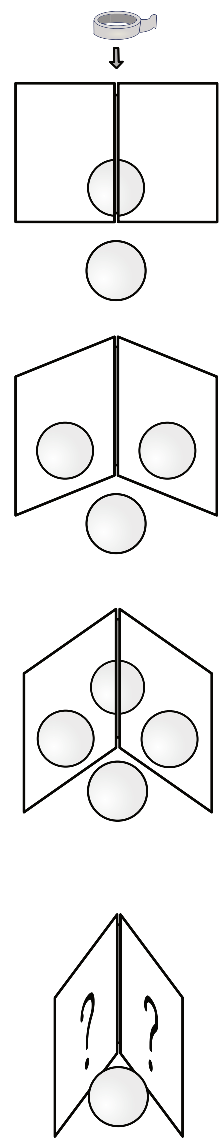
GOALS

- Create a kaleidoscope effect with mirrors.
- Explore the angle of reflection of light in a mirror.

* If you only have one hand mirror available, you can hold it up to a bathroom mirror and get the same effects. It works best if your mirror has no border.

INSTRUCTIONS:

1. Tape two mirrors side-by-side with a little space between them and add tape along the back creating the spine of a mirror-book.
2. Place an object up on a table.
3. Stand the mirrors vertically upright so they form a 180° angle with each other. You should see exactly two copies of your object (one mirrored across the spine of the mirror-book).
4. How many objects do you predict you will see if the mirrors are rotated to form a 120° angle? Make a prediction before trying it. If you don't have a protractor, print the following page and use it as a guide.
5. Continue rotating the mirrors to form other angles, and try viewing different objects.



At what angle should you use to see exactly 4 copies of your object?

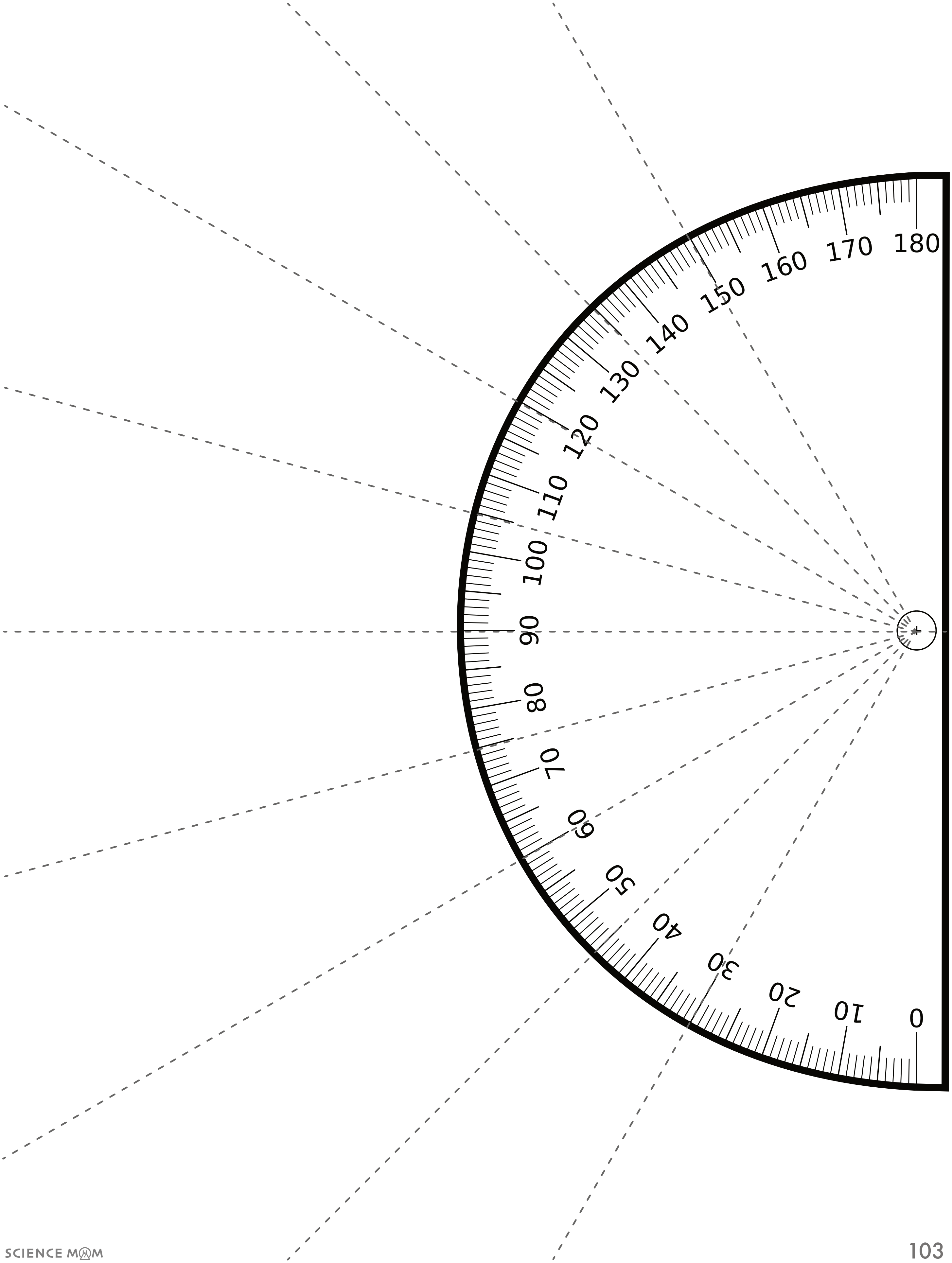
Is it possible to get exactly 5 copies of your object?

Fill in the table below to match the size of the angle with the number of objects you can see.

Describe any patterns you see.

angle	objects
180°	2
120°	3
	4
	5
	6
	8
	9
	10

Would it be possible to make 100 copies of an object visible using two mirrors? Explain.


0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

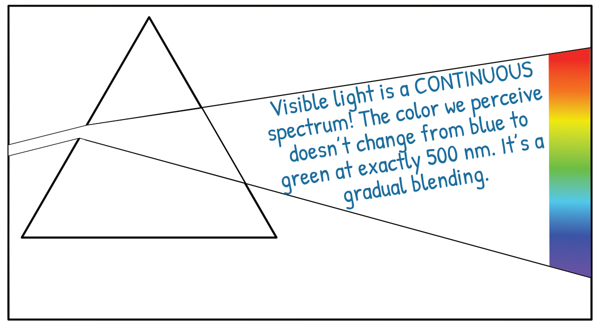
Colors & Sending Signals

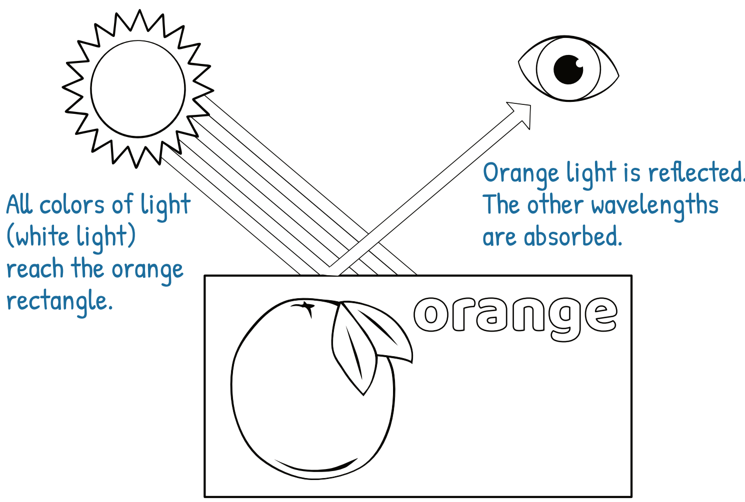
In reflection and refraction, light can change direction after interacting with an object, but there's another option we haven't talked much about yet: absorption! Draw your own comic or diagrams to go along with the text below:

WHEN LIGHT IS ABSORBED, THE ENERGY IS CONVERTED INTO OTHER FORMS LIKE HEAT.	EVERYTHING WE CAN SEE IS BEING HEATED UP?!?	YEP! THE AMOUNT OF TEMPERATURE INCREASE DEPENDS ON THE LIGHT INTENSITY. OFTEN IT'S VERY SMALL.	ALSO… MOST OBJECTS DON'T ABSORB ALL VISIBLE LIGHT. THEY REFLECT AT LEAST A FEW WAVELENGTHS.

White Light Contains These Wavelengths:

380-450 nm: Violet & Indigo
450-500 nm: Blue
500-570 nm: Green
570-590 nm: Yellow
590-610 nm: Orange
610-760 nm: Red





Black objects absorb most visible light. White objects reflect most visible light. This is why black cars or paper will get hotter when left in the Sun than white cars or paper.

It also explains why (when trying to start a fire using a magnifying glass) it's much easier to start the fire on a spot with black text.

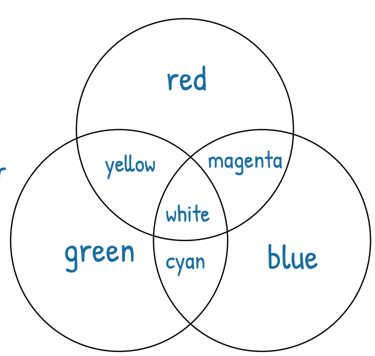
MIXING LIGHT

The Additive Color Model

RGB colors!

used in computer screens, electronics, etc.

Mixing all colors together makes white



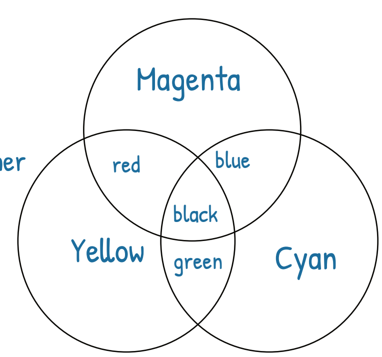
MIXING PIGMENTS

The Subtractive Color Model

CYMK colors!

used when printing with ink or painting etc.

Mixing all colors together makes black



ANALOG VS DIGITAL

ANALOG

The signal is continuously varying. A wave is either recorded or used to carry information. A clock with hands that move, old-school film tapes, VHS tapes, cassette tapes, and record players are all analog devices.

Ex. A cassette tape. The sound wave is recorded onto the tape in the form of waves. The analog waves can be read and converted back to sound but over time they will degrade and the tape can get static.

Advantage: can have richer tone quality (record player)

Disadvantage: with repeated use, the signal will degrade over time. Long distances can also cause a loss in signal quality.

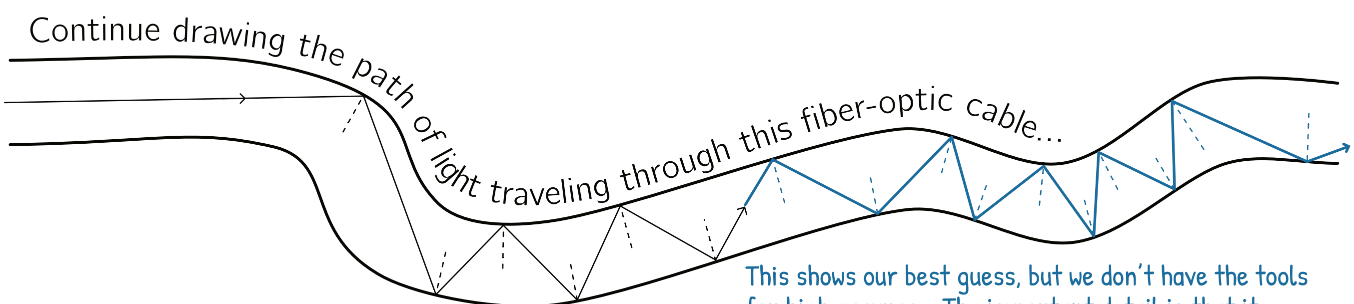
DIGITAL

The signal is discrete (such as a sequence of 1s and 0s). Information is stored in a sequence of numbers. DVDs, computers, CDs, digital clock with numbers, and cell phones are all digital devices.

Ex: A Compact Disk (CD) When making a music CD, the sound wave is sampled 44,000 times per second. The numbers can then be converted back into sound like the original sound wave.

Advantage: information will not deteriorate or degrade over time. Can be compressed. Can travel longer distances.

Disadvantage: compression can cause some (very slight) loss of tone quality. This is why vinyl records are still used by music aficionados.



This shows our best guess, but we don't have the tools for high accuracy. The important detail is that it bounces out with the same relative angle it comes in.

Communicating with waves

Bob uses a cell phone to call to a friend. What waves are involved? Label them and then describe whether the signals involved are analog or digital.

SOUND WAVES are created by a voice and reach the phone.

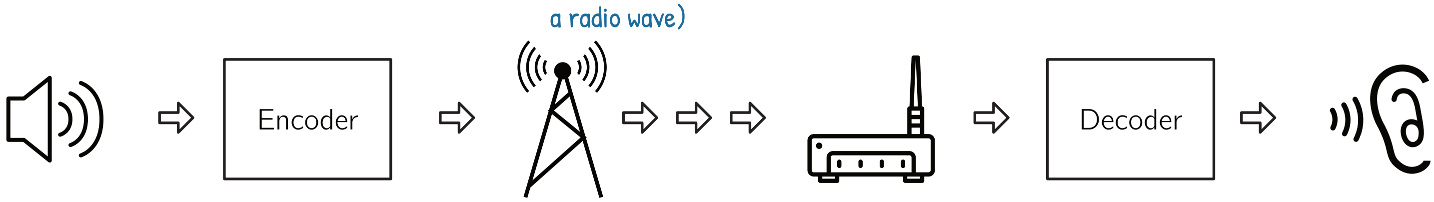
The phone converts the sound to a sequence of 0s and 1s and sends that signal in a low-frequency wave.

An EM wave signal is sent. The type can vary!

(e.g. microwave or radio wave to cell tower to light in fiber optic line to a modem where it is converted back to a radio wave)

The phone converts the sequence of 0s and 1s in the low-frequency wave into sound waves

Sound reaches your ears.



Analog Digital Analog

Practice Problems – Color & Sending Signals

1. Emily sends a text message to her brother. What type of electromagnetic wave is most likely used to send the text message?

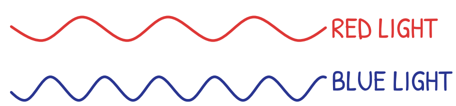
   A. Infrared
   B. Microwave
   C. Ultraviolet
   D. Violet

   Microwaves are EM radiation with a wavelength between 1 m and 1 mm. Most cell phones send their signals using microwaves. But this doesn't mean your phone can heat your lunch. A microwave oven uses much higher power (over 1,000 watts) than a cell phone (less than 2 watts) and has a specially-designed system that reflects and concentrates the waves inside the microwave. A microwave oven is also tuned to deliver the frequency that best causes water molecules to vibrate. A cell phone will use other wavelengths.

2. Which color of light has more energy, red light or blue light?

   A. Red light because it has a higher frequency
   B. Red light because it has a lower frequency
   C. Blue light because it has a higher frequency
   D. Blue light because it has a lower frequency

   Blue light has shorter wavelength (450 nm) and higher frequency. Red light has longer wavelength (600 nm) and therefore lower frequency.



3. Why are most plants green?

   A. They absorb green light.
   B. They reflect green light but absorb other wavelengths of color.

4. What color is produced when all wavelengths of light overlap or are "mixed" together?

   A. White
   B. Brown
   C. Black
   D. Magenta

   White light contains all wavelengths/colors of light.

5. A color printer can print photographs and other complex color images quickly and easily. It only has 4 ink cartridges. What color are the ink cartridges?

   A. Red, Yellow, Blue, and Brown
   B. Red, Green, Blue, and White
   C. Cyan, Yellow, Magenta, and Black
   D. Each of the cartridges contains many colors of ink

   The CYMK for printers or print settings stands for Cyan, Yellow, Magenta, and Key (the "Key" refers to black)

6. Which of the following statements is true?

   A. We don't see color in moonlight because only one wavelength is reflected from the Moon.
   B. Objects still have color in moonlight, it's just too faint for our eyes to detect.

7. Of the colors below, which has the longest wavelength?

   A. Violet
   B. Orange
   C. Green
   D. Yellow

Waves Unit Assessment

In your own words!

