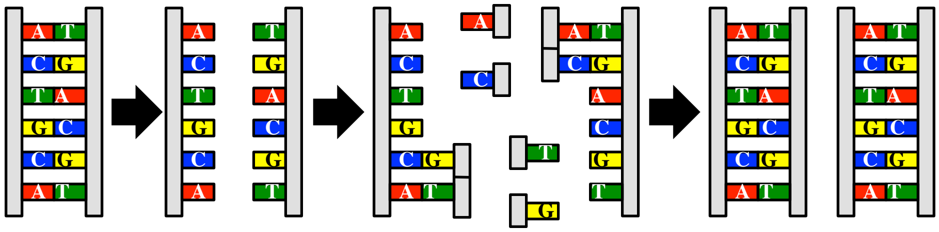
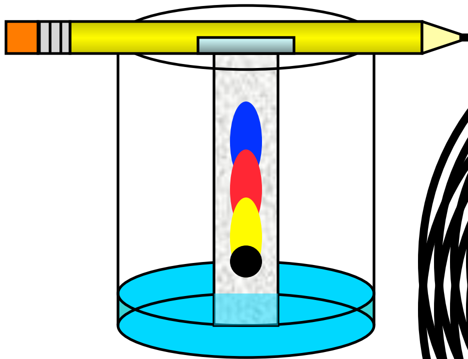
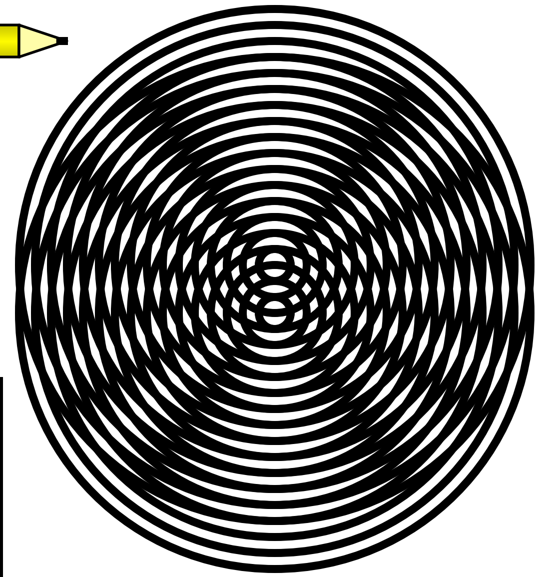
Mini Science Kit

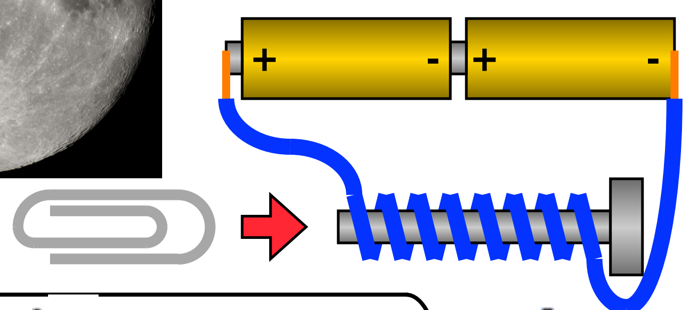
WARNING: CHOKING HAZARD--Small parts.
Not for children under 3 years old.
Adult supervision required for experiments.

This kit allows you to do 64 experiments in:









Some kit components are used for multiple experiments, so please keep them clean and in good condition after each experiment. Common household items not included in the kit (scissors, tape, milk, etc.) are required for some experiments as indicated. Experiments can be done in any order except where noted. Please don't pester us for extra parts. We have tried to include enough non-household items for all experiments. If you run out of some of these items or find that one is missing or damaged, you can obtain more from the sources below.