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

MECHANICAL WAVE: A vibration in matter that transfers energy through a material. Can be transverse (ocean wave) or longitudinal (sound).

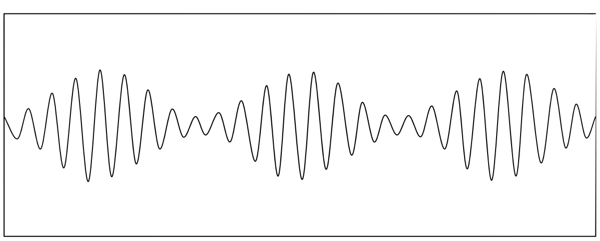
ELECTROMAGNETIC WAVE: Photons traveling at the speed of light! These waves can travel through a vacuum of empty space. Examples: gamma rays, x-rays, UV, visible light, IR, microwaves, radiowaves

AMPLITUDE: How tall the peaks of a wave are. From the middle (resting) part of the wave to the top of the crest.

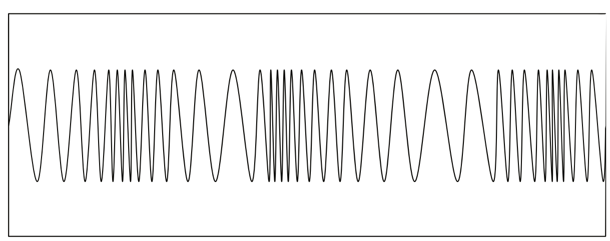
FREQUENCY: How fast the wave is oscillating up and down. Ex. Gamma rays have a much higher frequency than microwaves.

HERTZ: How many times something happens per second. Ex. A 100 hertz tone vibrates or oscillates 100 times per second.

Below are two diagrams of radio wave signals. One of them is an FM signal (Frequency Modulated) and one of them is an AM (Amplitude Modulated) signal. Which is which and why?



SIGNAL TYPE: AM (Amplitude Modulated) because the amplitude (rest to crest) varies from small to large.



SIGNAL TYPE: FM (Frequency Modulated) because the amplitude (rest to crest) stays the same but the frequency changes.

Waves Unit Assessment

1. What type of waves do NOT require matter to transport energy?
   A. Mechanical waves
   B. Electromagnetic waves
   C. Longitudinal waves
   D. Ocean waves

2. As the frequency of a wave *increases* its energy
   A. decreases
   B. increases
   C. remains the same

3. Why can't sound waves travel through the vacuum of outer space?
   A. It's too cold in outer space.
   B. Radiation from the Sun destroys them.
   C. Sound waves need physical matter to exist.
   D. There are sound waves in space, but no one is there to hear them.

4. What is the primary difference between radio waves and visible light?
   A. One travels faster than the other.
   B. One light is made of photons.
   C. One travels longer distances than the other.
   D. One has a longer wavelength than the other.

5. As the wavelength of a wave gets longer its energy will _______.
   A. decrease
   B. increase
   C. remain the same

6. What part of the electromagnetic spectrum can be seen by people?
   A. Infrared radiation
   B. Microwaves
   C. Ultraviolet light
   D. Visible light

7. What type of signal is made of continuously varying data or information?
   A. Analog
   B. Digital

8. What type of signal is commonly used in computers?
   A. Analog
   B. Digital

9. Which of the following statements is **false**?
   A. Digital signals are recorded and stored more easily than analog.
   B. Analog signals maintain their quality over long distances.
   C. Digital signals are considered more reliable than analog.
   D. Analog signals can be converted into digital signals.

10. When a straight pencil is placed in a glass that is half-full of water, it appears bent when viewed from the side. Which of these phenomena best explains why?
    A. Light being refracted
    B. Light being absorbed
    C. Light being reflected
    D. Light being diffracted

11. The ____________ of a wave is how many wavelengths pass a certain point each second.
    A. amplitude
    B. frequency
    C. wavelength

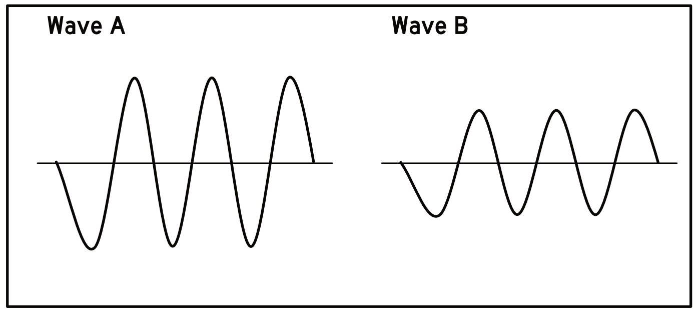
12. If a marmoset sees lightning strike a tree one mile away, which of the following is true?
    A. They will hear thunder at the same time they see lightning because sound and light travel at the same speed.
    B. They will hear thunder after seeing the lightening because sound travels more slowly than light.
    C. They will not hear any thunder because the lightning strike is too far away.

13. Why does a green ball appear green?
    A. It absorbs all wavelengths of light except for green.
    B. It only absorbs green light.

14. What are the primary colors of light?
    A. Red, Yellow, and Blue
    B. Red, Blue, and Green
    C. Orange, Green, and Purple
    D. Cyan, Magenta, and Yellow

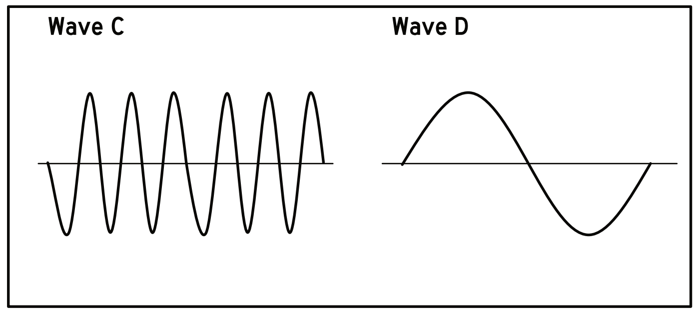
15. Of the colors listed below, which has the shortest wavelength?

A. Red
B. Yellow
C. Blue
D. Orange
E. Green



16. Look at the graphs of waves A and B drawn at the right. Which has greater energy and why?

A. Wave A carries more energy because it has higher amplitude.
B. Wave A carries more energy because it has higher frequency.
C. Wave B carries more energy because it has a shorter wavelength.
D. Wave B carries more energy because it has a lower amplitude.



17. Look at the graphs of sound waves C and D. What differs between these waves?

A. C has higher frequency than D.
B. D has lower amplitude than C.
C. C has shorter wavelength than D.
D. Both A and C
E. None of the above

18. Would you be able to see a full-body reflection of yourself in a mirror that is only half as tall as you? If so, how?

Yes, you would just need to stand further away. The further from the mirror you are, the smaller the reflected image in the mirror.

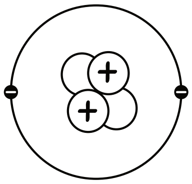
19. Bob wants to know why a red apple appears to be red during the day but looks grey at night when the light is dim. How would you explain it to him?

Human eyes have two different types of cells for detecting light. Rods just detect the presence of light and are much more sensitive. Cones detect color. When the only source of light is moonlight the light is enough to activate the rod receptors but not the cones. This is why everything appears to be in shades of gray.

ELECTROSTATICS

The study of stationary charges

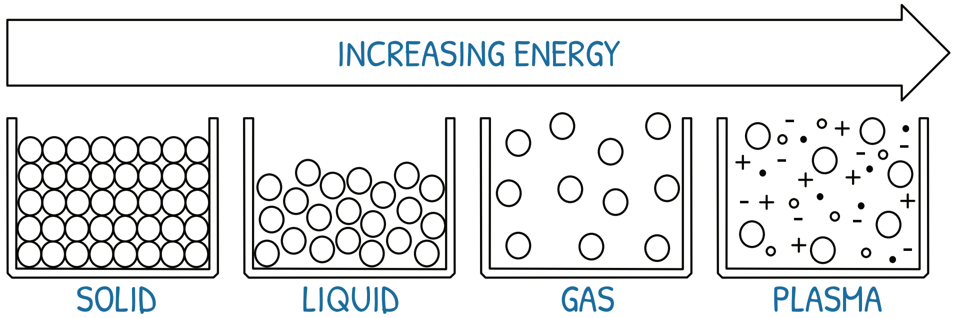
Quick Review:



Proton: In nucleus, positive charge

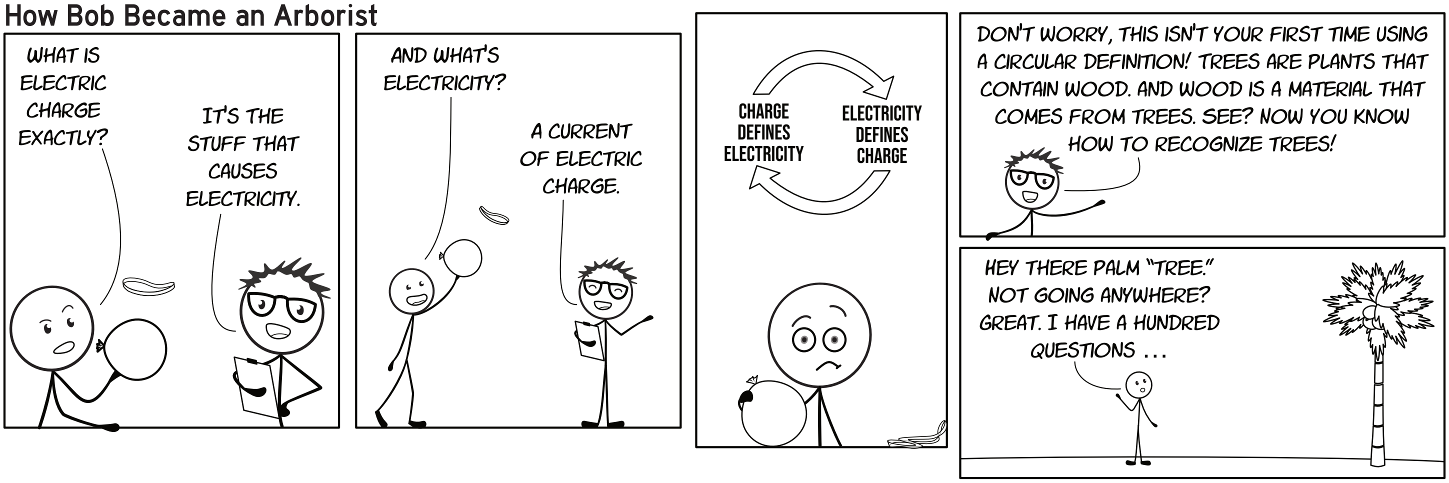
Neutron: In nucleus, no charge

Electron: Orbits the nucleus, negative charge



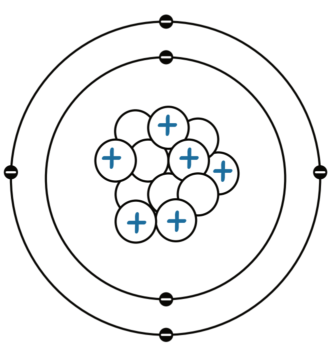
most abundant state of matter in universe

How Bob Became an Arborist



3 Important Facts About Charges:

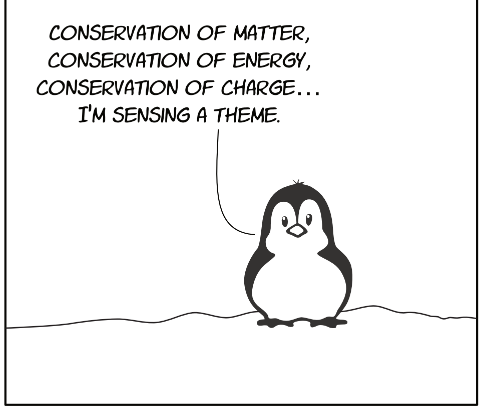
CHARGE IS A PROPERTY OF SUBATOMIC PARTICLES.



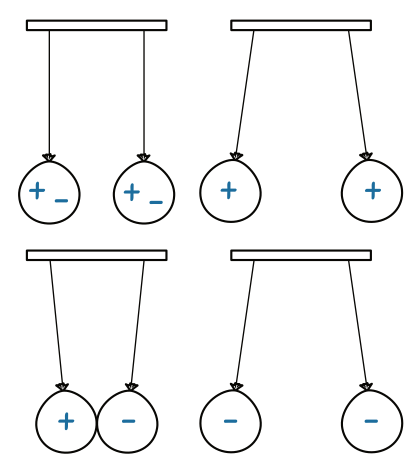
PROTONS HAVE positive CHARGE.

ELECTRONS HAVE negative CHARGE.

IN AN ISOLATED SYSTEM, CHARGE IS conserved. IT CAN BE TRANSFERRED BUT CANNOT BE CREATED OR DESTROYED.



Like CHARGES REPEL EACH OTHER AND opposite CHARGES ATTRACT EACH OTHER.



FILL IN THE BLANKS:

negative	positive	neutral	charge	fundamental

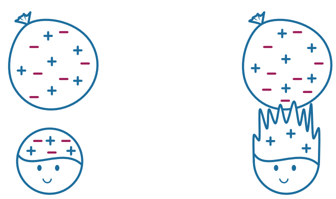
Charge is a fundamental property of matter. There are two types of charge which we call positive and negative. When an object has a negative charge, it possesses an excess of electrons compared to protons. When an object that has a net positive charge it has fewer electrons than protons. When an object has an equal number of protons and electrons, the result is a neutral state with no net charge.

Separating charges!

1. Peeling Scotch Tape

When scotch tape is pulled off it can develop either positive or negative charge depending on what surface/material it was pulled from and the order it was peeled. If the charges are the same, the pieces of tape bend away from each other. If the charges are opposite, the tapes bend toward each other. There is a force (electrostatic force!) at work here!

2. Rubbing a Balloon on hair



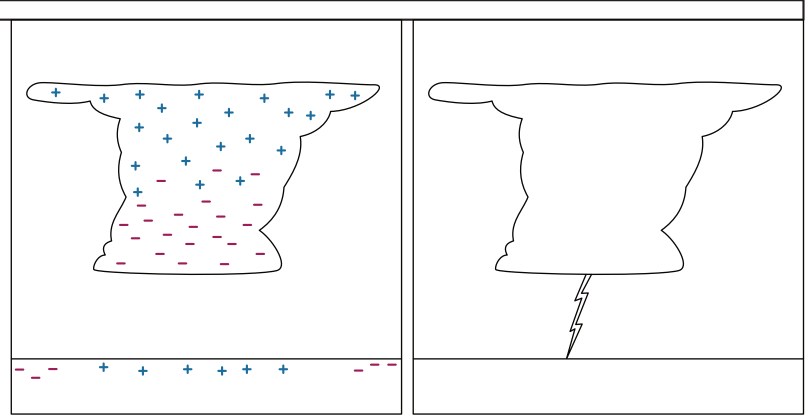
Before friction/rubbing, there are balanced charges on hair and balloon. Rubbing transfers electrons to the balloon, giving the balloon an overall negative charge and the hair an overall positive charge. This is why the hair rises up toward the balloon.

3. Rubbing a Balloon on a sweater

Before friction/rubbing, there are balanced charges on hair and sweater. Rubbing transfers electrons to the balloon, giving the balloon an overall negative charge and the sweater an overall positive charge.

Lightning!

The movement of air and other particles in large clouds causes the bottom of the cloud to develop a negative charge. This charge induces a positive charge in the ground below it. Lightning is an electrical discharge.



Practice Problems – Electrostatics

1. Two charged spheres are brought closer together. What happens to the electrostatic force between them?
   A. It increases.
   B. It decreases.
   C. It stays the same.

2. If the number of protons is equal to the number of electrons, the object will have:
   A. Negative charge
   B. Positive charge
   C. No charge
   D. Oscillating charge

3. Lightning is caused by
   A. friction from clouds rubbing against each other
   B. rapid temperature fluctuations inside storm clouds creating electrons
   C. air pressure differences between the upper and lower atmosphere
   D. the discharge of electrical charges between clouds or between clouds and the ground

4. Which of the following are examples of plasma?
   A. Super-cooled nitrogen
   B. Blood
   C. Neon lights
   D. Lasers

5. Two charged objects repel each other due to their charge. What could the charges of the objects be? (Select all that apply.)
   A. Positive and Positive
   B. Negative and Positive
   C. Negative and Negative

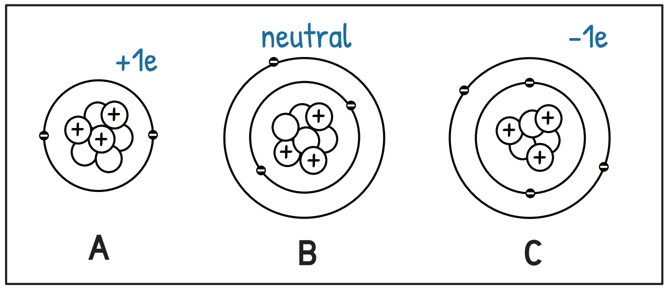
6. Two charged objects attract each other due to their charge. What could the charges of the objects be? (Select all that apply.)
   A. Positive and Positive
   B. Negative and Positive
   C. Negative and Negative

7. What happens to electrons when something is getting electrically charged?

   Electrons are transferred from one source to another at the point of contact. Objects that receive electrons become negatively charged, objects that lose electrons become positively charged.

Practice Problems – Electrostatics

(8) Lithium has 3 protons. Examples of lithium atoms are drawn in the figure below. Explain which atom is positive, which is negative, and which one has a neutral charge.

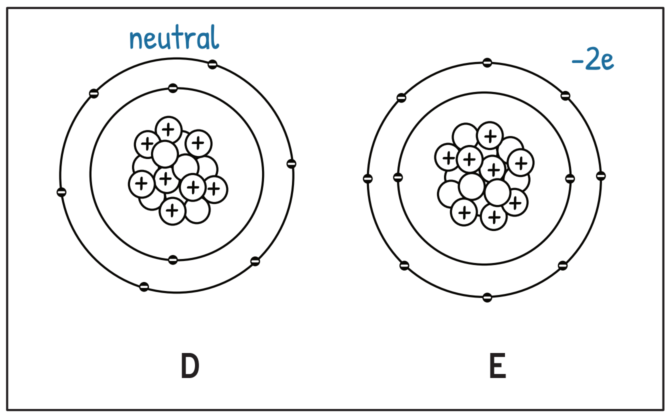


Atom A has 3 protons and 2 electrons. Since it has 1 more proton than electrons, it will have a positive charge.

Atom B has an equal number of protons and electrons, so it is neutral and has no net charge.

Atom C has 3 protons and 4 electrons, so it has a negative charge. Note: the number of neutrons does not impact the charge.

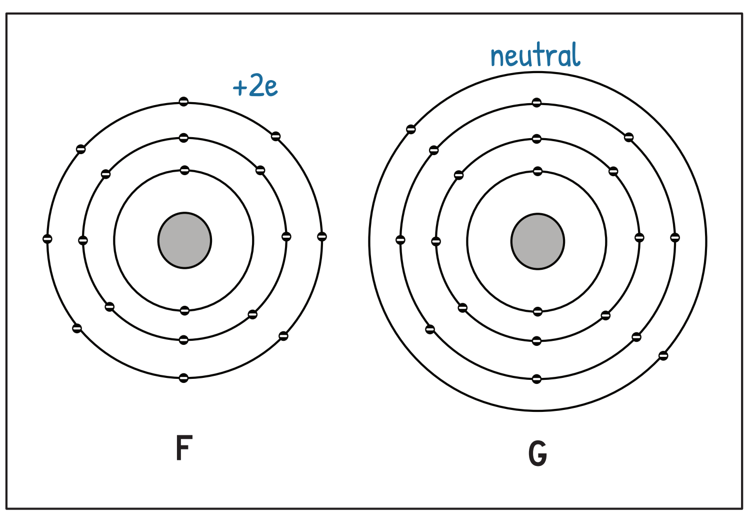
(9) Oxygen has 8 protons. Two examples of oxygen atoms are drawn in the figure below. Explain why each atom has a positive, negative, or neutral charge.



Atom D has 8 protons and 8 electrons. Since the number of protons and electrons is balanced, it will have no charge.

Atom E has 8 protons and 10 electrons so it has a negative charge.

(10) The filled-in circles in the diagram below represents the nucleus of calcium, which has 20 protons. Explain why each atom below has a positive, negative, or neutral charge.



Atom F has 20 protons and 18 electrons, so it has a positive charge (+2e).

Atom G has 20 protons and 20 electrons, so it has no charge.

The Current Event

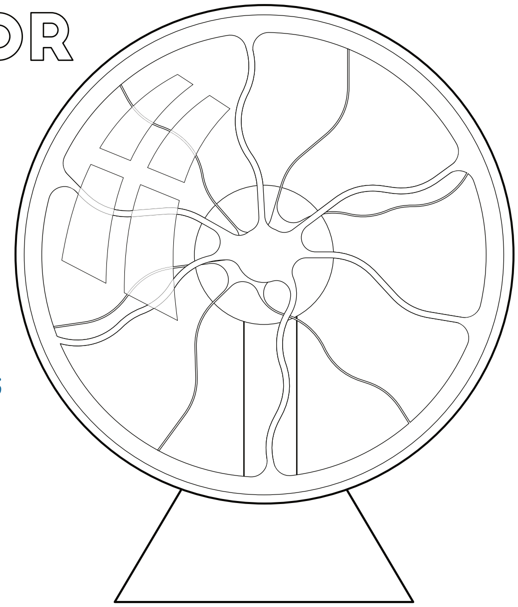
CONDUCTOR vs INSULATOR

CONDUCTORS have outer shell electrons that move freely

Examples: copper, aluminum, gold, silver. Most electric conductors are good thermal conductors too.

INSULATORS have electrons that are stuck with their atoms and don't move around freely. As a result, insulators are able to accept/store extra electrons.

Examples: air, plastic, glass, hair, cloth, diamond. Most electric insulators are also thermal insulators.

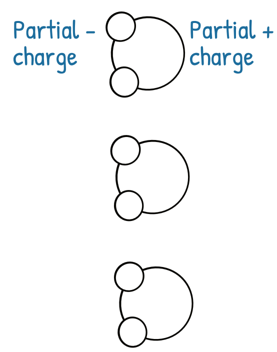


Is water an insulator or a conductor?

Pure water is an insulator because all of the electrons are bound and occupied with being a part of water.

But in reality, water isn't pure! Water that is exposed to air or just about any other substance contains ions. As a result, this type of water we encounter in every day life behaves as a conductor of electric charge.

A water molecule has a partially negative side and a partially positive side, so a narrow stream of water bends toward a charged surface.



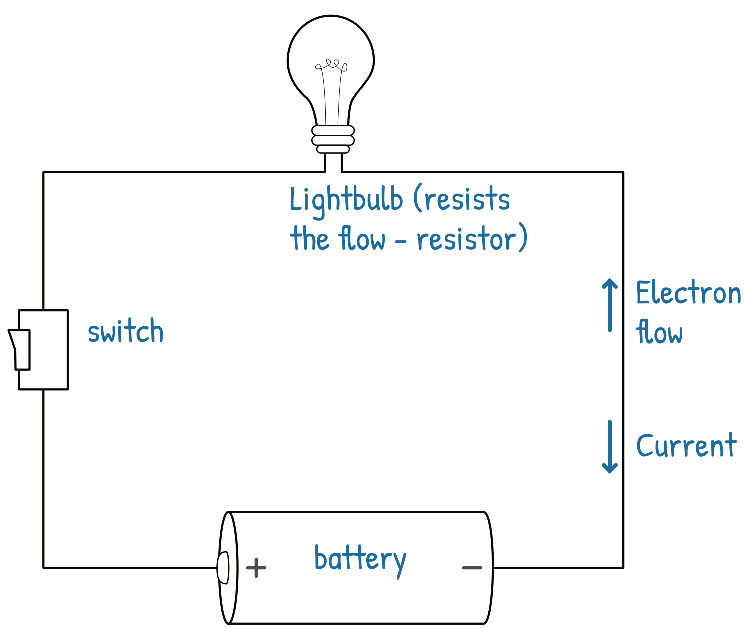
Will water be attracted to charged things?

Circuits

When electrons flow through an insulator (air) we get a discharge (lightning). When electrons flow through a conductor we get a current!

A circuit requires a closed loop.

Electrons flow from – to +



VOLTAGE (VOLT): • The work done to separate 1 C of charge
• The difference between 2 electric potentials

$\frac{J}{\text{Coulomb}}$ = Potential difference

CURRENT (AMPERE OR AMP): Charge is quantized because it always comes in multiples of an electron's charge!

$\frac{\text{Coulomb}}{\text{second}}$

RESISTANCE: A measure of the opposition to electric current. Measured in ohms, which are equal to 1 volt/1 amp. Insulators have higher resistance than conductors.

Ω OHM'S LAW: VOLTAGE = CURRENT · RESISTANCE

V=IR Voltage (V) = Current (I) · Resistance (R)

Sasha needs to charge her phone but the only charging cable available doesn't have visible specifications for the voltage. It only lists the cable's resistance, which is 1.8 ohms. When Sasha uses her multimeter, she measures a current of 0.9 amperes flowing through the cable while charging. To charge her phone safely, the voltage needs to be below 5V. Is it safe for Sasha to use the cable?

Use Ohm's law: V = IR.

V = 0.9 A · 1.8 Ω

(Remember, ohms are equal to volts/amps, so amps multiplied by ohms = volts.)

V = 1.62V

It is safe for Sasha to use the charging cable. 1.62V is well under the 5V limit.

WHAT IS A COULOMB?

The coulomb (C) is the SI unit for electric charge.

It's named after Charles-Augustin de Coulomb, a French scientist who calculated the amount of force between two electrically charged particles and developed Coulomb's inverse-square law.

1 COULOMB = THE ELECTRIC CHARGE DELIVERED BY 1 AMP OF CURRENT IN 1 SECOND.

Practice Problems – The Current Event

1. Select each substance that is an electrical insulator.
   A. Plastic
   B. Copper
   C. Glass
   D. Wood

2. A material is made of atoms that loosely hold onto their electrons, leaving the ones in the outer shell free to wander around. This material will be a
   A. Conductor
   B. Insulator

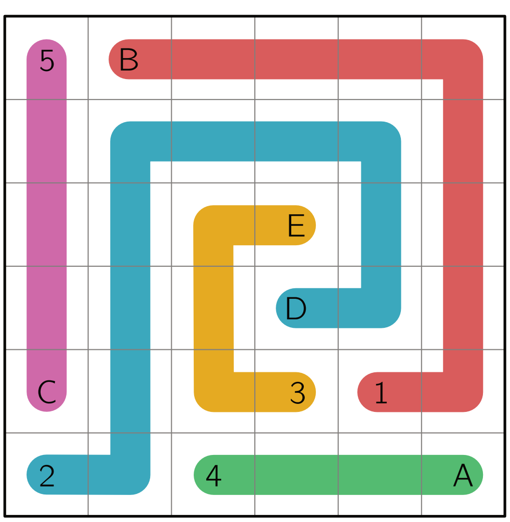
3. What happens when a charged object such as a balloon comes close to an uncharged insulator, such as a piece of paper? (but does not touch the object)
   A. The paper becomes charged as well by induction
   B. The paper is repelled and moves away from the balloon
   C. There is no change; the paper remains uncharged
   D. The paper is attracted to the ballon because all insulators have the same charge

4. **Electrical potential** is called:
   A. Voltage
   B. Current
   C. Resistance
   D. Amp

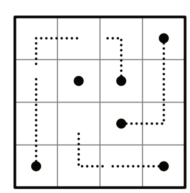
5. The **flow** of electrons in an electrical current is called:
   A. Voltage
   B. Current
   C. Resistance
   D. Amp

Pipe Flow Matching

6.



Match each numbered word with its lettered description by joining the number and letter with a continuous stroke (pipe).



Each square in the grid should be visited by exactly one pipe.

1. Electrostatics	A. A charged atom
2. Conductor	B. Electricity at rest
3. Insulator	C. SI unit of electric charge
4. Ion	D. Allows charged particles to flow
5. Coulomb	E. contains no free charged particles

Practice Problems – The Current Event

(7) What unit is used to measure electrical current?
A. Ohm
B. Volt
C. Ampere
D. Watt

(8) What does Ω stand for in physics?
A. Ohms
B. Amps
C. Volts/Amps
D. Coulombs

Resistance is measured in ohms (Ω).

1 ohm is equal to 1 volt/1 amp.

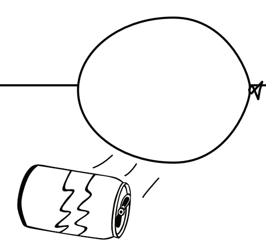
(9) What is required for current to flow in a circuit?
A. A resistor
B. An insulator
C. A light bulb
D. A closed loop

(10) Why do birds sitting on power lines not get electrocuted?
A. They are too small to complete the circuit.
B. Their bodies do not provide a path to the ground
C. They wear natural insulating materials.
D. They are immune to electricity.

(11) What is voltage equal to?
A) the inverse of resistance
B) Current
C) Current multiplied by resistance
D) Resistance divided by current

Voltage (V) = Current (I) · Resistance (R)

Explain the rolling can:



When the balloon is rubbed on another material it accumulates excess electrons and develops a charge. Since the aluminum can is a conductor it cannot develop a charge unless it is well insulated from its surroundings. So it has both + and – charges.

When the balloon is brought close to the can, the negative charge in the can gathers on the opposite side of the can. This gives the part of the can closest to the balloon a net positive charge.

Positive and negative attract. This is why the can rolls toward the balloon.

SUPER STATIC

MATERIALS (WILL VARY DEPENDING ON WHICH ACTIVITIES YOU CHOOSE TO DO)

Sticky Balloons
- two balloons
- a soft cloth for charging the balloon
- a wall, a window, and various furniture items

Levitating Ring
- balloon or a short length of PVC pipe
- a soft cloth for charging the balloon
- a very thin plastic bag (such as the type used grocery stores in the produce department)
- scissors

Paper Vacuum & Scooting Bubbles
- balloon or short length of PVC pipe
- a soft cloth for charging the balloon
- tissue paper
- scissors
- bubble solution or water and dish soap
- a flat counter or table

Bending Water
- balloon or short length of PVC pipe
- a soft cloth for charging the balloon
- a faucet or or container that can create a thin stream of water

STICKY BALLOON:

1. Blow up two balloons by the same amount and tie them off.
2. Charge the balloons. Ideally, try to charge them by the same amount by rubbing them the same number of times on a large blanket (in practice, it will be very difficult to charge them by *exactly* the same amount, but if you are careful you should be able to develop similar charges)
3. Make a prediction! Will the balloons "stick" to a wall or to glass?
4. Hold one balloon next to a wall made of sheetrock or plaster. SLOWLY let go and observe whether the balloon stays on the wall or falls to the ground.
5. Hold the other balloon next to a window made of glass. SLOWLY let go and observe whether the balloon stays on the window or falls to the ground.
6. Record how long each balloon stayed on its surface.

Extension: Try different materials! Does the balloon stick to metal, plastic, glass, wood, fabric? Does it stick better on cold days than warm days? Does the weather make a difference?

LEVITATING RING:

1. Blow up a balloon and tie it off OR get a short length of plastic PVC pipe.
2. Use scissors to cut a small ring from a very thin plastic bag. The produce bags in US supermarkets usually work very well. Tip: Make sure the bag is not wet. It will only be able to acquire a static charge if it is dry.
3. Charge the balloon or pipe by rubbing it with a material such as a soft fuzzy blanket.
4. Charge the ring of thin plastic by rubbing it gently in a soft cloth or someone's hair.
5. Hold the ring of plastic above the balloon or length of pipe.
6. Drop it and observe!

With practice, you can keep the plastic ring floating for many seconds by moving the balloon so that it stays underneath.