Replacement parts (part numbers in parentheses):

#4 or 6 coffee filter	Walmart, Target, etc.
Balloons, straws	Walmart, Target, etc.
4" steel bolt	Home Depot, Lowes
Washer 3/8" ID 1" OD	Home Depot, Lowes
Thread	Walmart, Michaels
Clear plastic utensils	Walmart, Target, grocery stores
Optical fiber	www.sciplus.com (91068)
pH paper	scientificsonline.com (3021313)
Magnets	Michaels, www.sciplus.com, scientificsonline.com, www.hometrainingtools.com, www.christianbook.com
Insulated wire	Home Depot, Lowes
1.5-3V electric motor	scientificsonline.com (3082264), www.sciplus.com (34566P4)
LEDs	www.sciplus.com (31620)
Diffraction grating	www.rainbowsymphony.com (01505), scientificsonline.com (3054509)
Optical polarizers	scientificsonline.com (3038490), www.sciplus.com (34243)
Liquid crystal sheet	scientificsonline.com (3072374), www.sciplus.com (91582)
Plastic test tubes	www.hometrainingtools.com (CE-TTUBCAP)
Plastic pipettes	www.hometrainingtools.com (CE-PIPET)
Plastic cups	www.christianbook.com (WW29545)
Glucose test strips	www.testyourselfathome.com (URS-1G-100 Teco glucose assay strips)

Help improve our mad science:

Email Dr. Todd H. Rider (thor@riderinstitute.org) if you have any suggestions for future improvements to these science kits.

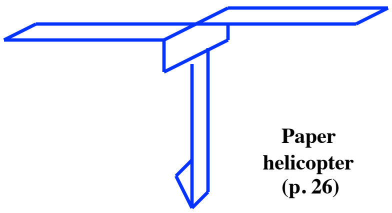
Science experiments for fun and profit:

Students can win free trips and thousands of dollars in scholarships in middle- and high-school science fairs. It's never too early to start!

www.societyforscience.org

Explore further: www.hometrainingtools.com (usually lowest prices/widest selection, free project ideas; Danger, Will Robinson—some unscientific creationist books); www.sciplus.com (ever-changing stock of interesting stuff); scientificsonline.com (fairly wide selection, often overpriced); www.a-two-z.com (science store in Northampton, MA). Science book series by Janice VanCleave (good experiments), Golden Guide (most by Frank Rhodes or Herbert Zim, good overviews), DK Eyewitness (great photos), Joanna Cole (Magic School Bus, educational and entertaining); Brinley, *Mad Scientists' Club*, and Appleton II, *Tom Swift Jr.* (very inspirational, need a modern equivalent), Judy Sierra & Stephen Gammell, *The Secret Science Project That Almost Ate the School* (just plain fun!). *Schoolhouse Rock!* on DVD & YouTube (great science songs and multiplication tables).

Aerospace Engineering



Experiment 1: Paper helicopters

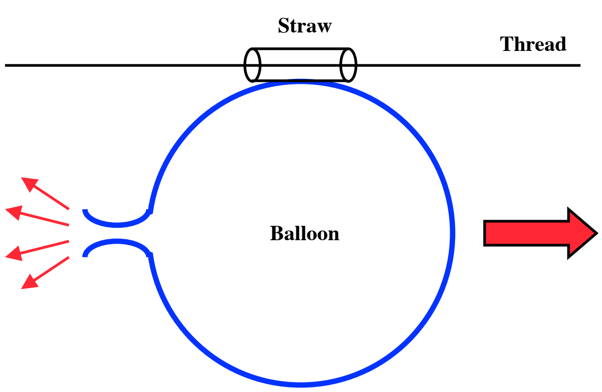
Kit provides: Paper helicopter pattern sheet (p. 26)

You provide: Scissors

Aerospace engineers build aircraft and spacecraft, so now you get to be a rocket scientist.

Everyone makes paper airplanes. True science and engineering nerds make paper helicopters. The pattern sheet on p. 26 contains five paper helicopters of varying sizes. (See also www.paperairplanes.co.uk/heliplan.php.) Cut one out, cutting on all the solid lines. Fold flap A one way and flap B the other way, to make the two blades of the helicopter. Fold flaps C and D back to make a weight at the bottom. Fold line E upward to complete the weight. Your helicopter should look like the drawing above.

Hold the helicopter as high as you can, with the blades on top and the weight on bottom. Hold it by the paper rectangle beneath the blades, then let it go and quickly pull your hand out of the way.



Experiment 3: Action and reaction

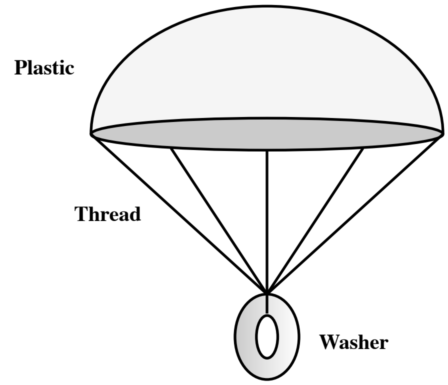
Kit provides: Balloons, straws, thread

You provide: Scissors, tape, strong lungs

This is aerospace engineering, so go ahead and blow the wrappers off your straws (if you haven't already) in the name of science education. Now stretch a balloon with your hands for a while to ensure that it can inflate easily. Cut a 2-inch piece of straw, pass the thread through it, and stretch the thread taut across the room like a clothes line. Blow up the balloon, tape its side securely to the straw, and let it fly across the room on the thread. If you thought that was fun, we gave you four balloons—now get busy and see what you can do. Just don't launch the family cat across the room.

See also: www.hometrainingtools.com/balloon-rocket-car-project/a/1346/

When you are finished with this experiment, keep the balloons clean and don't tie off the ends. The balloons can be used in other experiments.



Experiment 2: Time to hit the silk, or at least the plastic

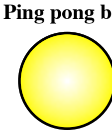
Kit provides: Thread, metal washer, wire

You provide: Plastic grocery or trash bag (**keep away from young children**), scissors, tape

Make a parachute by cutting off the dome-shaped bottom of a plastic grocery bag or trash bag. Cut 6-8 pieces of thread of the same length, say 12 inches long or so. (Do Expts. 3 and 60 first, or at least save a very long piece of thread for them.) Tape one end of each thread to the edges of the dome-shaped plastic, spacing them evenly around the dome. Tie the other end of each thread to a washer or small wadded-up piece of wire. Now drop the parachute and see if your washer or wire sky diver survives.

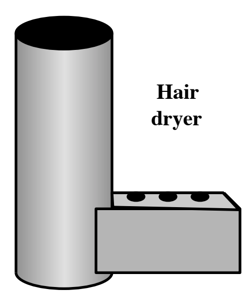
What happens if you make parachutes of different sizes or shapes? What happens if you attach a parachute to several washers or other weights?

Experiment 4: Up in the air



Kit provides: Moral support

You provide: Ping pong ball, hair dryer or leaf blower with round (not oval) opening **(use ear protection if the blower is loud)**



Normal people use hair dryers so they will look nice. Science nerds use hair dryers to levitate objects in the air. Point a hair dryer (preferably on the cool setting) or leaf blower straight up and try to levitate a ping pong ball in the air stream. Try holding and releasing the ball at different heights above the blower. Why does the ball hang in the air stream instead of being immediately blown out of it?

The air around us has pressure (Expt. 41), which is a form of energy. When the blower forces the air to move, it converts part of that pressure energy to kinetic or moving energy, so the moving air stream has less pressure than the still air around it. The higher-pressure still air pushes on the ping pong ball and holds it in the lower-pressure air stream. This effect that moving air has less pressure than still air is known as Bernoulli's principle and also helps airplane wings keep planes in the air.

Try to levitate more than one ping pong ball, or try balls of other size or weight. Can you levitate objects with other shapes?