PAPER VACUUM and SCOOTING BUBBLES:

1. Blow up a balloon and tie it off OR get a short length of plastic PVC pipe.
2. Use scissors to cut tissue paper into very small pieces and scatter them on a table or countertop. (An alternative option if you don't have thin wrapping paper or tissue paper is to sprinkle some salt and pepper on a plate)
3. Charge the balloon or pipe by rubbing it on a blanket, coat, or hair.
4. Hold the balloon or PVC pipe above the small pieces of paper or the salt and pepper and observe!
5. Next, clean the table or counter and get it slightly wet with soapy water.
6. Blow bubbles using a bubble wand or your thumb and finger to form a loop. Let them land on the wet surface. With some practice, you should end up with several bubbles that are resting on the surface as hemispheres.
7. Charge the balloon or pipe again by rubbing it on a soft cloth.
8. Bring the balloon or pipe close to the bubble hemispheres and observe how they react. Do they move toward or away from the charge?

Extensions: Is there a limit to how large a piece of paper you can lift up? If you trace and make some paper figures and tape one side of them to the plate, can you use the balloon to get them to stand up?

If you blow a bubble in the air can you change how the bubble drifts using the balloon?

GOALS

- Explore conductors and insulators.
- Collect and observe static charge.

BENDING WATER:

1. Blow up a balloon and tie it off OR get a short length of plastic PVC pipe.
2. Arrange a faucet or a jug with a hole so that you have water flowing with a very narrow and calm stream.
3. Charge the balloon or pipe by rubbing it on a soft cloth.
4. Bring the balloon or pipe close to the stream of water and observe how it reacts. Do they move toward or away from the charged object?

WHAT'S A WATT?

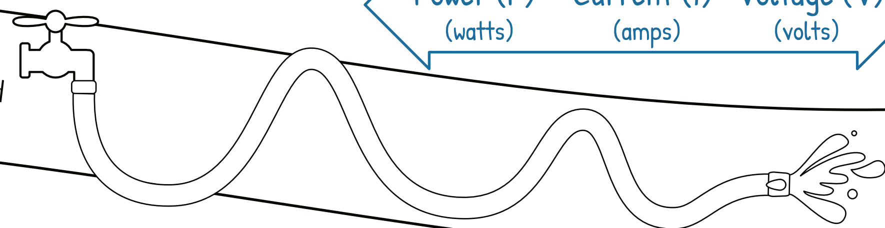
THE UNIT OF ELECTRICAL POWER: Watts measure power. They are the rate of electrical work (1 watt = 1 ampere of current flowing across an electric potential difference of 1 volt)

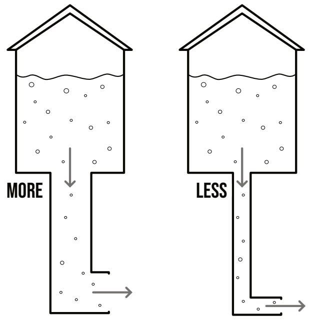
1 watt = 1 Joule/second

Power (P) = Current (I) · Voltage (V)
(watts) (amps) (volts)

THE WATER PIPE ANALOGY*

Where the flow of electrons is likened to water flowing in a pipe or hose



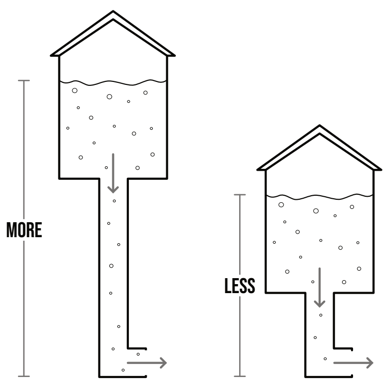


FLOW RATE IS LIKE:

Electric current (amps)

Electrons don't actually push each other through the wire. They are propelled by an electric field which is created by the charges on the battery and/or wires. The energy is actually carried by these fields rather than the electrons themselves. This is why it's possible to charge something with a wireless charger.

While electrons don't flow through wire like water through a pipe, the analogy is still helpful for learning the terms.

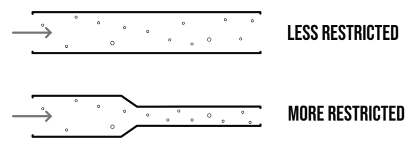


WATER PRESSURE IS LIKE:

Voltage (volts)

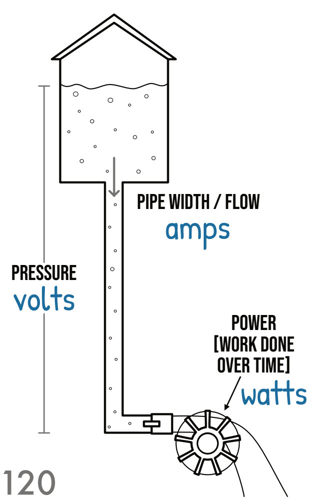
A RESTRICTION IN THE FLOW IS LIKE A CHANGE IN:

Resistance (ohms)



THE AMOUNT OF POWER A WATER SYSTEM HAS IS LIKE:

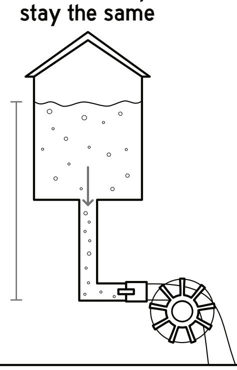
Wattage (watts)



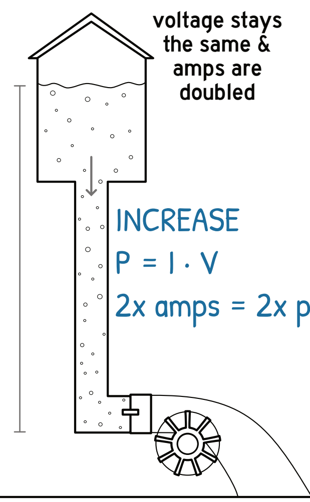
WHAT WILL HAPPEN TO POWER (WATTS) IN EACH OF THESE CASES? COMPARED TO THE FIRST TOWER WITH A WATER WHEEL, WILL THE POWER/WATTAGE INCREASE, DECREASE, OR STAY THE SAME?

DECREASE
Power = Current · Voltage
½ voltage = ½ power

voltage is cut in half & current (amps) stay the same



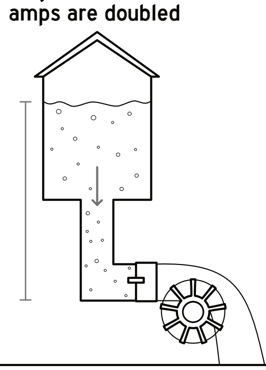
voltage stays the same & amps are doubled



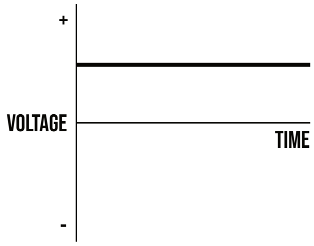
INCREASE
P = I · V
2x amps = 2x power

STAY THE SAME
P = I · V
2x amps · ½ voltage = same power as before

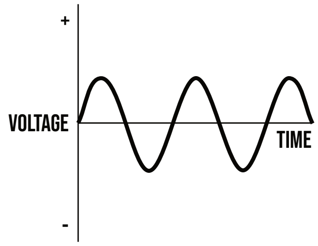
voltage is cut in half & amps are doubled



ALTERNATING CURRENT VS DIRECT CURRENT

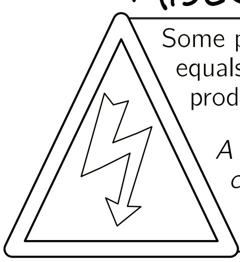


Direct current: Has constant voltage. Used in electronic devices like computers and phones. All batteries use DC. Solar panels too.



Alternating current: Flow of electric charge reverses or alternates. Voltage also alternates. AC is more efficient for being transmitted over long distances. Homes are wired for AC and AC is most common in the electric grid as a whole.

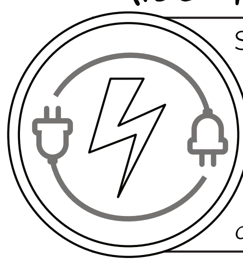
MISCONCEPTION ALERT #1



Some people think higher voltage automatically equals more power, but remember power is a product of voltage AND current!

A device with high voltage but low current could use less power than a device with low voltage and high current (amps).

MISCONCEPTION ALERT #2



Some people think voltage and watts mean the same thing. Or they think that any situation with low voltage is safe.

Remember that watts and voltage measure different things! High levels of either one can be dangerous.

INCANDESCENT VS LED LIGHTBULB

Typical LED lightbulb that produces 750 lumens of light requires 120 volts but only uses 9 watts.

An incandescent bulb that required 120 volts would use around 60 watts to produce the same amount of light.

LAPTOP CHARGER VS HAIR DRYER

The laptop charger and hair dryer both plug into the same outlet with the same voltage. But the dryer will use a LOT more power than the charging cord!

CAR BATTERY

Relatively low voltage but still dangerous! If short-circuited it can cause dangerous burns and/or painful shocks.

WELDING EQUIPMENT

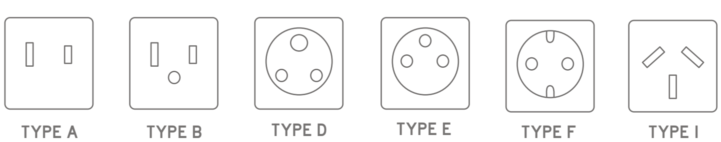
Relatively low voltage (10 to 30 volts) but very high current (up to 500 amps) and thus VERY high heat!

TESLA COIL

Incredibly high voltage - large ones can make over 1 million volts and small desktop ones can produce over 50,000 volts! While the voltage of a tesla coil is high, the CURRENT is low (milliamp range), which makes them relatively safe.

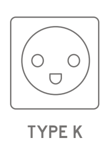
VAN DE GRAAFF GENERATOR

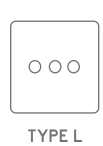
Can create incredibly high voltage (small models can generate over 100,000 volts) but because their current is low (around 0.0000001 amps) they are quite safe. People will often touch them in science demonstrations, making their hair stand on end.



How many volts from the outlet?

The plug design and voltage of power outlets vary by country! Power outlets in the US and Canada deliver 120 volts. Much of Europe and India use 230V outlets. China typically uses 220 volts. When traveling to another country, be careful about how and what you plug in!





Practice Problems - Whats a watt?

1. The volume of electrical charge flowing through a wire is best described as the:
   A. Amperage (current)
   B. Voltage
   C. Resistance
   D. Wattage

2. What does DC stand for in electricity?
   A. Direct Current
   B. Dual Current
   C. Direct Circuit
   D. Dynamic Current

3. What is the best course of action if an electrical fire starts in the wiring of your kitchen wall?
   A. Pour water on it
   B. Use a standard fire extinguisher
   C. Turn off the electricity if possible
   D. Smother the fire by covering it with a towel

   The first step in dealing with an electrical fire is to turn off the electricity. Otherwise, there could be a continual supply of new heat and sparks from the current that would overcome whatever suppression efforts were being used. Adding water would be VERY dangerous.

4. What is the main difference between AC and DC?
   A) AC can only flow in a vacuum
   B) DC is faster than AC
   C) AC changes direction periodically while DC flows in one direction
   D) DC cannot be used in homes

5. What does a watt measure?
   A. Force
   B. Resistance
   C. Power
   D. Current

6. If a device draws a current of 2 amperes from a 120 volt source, how many watts does it use?
   A. 60 watts
   B. 120 watts
   C. 240 watts
   D. 100 watts

   Remember that Power (W) = Current (measured in amps) · Voltage (V)
   2 amps · 120 volts = 240 watts

7. How does the resistance of a circuit affect the current?
   A. Higher resistance increases the current
   B. Higher resistance decreases the current
   C. Resistance does not affect the current

8. True or false: Batteries use AC current.
   A. True
   B. False

   Batteries use direct current.

Practice Problems – Whats a watt?

(9) What does it mean if a light bulb is rated at 60 watts?

A. It uses 60 volts of electricity
B. It draws a current of 60 amperes
C. It uses 60 joules of energy per second
D. None of the above

Remember a watt is defined as 1 joule/second.

(10) Amil uses an 800 watt microwave at work and a 1200 watt microwave at home. Which one will cook food faster?

A. The 800 watt microwave
B. The 1200 watt microwave
C. There will be no difference in cook time between the two microwaves

A 1200W microwave will heat food significantly faster than an 800W microwave. Although it uses the same voltage (is plugged into the same type of outlet) it uses much more power.

(11) What would happen if you plug a device rated for 220 volts into a 120 volt socket?

A. The device will operate more efficiently
B. The device will operate faster
C. The device will overheat because it is receiving too much current
D. The device might not operate correctly or at all

(12) A new appliance is advertised as being low voltage, but it uses a lot of watts. How could this mystery appliance be both high wattage and low voltage?

A. By using a high amount of current
B. By using a low amount of current
C. By having incredible resistance
D. There is no such thing as a high wattage but low voltage device

Remember power (watts) = current · voltage
Low voltage · high current would equal high wattage.

(13) If an LED lightbulb and an incandescent lightbulb both produce the same amount of light but the LED light is 8 watts and the incandescent is 60 watts, what does this mean?

A. The LED uses higher voltage
B. The incandescent bulb is more efficient
C. They use the same amount of electrical current
D. The LED bulb uses less current

(14) True or false: A 120V appliance is safer than a 240V appliance. Provide an example to justify your answer.

A. True
B. False

Voltage is not the only factor determining electrical safety or risk! The CURRENT determines what degree of shock could occur and that depends on both the voltage and the power.

If the devices were electric heaters that were both going to produce 2400 watts, then the 240V device would use 10 amps of current while the 120V device would use 20 amps of current. The higher current used in the 120V device would be more likely to trip breakers or blow fuses.

(15) Which of these appliances would use the most electric current (amperes) when operating?

A. A 10-watt LED bulb running on a 120 volt supply
B. A 1,500-watt hair dryer running on a 120-volt supply
C. A 1,000-watt electric stove burner running on a 240-volt supply
D. A 5-watt phone charger on a 120-volt supply

Remember watts = current· voltage
Divide both sides of the equation by voltage to get current = watts/voltage.
Hair dryer uses 12.5 amps. Stove uses 4.6. The phone and lighbulb use less than 1.

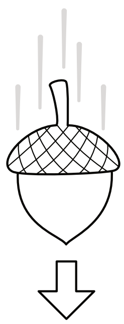
Marvelous Magnets

Fill in the blanks:

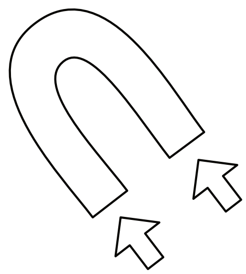
gravity | *electrostatics* | *repel* | *force*

In magnetism, like charges ___repel___ each other and opposite charges attract. If this sounds reminiscent of electrostatics, it's because ___electrostatics___ and magnetism are closely linked! They both occur because of the electromagnetic ___force___ , which, like ___gravity___ , is one of the fundamental forces at work in the universe.

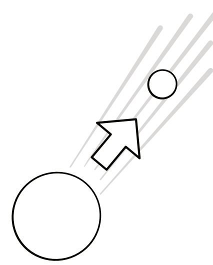
The 4 Fundamental Forces:



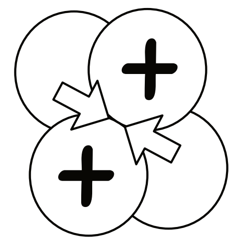
Gravitational force



Electromagnetic force



Weak force



Strong force

Infinite range but strength very strongly linked with distance

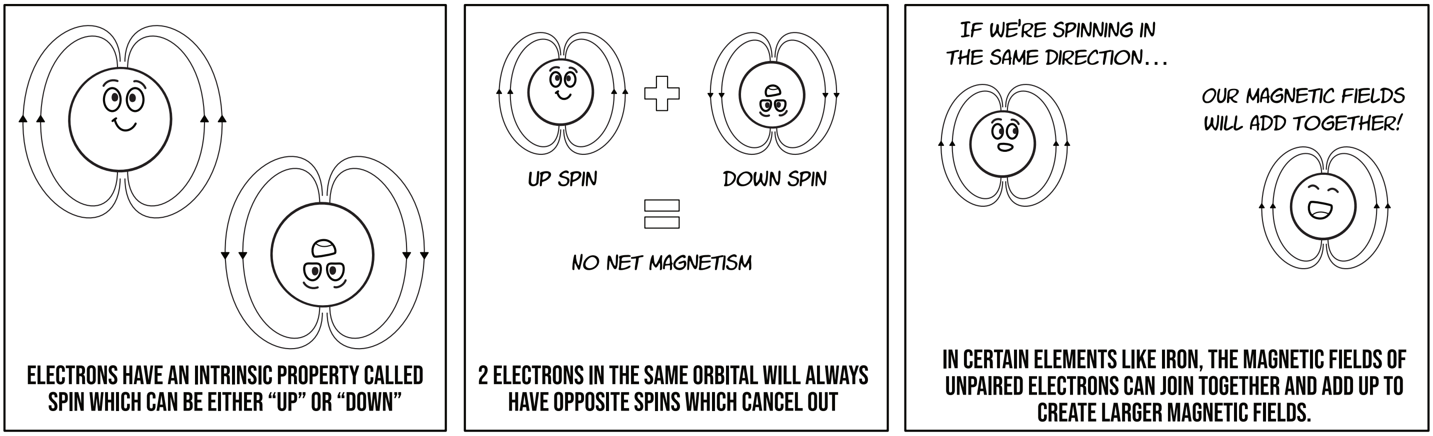
Only effective at short range, the dominant forces at subatomic level

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

Answers will vary!

Science Mom's favorite was the "flipping magnets" demonstration. When similar poles of a magnet get close together, the repelling force is strong enough to flip one of the magnets over. Then the attractions between the N and S poles will pull them together.

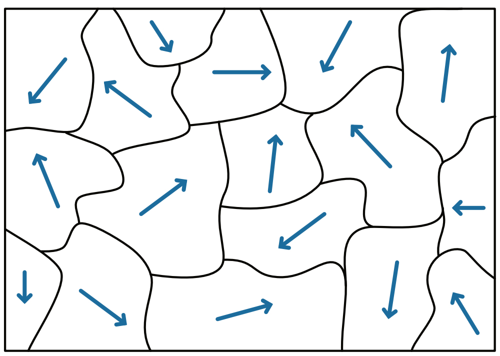
But what is magnetism? It's a force produced by the movement of charges! Since electrons are charged particles that move… they create small magnetic fields.

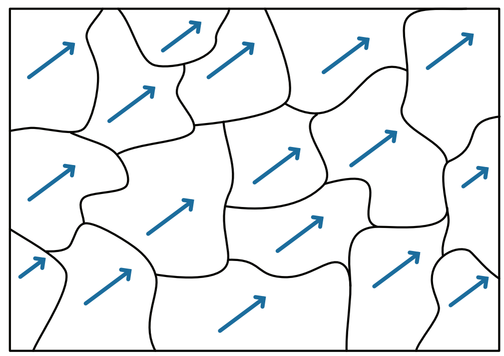


Most atoms have electrons which are paired in a way that cancels out their magnetic fields. Certain elements (like iron) have atoms with magnetic fields that can join together and add up instead of canceling out.

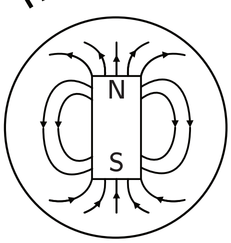
A piece of iron has domains where electrons spinning in the same direction align, producing a stronger magnetic field. When magnetized, all of the domains will align in the same direction.

HERE ARE DIAGRAMS OF THE DOMAINS IN 2 BLOCKS OF IRON. DRAW ARROWS TO SHOW HOW THE MAGNETIC FIELDS ARE ALIGNED IN EACH.


weak magnet / not magnetic

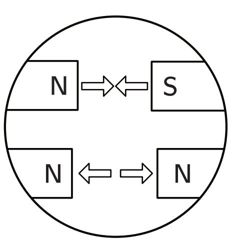

strong magnet

PROPERTIES OF PERMANENT MAGNETS:



Have magnetic poles (North / South) with magnetic field lines (go from north to south)

Ferromagnetic materials are attracted to magnets and can become magnetized. Iron, cobalt and nickel are strongly ferromagnetic but they aren't the only materials that respond to magnetic fields. Others are paramagnetic (weakly attracted) or diamagnetic (weakly repelled).



Opposites poles attract each other, like poles repel each other

Practice Problems - Marvelous Magnets

1. What happens when you bring the north pole of one magnet close to the south pole of another magnet?
   A. They repel each other.
   B. They attract each other.
   C. They become demagnetized.
   D. Nothing happens.

2. Which of these materials are NOT attracted to a magnet?
   A. Aluminum
   B. Copper
   C. Cobalt
   D. Iron

3. What is the term for the invisible area around a magnet where forces are felt?
   A. Magnetic aura
   B. Magnetic bubble
   C. Magnetic field
   D. Magnetic zone

4. Why does a compass point north?
   A. Because of gravity
   B. Because the Earth is a giant magnet
   C. Because of the Sun's magnetic field
   D. Because of the orientation of the Moon

With the early compasses, the north-seeking pole of a magnet was defined to be "north" because it pointed in the direction we called "north." But remember, opposite poles attract!

This means the magnetic pole near Earth's geographic north pole is actually the south magnetic pole. If you stood at this location with a compass that could move in 3D, the needle would point straight down.

If you hold a compass by a bar magnet, it will always point at the S end of the magnet.

5. What would happen to the magnetic field of a magnet if it were broken in half?
   A. The magnetic field would disappear. The pieces would no longer be magnetic.
   B. The magnetic field would weaken. Each of the pieces would be weakly magnetic.
   C. Each piece would become a separate magnet with its own north and south poles.

6. What can happen to a magnet if it is heated up to a very high temperature?
   A. It becomes stronger and attracts magnetic material with more force.
   B. It loses its magnetic properties and is no longer magnetic.

7. What is the most likely result of an nail being placed next to a magnet for an extended period of time? (Assume the nail is made of iron and is not magnetized before being placed next to the magnet)
   A. The nail is temporarily magnetized and will exert its own magnetic field.
   B. The nail is now a permanent magnet.
   C. The nail experiences no change.

8. True or False: Magnets can attract any type of metal.
   A. True
   B. False

9. True or False: Magnets work in air, water, and the vacuum of outer space.
   A. True
   B. False

Practice Problems – marvelous magnets

(10) True or False: Holding papers to a fridge is one of the most practical uses for magnets. They don't have many other applications or uses.

A. True

B. False

(11) What statement is true about the force responsible for the interaction between two magnets?

A. The force between magnets is not related to the force responsible for electric charge

B. The force between magnets decreases with proximity

C. The force between magnets increases with proximity

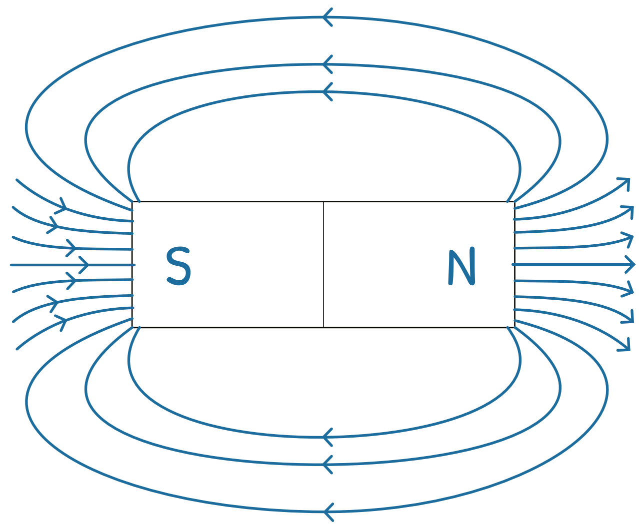
D. The force between magnets is dependent on gravity

(12) What is the term used to describe materials that are attracted to magnets?

ferromagnetic

(13) Draw lines to represent the magnetic field surrounding a bar magnet.

Drawings may vary – important aspect is that lines go from N to S and are strongest / most concentrated at the poles of the magnet.



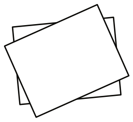
(14) List 3 examples of devices that use magnets:

There are a lot of options! Here are a few:

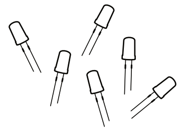
- Hard drive in a computer
- MRI machine
- Electric motors and generators
- Compass
- Credit card or debit cards – have a magnetic strip that encodes information to connect to financial institution
- Speakers and headphones – most speakers use a permanent magnet to convert the signal (electric energy) into sound (mechanical energy)
- Wireless charging pads
- Wind turbines
- Generators in a dam
- Maglev train
- Some computer cords have a magnet so it can snap off without damaging the cord or computer if it's tripped over

LED HOLIDAY CARD

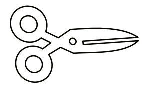
MATERIALS (TO MAKE 2 CARDS)



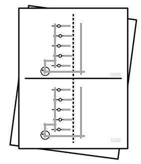
1 piece of cardstock



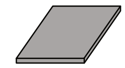
Between 3 to 20 LED lights (3 mm)



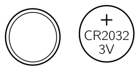
Scissors



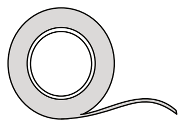
Printed templates OR pencil and pen to create your own design



A small piece of cardboard (optional)

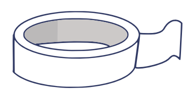


2 Button batteries (CR2032 3-volt batteries work well)

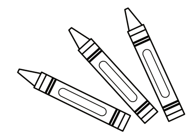


0.5 meters of conductive maker tape

Push pin OR sewing needle



Glue stick and tape



Coloring supplies

FOR BEST RESULTS:

Be careful when using different colors! Blue/whites LED bulbs often use a different voltage than red/green/yellow. Mixing all the colors will only work if you have them come on one-at-a-time or you use resistors.

GOALS

- Create an LED circuit card
- Gain increased understanding of how circuits work
- Persevere and troubleshoot any problems that emerge.

INSTRUCTIONS FOR A "PRESS & LIGHT" CARD:

Matches the string of lights template.

1. Print the template (front and back) on cardstock and then cut the paper in half along the solid line.
2. Color the string of lights and write a phrase of your choice such as Merry Christmas, Happy Diwali, Eid Mubarak, Happy Hanukkah, Happy New Year, or You LIGHT up my day!
3. Fold the paper along the dotted line so that the diagram for the conductive tape is on the inside of the card.
4. Using the pin or sewing needle, poke two small holes where each LED light will be placed. *TIP: For poking the holes, it helps to have a piece of cardboard on the other side.*
5. Insert the LED lights so the wires are on the inside of the card. Bend the wires out so the long wires go toward the + symbols and that the short ends are toward the - symbols.
6. Create your circuit by placing conductive tape along the lines.
7. Tape the battery to the card so that the negative side of the battery is connected to the short wires and the positive side is connected by the tape to the long wires (figure A). If the battery orientation is reversed (figure B), the LED bulb will not light up! If needed, use additional pieces of regular tape to secure the battery to the card.
8. Close the card. Press along the wire above the lights and watch them light up!

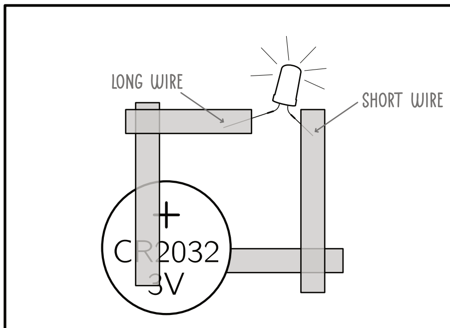


Figure A

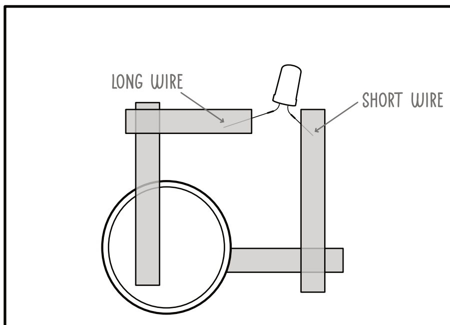
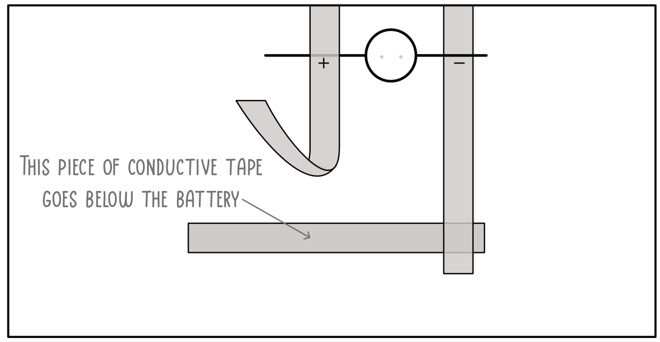


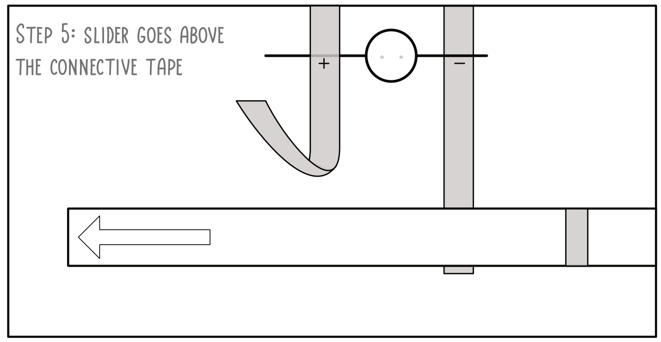
Figure B

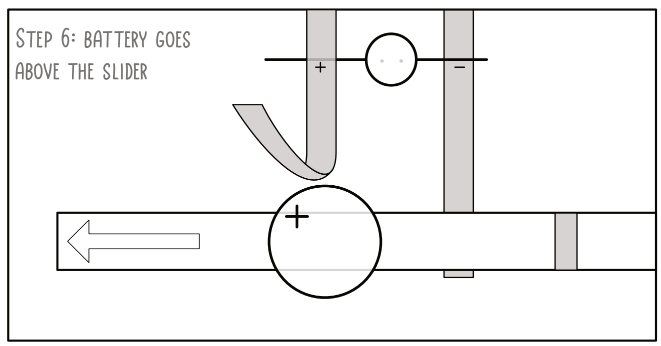
INSTRUCTIONS FOR A "SLIDER" CARD:

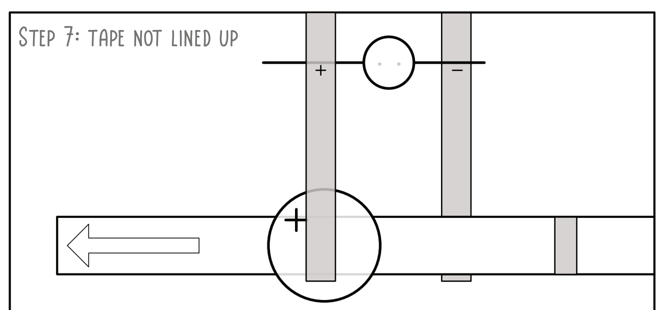
Matches the paper slider card template.

1. Print the page with the flowers and leaves, color them, and carefully cut them out. Glue the leaves on the front of the card so that the center hole matches the markings for the LED bulb. Tip: poke holes where the LED wires will go so that its easier to line up the leaves with the holes.
2. Use a glue stick to glue the petal templates together so that they are offset and make a full flower. Glue the center circle to each flower so that there are 3 flowers in total. Glue them over the leaves.
3. Place the card on a thick piece of cardboard. Use the pin or sewing needle to poke holes where each LED light will be placed.
4. Insert the LED light so that the wires are on the inside of the card. Bend the wires out so the long wires go toward the + symbols and that the short ends are toward the - symbols. Apply conductive tape to match the circuit lines and keep the wires in place.
5. Make the slider by wrapping a strip of connective tape around a piece of cardstock. Place the slider above the conductive tape.
6. Place the battery on top of the slider (positive side facing up). Use tape to connect the battery to the line of tape that is labeled with + symbols.
7. Adjust the slider so that the line of tape is not lined up with the circuit. The lights should be off.
8. Pull the slider so that the line of tape touches the circuit. The lights should come on!
9. Close the card and move the slider back and forth.

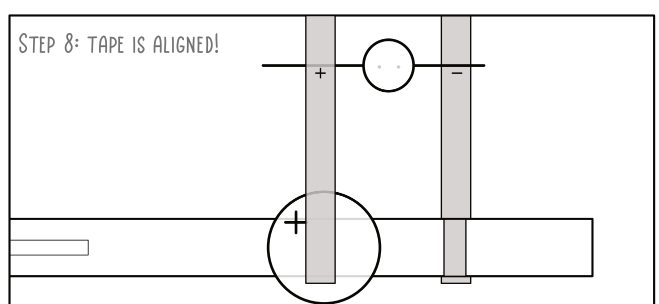








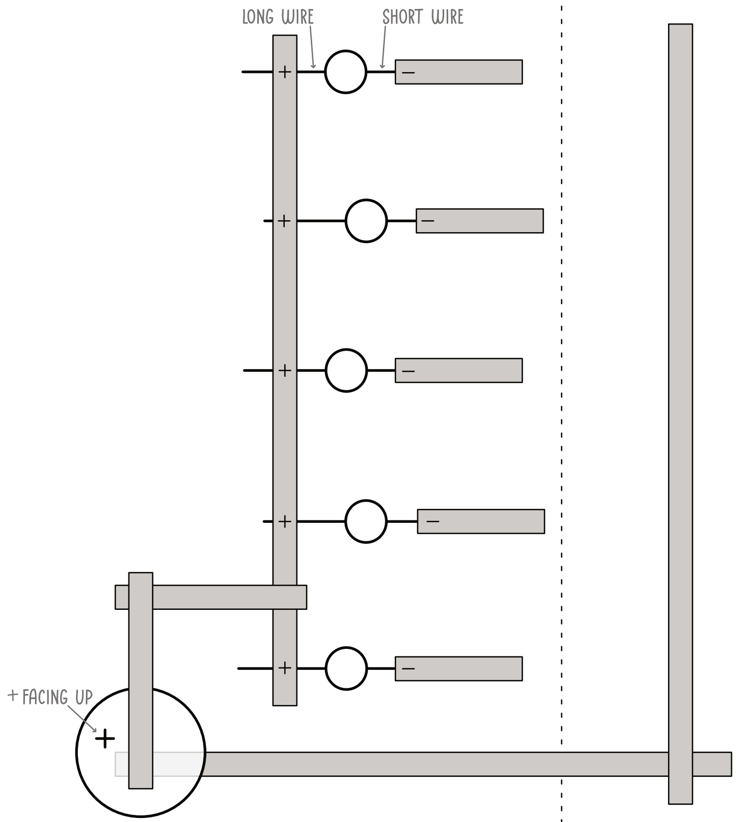
Circuit incomplete = lights off



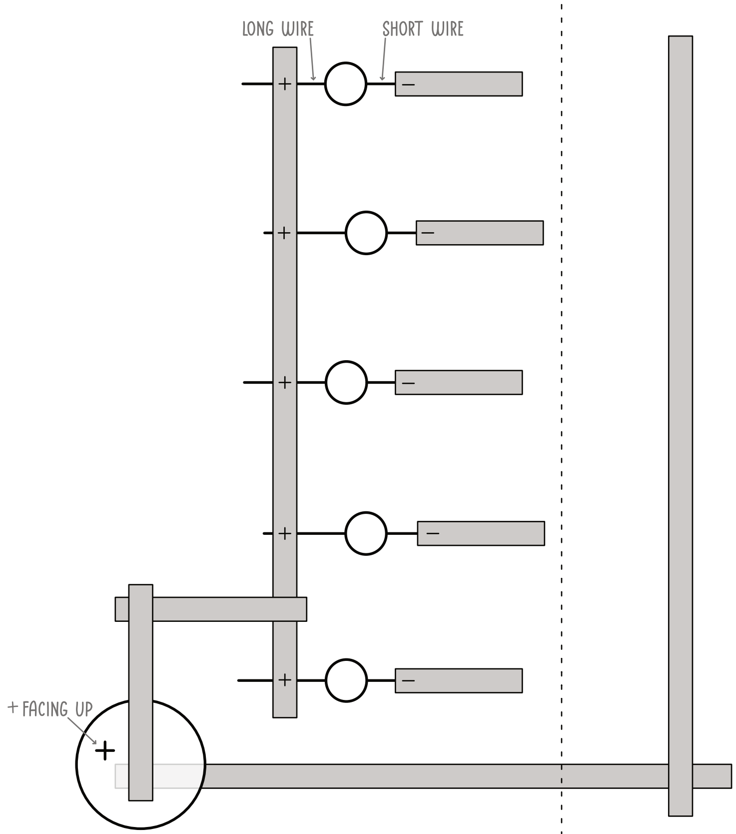
Circuit complete = lights on

TO MAKE YOUR OWN CARD:

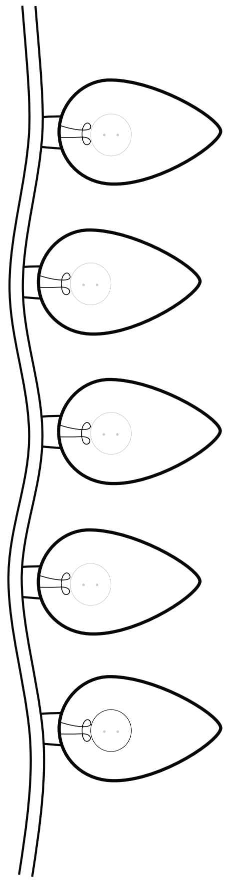
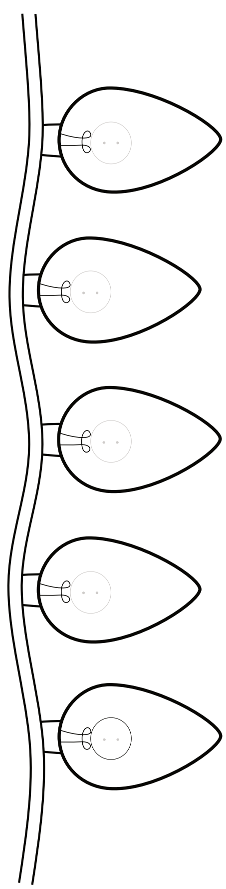
1. Design a circuit so that the circuit will be complete either when the card is closed or when a slider is moved into place.
2. Arrange the LED lights so that the long wires and short wires are all on the same sides.
3. Connect a button battery to the conductive tape so that the positive side connects to the long wires of the LED bulbs. The negative side of the battery should connect to the short wires.
4. Test your card and see if it works! If needed, adjust the design of the circuit or add more tape to get a better connection.

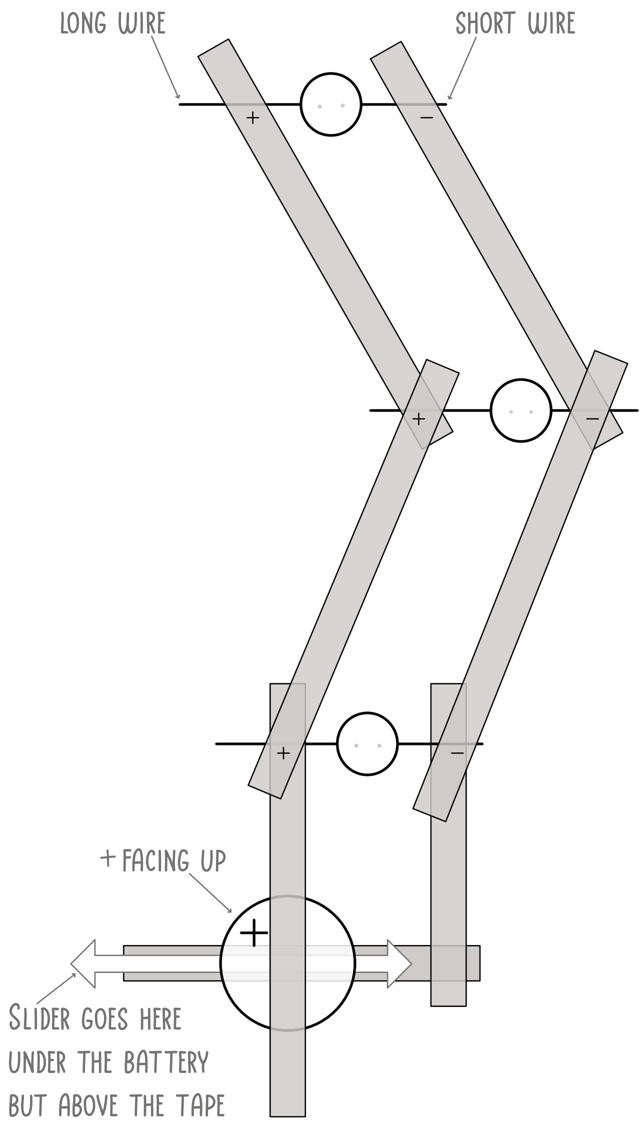


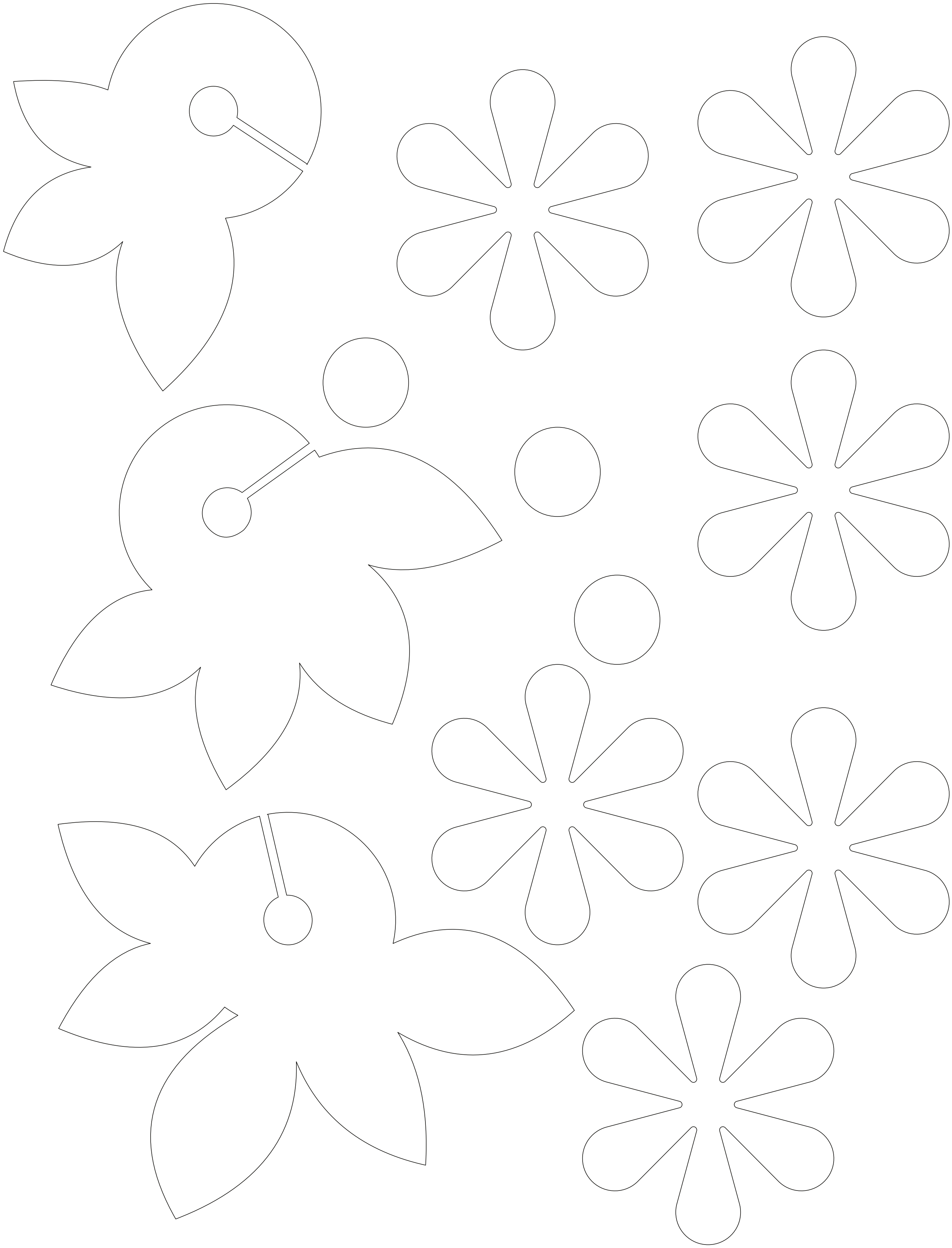
String of Lights LED
Circuit Card Template
SCIENCE MOM

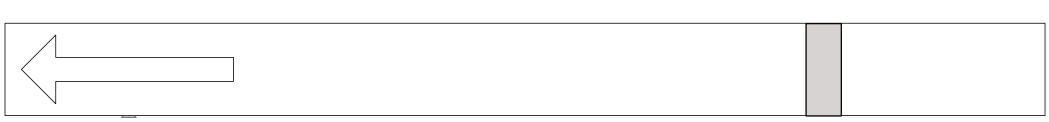


String of Lights LED
Circuit Card Template
SCIENCE MOM


LONG WIRE
SHORT WIRE
+
−
+ FACING UP
SLIDER GOES HERE
UNDER THE BATTERY
BUT ABOVE THE TAPE





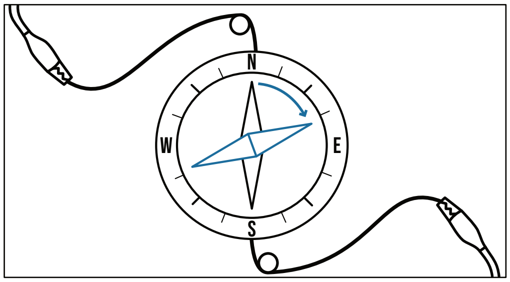
Slider

Flowers and slider for
Paper Slider LED
Circuit Card

ELECTROMAGNETISM

What do you expect to happen to a magnet or ferromagnetic objects when they are around wire carrying electric current? Make predictions for each of these demonstrations. Then record what happens!

1.



CURRENT FLOWS THROUGH A WIRE.
HOW WILL THE COMPASS BEHAVE?

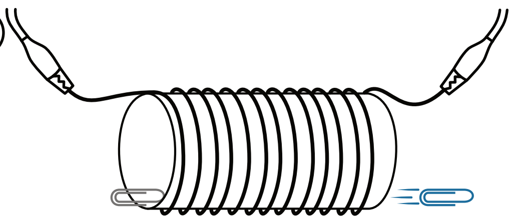
PREDICTION:

- ☐ Compass remains pointing north
- ☐ Compass points different direction
- ☐ Compass oscillates back and forth
- ☐ Something else

RESULT:

The compass points a different direction! It behaves similar to how a compass behaves when placed by a magnet. The change in direction depends on the strength and direction of the electric current.

2.



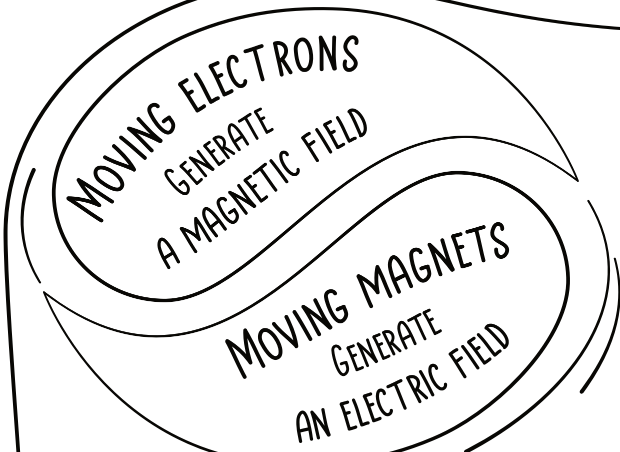
CURRENT FLOWS THROUGH A COIL OF WIRE.
A PAPERCLIP IS PLACED AT THE INNER EDGE OF THE COIL. WHAT WILL HAPPEN?

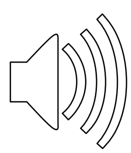
PREDICTION:

- ☐ Paperclip remains in place
- ☐ Paperclip is repelled by coil
- ☐ Paperclip moves through the coil
- ☐ Something else

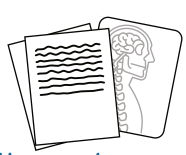
RESULT:

The paperclip shoots through the coil! (The coil is called a solenoid and has a stronger magnetic field than a straight wire with current.)

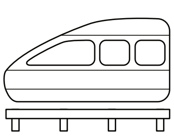




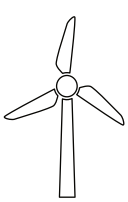
Speakers use an electromagnet to create sound waves. They use the magnetic field to convert the electric signal into movement.



An MRI machine has strong magnets which force protons in the body to align with their field. Short bursts of radio waves then knock the protons out of the alignment. As they go back, they emit radio signals which are used to make the images.

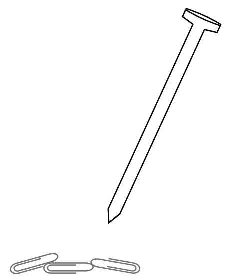


Superconducting magnets with strength 10x stronger than ordinary magnets repel each other so the train hovers above the track. Electricity is used to propel the train forward.

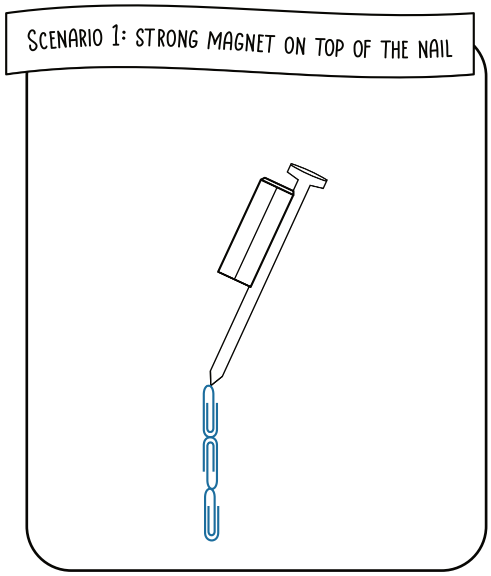


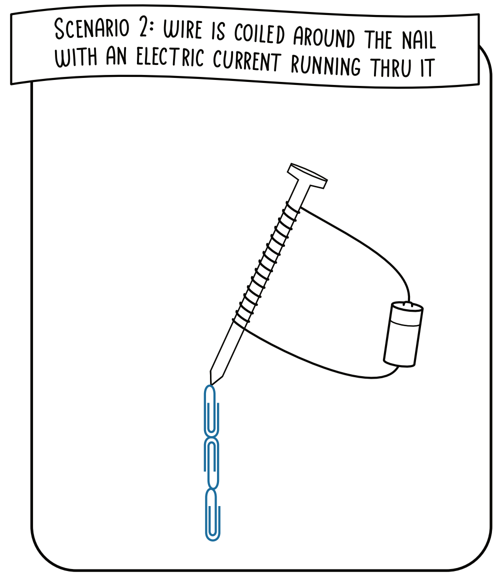
Generators in wind turbines, hydroelectric dams, and other devices operate by spinning a magnet to generate an electric current or by spinning a coil of wire around a magnet.

A LARGE ORDINARY IRON NAIL COMES NEAR PAPERCLIPS. THE NAIL IS NOT MAGNETIC, SO NOTHING HAPPENS.



What would happen to the nail & paperclips in each of these scenarios and why?





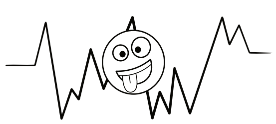
MAGNET ON NAIL:

Magnetic induction! The magnetic field of the magnet causes domains in the nail to align, strengthening their magnetic field. This alignment turns the nail into a temporary magnet by inducing a magnetic field throughout the nail.

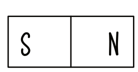
WIRE CONNECTED TO BATTERY:

Electromagnet! The electric current generates a magnetic field around the wire. This magnetic field causes the domains in the nail to align and point the same direction, making the nail a strong magnet (temporarily).

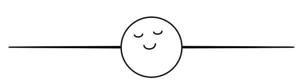
Draw lines to match each of these descriptions as belonging to a permanent magnet or electromagnet.



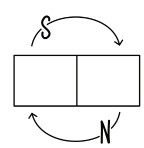
VARIABLE MAGNETIC FIELD
STRENGTH CAN BE EASILY ADJUSTED OR CHANGED



FIXED POLARITY
FIXED NORTH AND SOUTH POLES



CONSTANT MAGNETIC FIELD
HAVE CONSTANT FIELD THAT DOESN'T NEED A POWER SOURCE



ADJUSTABLE POLARITY
DIRECTION OF MAGNETIC CURRENT EASILY REVERSED

CAN BE STRONGER
CAN HAVE MORE MAGNETIC PULL GIVEN THEIR SIZE

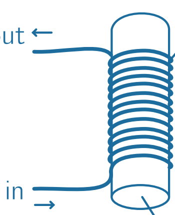
PERMANENT MAGNET

ELECTROMAGNET

Practice Problems – Electromagnetism

1. What is an electromagnet? Describe it briefly and draw a diagram. Then list 2 examples of devices or machines that use electromagnets.

An electromagnet uses electricity to produce a magnetic field. It has a core made of ferromagnetic material (usually iron) and is wrapped with a coil of insulated wire. When current flows through the coil, the core is magnetized.



Examples:

Electric motors, MRI machines, speakers, electric door locks, relays, maglev trains, telegraph

2. A magnet that can be repeatedly turned on and off is called:
   A. A bipolar magnet
   B. An electromagnet
   C. A permanent magnet
   D. A temporary magnet

3. What is always created when an electric current flows through a wire?
   A. A vacuum
   B. High temperature
   C. A magnetic field
   D. Sound waves

4. What happens to the magnetic field of an electromagnet when more current is put through the coil?
   A. The magnetic field increases
   B. The magnetic field decreases
   C. The direction of the magnetic field reverses
   D. The magnetic field becomes unstable

5. An electric generator does which of the following?
   A. Converts mechanical energy into sound energy
   B. Converts light energy into electrical energy
   C. Converts electrical energy into mechanical energy
   D. Converts mechanical energy into electrical energy

6. True or False: A moving magnet creates an electric field.
   A. True
   B. False

7. True or False: Electromagnets are preferred over permanent magnets in many devices.
   A. True
   B. False

Electromagnets are preferred because they can be turned on and off

PRACTICE PROBLEMS – ELECTROMAGNETISM

8. What happens when the electric current in an electromagnet is reversed?
   A. The poles of the magnet are inverted (flip to have opposite orientations)
   B. The magnetic field stops and the core is no longer magnetic
   C. The magnetic field gets stronger
   D. The magnetic field gets weaker

Most electromagnets use cores of soft magnetic materials where the domains quickly return to a random state. They do not retain magnetization after the electric field is removed. But some core materials would have domains that went out of alignment more slowly. These would retain some residual magnetism after the electromagnet was turned off.

9. What happens when the electric current in an electromagnet is turned off?
   A. The magnetic field becomes permanent
   B. The magnetic field disappears
   C. There is no change to the magnetic field
   D. The magnetic field is inverted or changes direction

10. The magnet in a scrap yard can be used to pick up metal scraps and drop them in other locations. Which statement about this magnet is true?
    A. It must be an electromagnet
    B. It must be a permanent magnet
    C. There is not enough information to know what type of magnet it is

11. Assuming that the amount of current remains constant, what happens to the strength of an electromagnet when the number of coils around its core is increased?
    A. It decreases
    B. It remains the same
    C. It increases
    D. It becomes zero

12. In an electromagnet, what type of material is used in the core to enhance the magnetic field?
    A. A highly conductive material such as copper
    B. A ferromagnetic material such as iron
    C. A gaseous material such as neon
    D. A non-metallic material such as carbon

13. The process where a current is produced due to a changing magnetic field is called:
    A. Electrostatic discharge
    B. Resonance
    C. Electromagnetic induction
    D. Triboluminescence

14. What role did the electromagnet play in the telegraph?
    A. It stored electric charge for sending messages
    B. It converted electrical signals into mechanical movements
    C. It provided a path for electrical currents to travel from the sender to the receiver
    D. It translated words into a series of dots and dashes

15. True or False: Electric guitars use permanent magnets to convert string vibrations into electrical signals.
    A. True
    B. False

They use electromagnets (called pickups) to convert string vibrations into electrical signals.

NUCLEAR FISSION VS NUCLEAR FUSION

NUCLEAR FISSION

Fission occurs when one atomic nucleus SPLITS apart.

Releases energy ($E=mc^2$)

Can only yield net energy if atoms are larger than iron

Too many neutrons can cause an atom to become unstable and undergo fission (radioactive decay). In certain elements (like plutonium) one fission event can set off a chain reaction that causes all of the other atoms to split as well.

NUCLEAR FUSION

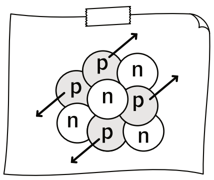
Fusion occurs when two atomic nuclei COMBINE to form a larger nucleus.

Releases energy ($E=mc^2$)

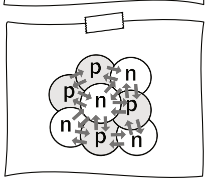
Can only yield net energy if atoms are smaller than iron

Powers our sun, where intense pressure and heat convert H to He

In theory, fusion could be a clean and incredibly powerful energy source but we haven't yet been able to create a sustainable system/method.



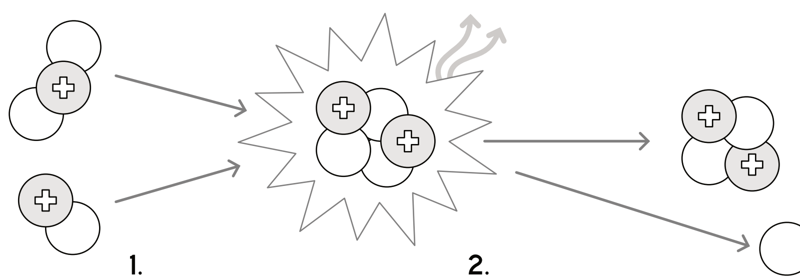
Electrostatic force:
Positively charged protons repel each other.



Strong nuclear force:
All nucleons (protons or neutrons) are attracted to each other by the strong nuclear force. Which force "wins" depends on the size of the atom and the ratio of protons to neutrons.

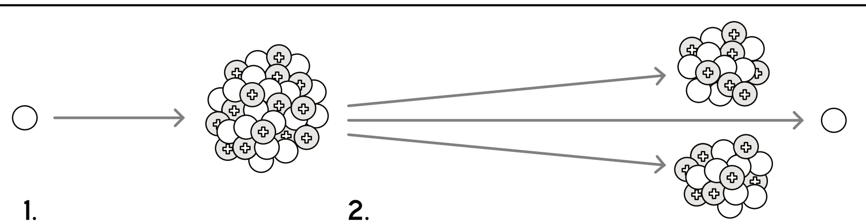
Label each reaction pictured below as being either fission or fusion, and describe the steps:

Nuclear Fusion



1. Two atoms collide and combine
2. Energy and a neutron are released

Nuclear Fission



1. A neutron collides with a nucleus, making it unstable
2. The atom splits into lighter elements, releasing energy and expelling a neutron

Draw a line to match each description with fission, fusion, or both.

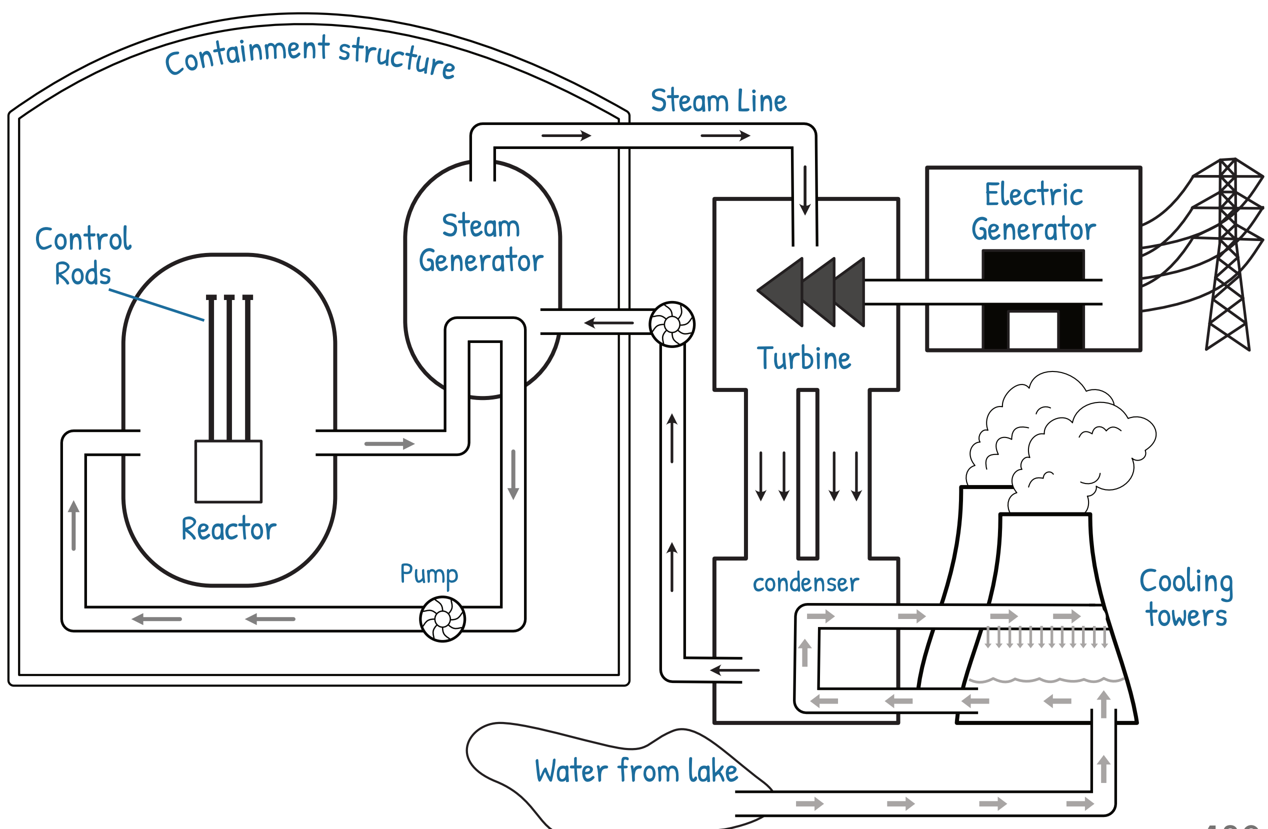
Releases the most energy		Principle behind atomic bombs
Requires high heat and pressure	Fission	Primary source of power in stars
Principle behind nuclear reactors		Poses risks of radiation
Uses uranium	Fusion	Requires light abundant elements
Hydrogen atoms combine to make helium.		Requires very heavy elements like plutonium

Nuclear Reactors

Nuclear reactors generate energy through controlled nuclear fission. Inside the reactor, uranium or plutonium fuel undergoes fission, releasing heat. This heat warms a coolant, which then produces steam. The steam drives turbines connected to generators, producing electricity. Reactors are designed with safety systems to control the fission process and contain radiation.

LABEL THE PARTS OF THE NUCLEAR REACTOR

Steam Generator	*Turbine*	*Steam line*	*Control rods*
Electric Generator	*Cooling towers*	*Reactor*	*Containment structure*



Practice Problems – Going Nuclear

1. What is nuclear fission?
   A. Two nuclei combining to form a larger nucleus
   B. A nucleus splitting into two smaller nuclei
   C. The process of losing an electron
   D. The orbit of electrons changing in an atom

2. What process powers the sun and stars?
   A. Nuclear fission
   B. Chemical reactions
   C. Nuclear fusion
   D. Solar flares

3. What particle is often used to initiate nuclear fission?
   A. Electron
   B. Neutron
   C. Proton
   D. Photon

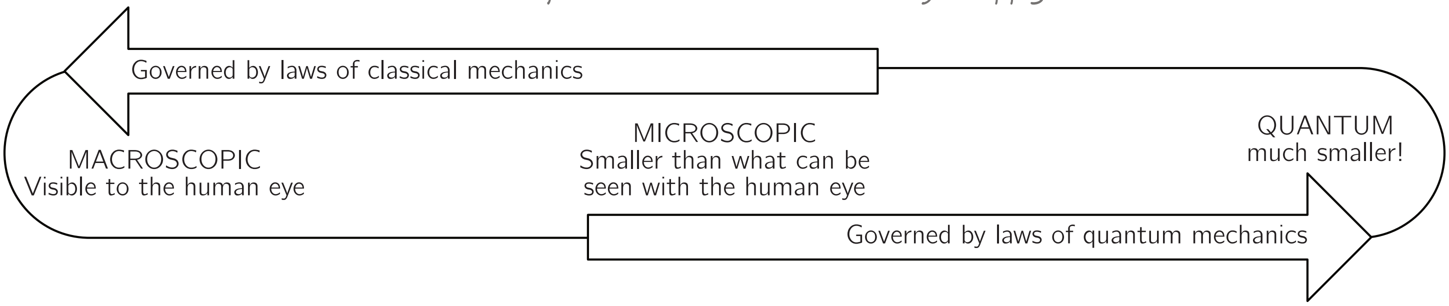
4. What is radioactivity?
   A. A process that strengthens materials
   B. The absorption of radiation by atoms
   C. The emission of energy as atomic nuclei decay
   D. The production of light by atoms

5. Why is nuclear fusion not yet widely used to generate electricity on Earth?
   A. It does not produce enough energy.
   B. It requires conditions that are difficult to achieve and maintain.
   C. It produces too much radioactive waste.
   D. It only works in space.

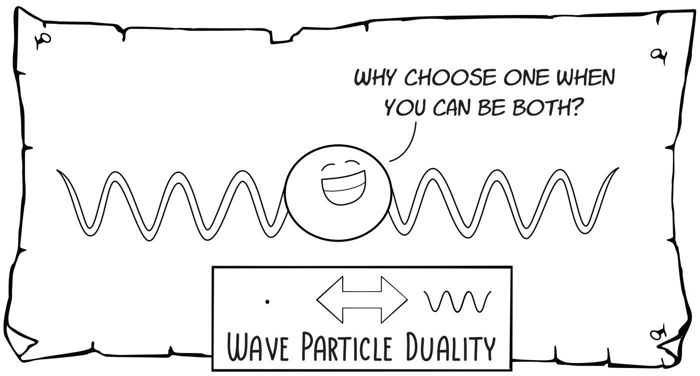
6. Decide whether each statement is true or false.
   T F Nuclear fusion releases more energy than nuclear fission.
   T F Nuclear fission is the process used by the Sun to produce energy.
   T F Nuclear fusion requires very high temperatures to occur.
   T F Nuclear reactors use fusion reactions to generate electricity.
   T F Fission is the combining of two lighter atoms into a heavier atom.
   T F Fusion reactions are easy to control and widely used on Earth for energy production.
   T F The waste from nuclear fission is more radioactive than the waste from nuclear fusion.
   T F Fusion reactions produce heavy radioactive elements as byproducts.

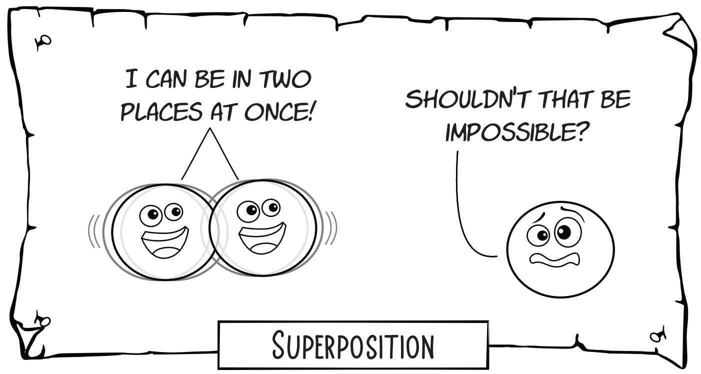
The Weird World of Quantum

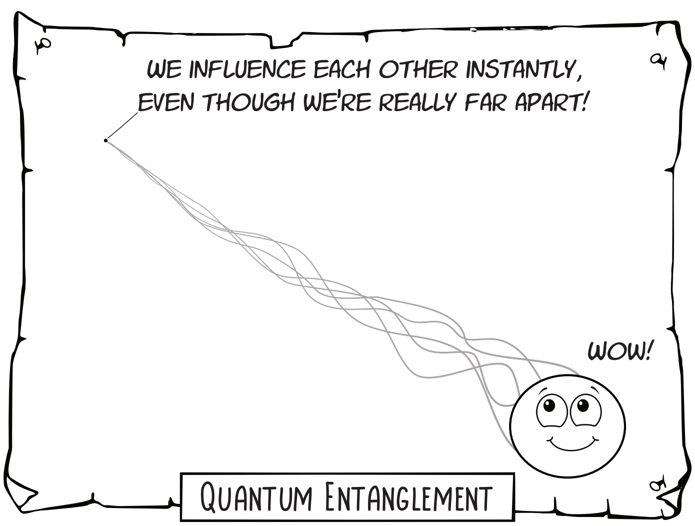
The rules of classical mechanics no longer apply!

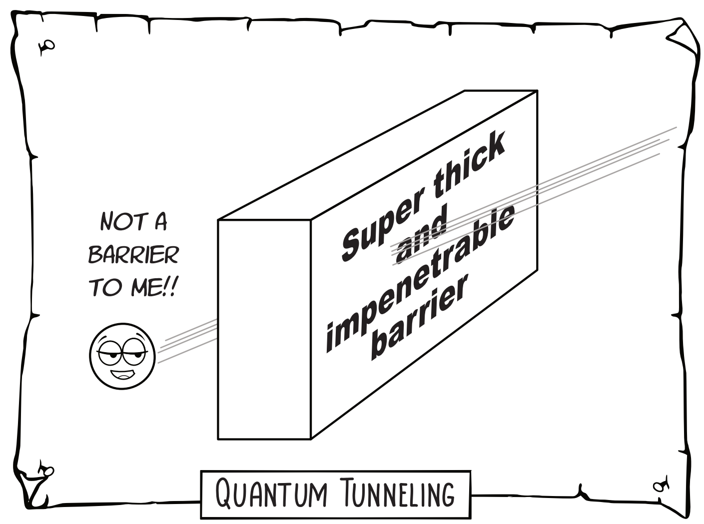


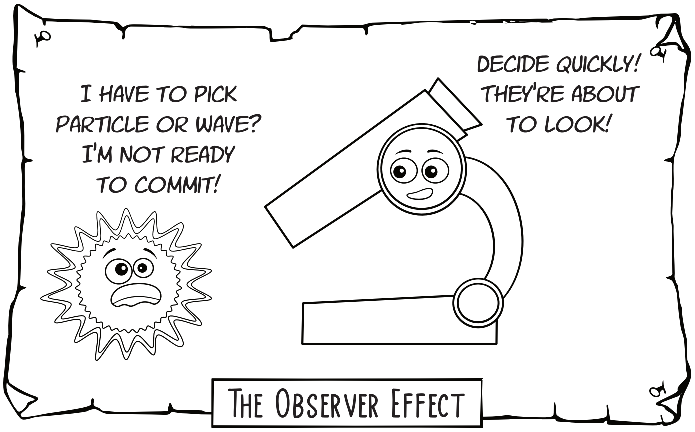
Particles and physical matter exist in a spectrum of different sizes. The smaller things become, the more strongly the rules of quantum physics apply. The world of quantum physics is VERY different than classical mechanics! Below are 6 of the more common properties or effects seen at the quantum level.

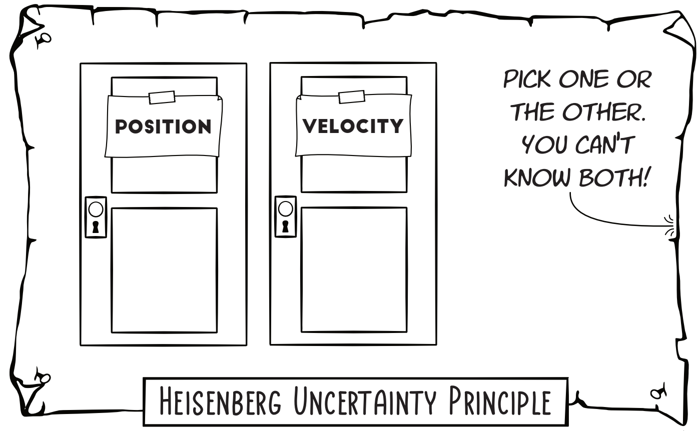












Practice Problems – The Weird World of Quantum

1. What phenomenon allows a particle to pass through a potential energy barrier that it classically cannot overcome?
   A. Quantum entanglement
   B. Quantum tunneling
   C. Observer effect
   D. Superposition

2. According to the Heisenberg Uncertainty Principle, which pair of properties of a particle cannot be simultaneously precisely determined?
   A. Position and velocity
   B. Mass and charge
   C. Momentum and energy
   D. Spin and angular momentum

3. Which phenomenon describes the ability of particles to exist in multiple states simultaneously until observed?
   A. Quantum tunneling
   B. Superposition
   C. Observer effect
   D. Wave-particle duality

4. What term describes the concept that the act of measurement can alter the behavior of the system being observed?
   A. Quantum tunneling
   B. Superposition
   C. Observer effect
   D. Wave-particle duality

5. The double slit experiment was foundational in demonstrating which property:
   A. Quantum tunneling
   B. Superposition
   C. Wave-particle duality
   D. Observer effect

6. What is your favorite fact or question related to quantum mechanics?

Answers will vary.

Science Mom's favorite fact is the observer effect, which directly ties into her favorite question. How is it possible that something like an electron knows it is being observed?

Math Dad's favorite fact is wave-particle duality. It's fascinating that photons and other "particles" can be both! His favorite unanswered question related to quantum physics is "What is dark matter and why does it exist?" Maybe one of our students will find the answer someday. For now, we don't know!

Final Assessment

1. Which of the following best describes the First Law of Thermodynamics?
   A. Energy cannot be created nor destroyed, only transferred or transformed.
   B. Entropy of a closed system always increases.
   C. Heat flows from cold objects to hot objects naturally.
   D. The efficiency of a heat engine can never be 100%.

2. What type of heat transfer can occur in the vacuum of outer space?
   A. No heat transfer can occur in a vacuum.
   B. Radiation only.
   C. Convection and conduction.
   D. Conduction, convection, and radiation.

3. What is the latent heat of vaporization?
   A. The heat required to melt a solid.
   B. The heat required to freeze a liquid.
   C. The heat required to change a liquid into a gas.
   D. Heat released when gas condenses.

4. What is the typical speed of sound in air at room temperature?
   A. 25 m/s
   B. 343 m/s
   C. 562 m/s

5. The buoyant force on an object submerged in a fluid is equal to the:
   A. Volume of the fluid displaced.
   B. Density of the fluid.
   C. Weight of the fluid displaced by the object.
   D. Weight of the object.

6. The phenomenon of light bending as it passes from one medium to another is called:
   A. Diffraction
   B. Interference
   C. Reflection
   D. Refraction

7. The frequency of a wave is 500 Hz and its speed is 340 m/s. What is the wavelength?
   A. 0.68 m
   B. 1.52 m
   C. 0.85 m
   D. 2.00 m

8. If the distance between two charges is DOUBLED, the force attracting them to each other will:
   A. Double
   B. Stay the same
   C. Be ½ as strong
   D. Be ¼ as strong

9. Which of the following statements about magnetic fields is true?
   A. Magnetic fields require a medium to travel through space.
   B. Magnetic fields are only produced by permanent magnets.
   C. Most of the elements in the periodic table are ferromagnetic.
   D. Magnetic fields are created by moving electric charges.

10. If the volume of a gas is decreased from 4 liters to 2 liters while the temperature remains constant, what happens to the pressure of the gas assuming the initial pressure was 1 atm?
    A. The pressure decreases to 0.5 atm.
    B. The pressure increases to 2 atm.
    C. The pressure remains the same.
    D. The pressure decreases to 0.25 atm.

11. Increasing the amplitude of a sound wave will:
    A. Increase the pitch
    B. Decrease the pitch
    C. Increase the volume
    D. Decrease the volume
    E. Increase the frequency
    F. Decrease the frequency

12 Bernoulli's principle states that, in a fluid, an increase in velocity occurs simultaneously with what other change?

A. Increase in pressure
B. Decrease in pressure
C. Increase in temperature
D. Decrease in temperature

13 Of the colors listed below, which color of light has the shortest wavelength?

A. Red
B. Green
C. Blue
D. Yellow

14 The phenomenon of light bouncing off an object at the same relative angle it arrived is called:

A. Reflection
B. Refraction
C. Diffraction
D. Dispersion

15 If the wave speed doubles while the frequency stays the same, what happens to the wavelength?

A. It doubles
B. It is halved
C. It remains the same
D. It quadruples

Remember wave speed = frequency · wavelength

16 If the current in a wire increases, the magnetic field around the wire will:

A. Increase
B. Decrease
C. Remain unchanged
D. Temporarily disappear

17 A 20 lb weight falls into a pool and displaces a volume of water that weighs 4 lb. How much upward force will be needed to lift the weight while it is underwater?

A. 5 lb
B. 16 lb
C. 24 lb
D. 80 lb

18 What happens to the liquid pressure experienced by a submarine when it doubles its depth in the ocean?

A. Liquid pressure is cut in half.
B. Liquid pressure remains the same.
C. Liquid pressure doubles.
D. Liquid pressure quadruples.

19 What is the human audible range of sound frequency?

A. 20 Hz to 2 kHz
B. 20 Hz to 20 kHz
C. 2 Hz to 20 kHz
D. 20 kHz to 2 MHz

20 If a 400 N weight is placed on a cube that measures 4 cm × 4 cm × 4 cm, how much pressure is applied to the cube face?

A. 100 kPa
B. 250 kPa
C. 400 kPa
D. 1600 kPa

Remember pressure is force per unit area and pascals are N/m^2

$400\ N / (0.04\ m \times 0.04\ m)$

21 What quantity measures the average kinetic energy of particles in a substance?

A. Temperature
B. Heat
C. Entropy
D. Enthalpy

22 Write out the seven types of electromagnetic radiation from lowest frequency to highest frequency.

1. Radio
2. Microwaves
3. Infrared
4. Visible light
5. Ultraviolet
6. X-rays
7. Gamma rays

Electromagntic Spectrum Song

adapted from Ghost Riders in the Sky

Stan Jones / Serge Ballif

Useful Formulas

Temperature

C = temp in °C, F = temp in °F

$$F = \frac{9}{5}C + 32$$

Density

ρ = density, m = mass, V = volume

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

Pressure

P = pressure, F = force, A = area

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

Weight

w = weight, m = mass, $g = 9.8\,m/s^2$

$$w = mg$$

Liquid Pressure

P_{fluid} = pressure, ρ = density,
$g = \frac{9.8\text{m}}{\text{s}^2}$, h = depth

$$P_{fluid} = \rho g h$$

Boyle's Law

P_1 = first pressure, V_1 = first volume,
P_2 = second pressure, V_2 = second volume

$$P_1V_1 = P_2V_2$$

Ideal Gas Law

P = pressure, V = volume, n = number of mols,
$R \approx 8.314\frac{\text{J}}{\text{K}\cdot\text{mol}}$, T = temperature in K

$$PV = nRT$$

Wave Speed

v = wave speed, f = frequency,
λ = wavelength

$$v = f\lambda$$

Electrical Power = Voltage × Current

P = power (watts), V = voltage (volts), I = current (amps)

$$P = VI$$

Ohm's Law

V = voltage (volts), I = current (amps), R = resistance (ohms)

$$V = IR$$