Explore further: www.hometrainingtools.com/aquapod-bottle-rocket-launcher/p/MC-AQUAPOD/ water rockets (amazon.com and Toys R Us); Estes rockets (www.estesrockets.com, Walmart, Michaels, Toys R Us); *Klutz Book of Paper Airplanes* (2004); Guillow balsa gliders and rubber-band-powered planes (amazon.com and hobby stores); DVDs: *From the Earth to the Moon, In the Shadow of the Moon, Voyage to the Planets*

Archaeology

Archaeologists dig up and study artifacts from Egypt and other ancient cultures. (Picture Indiana Jones digging with a trowel all day instead of chasing bad guys…) With a little practice, you can read many of the inscriptions on Egyptian artifacts in museums. Instead of letters, Egyptians wrote in characters called hieroglyphs. Egyptian could be written left-to-right (like English), right-to-left, or top-to-bottom. If written left-to-right or right-to-left, human- and animal-shaped hieroglyphs face the beginning of the sentence. Most hieroglyphs only spelled out the consonants of words, not the vowels. For simplicity, we usually guess "e" for the vowels between the consonants. One hieroglyph could have one, two, or three sounds or letters. Just be careful how you pronounce things—you don't want to accidentally bring a mummy back to life…

Egyptian kings (pharaohs) had a first name and a last name, each written inside an oval (cartouche), making them easy to spot. Sometimes only one of the names is written. Kings' names often incorporated the name of a god. As a sign of respect, a god's name was written first, even though it was usually pronounced last in a king's name. Some famous gods and kings were:

Egyptian god	Job description
Re or Ra	Sun god. "Hail to the sun god—he sure is fun god. Ra! Ra! Ra!"
Amun or Amun-Ra	Other names for Ra
Ptah	Arts and crafts
Osiris	Head honcho of the afterlife

King's first name	King's last name	Reigned (years BC)
Menkheperure	Thutmose (IV)	1400-1390
Neferkheperure	Amenhotep (IV, Akhenaten)	1352-1336
Nebkheperure	Tutankhamun	1336-1327
Usermaatre	Rameses II	1279-1213
Ptolmys (Ptolemy V)		204-181

Some common hieroglyphs are shown on this page and p. 4. Can you write your name in hieroglyphs? If Egyptian does not have the right letter, choose one that sounds similar. Now see if you can translate the inscriptions in Expts. 5-8 on p. 5. If a king's name is given, which king was it, and when was he king? Answers are on p. 29—no peeking!

pr-aa "Great House"=Pharaoh

nsw bty King of upper [plant] & lower [bee] Egypt

tawy the two lands [upper & lower Egypt]

djt forever

heaven

mry beloved [of a god]

son of Ra

ruler of Thebes

true of voice = deceased [RIP]

Osiris

year of king's reign

1

10

the king | a gift | gives

so that he will give a voice offering [say nice things about someone]

Some hieroglyphs that silently indicate a meaning

man	house, building	book, writing, abstract
woman	town, village	small, bad, weak
god, king	desert, foreign country	wood, tree
force, effort	sun, light, time	*logogram indicator*
eat, drink, speak	walk, run	*plural indicator*

foreign

1-letter hieroglyphs

a	*b*	*n*	*s*	*t*
i	*p*	*l/r*	*s*	*tj*
y	*f* his	*l/r*	*sh*	*d*
y	*m*	*h*	*k*	*j/dj*
a/o	*m*	*h*	*k*	
w/u	*m*	*kh*	*g* throne	
w/u	*n*	*kh*	*t*	

Explore further: Collier & Manley, *How to Read Egyptian Hieroglyphs* (revised ed., 2003); DK Eyewitness *Ancient Egypt* (2008) & *Archeology* (2000); John White, *Hands-On Archaeology* (2005); Richard Panchyk, *Archaeology for Kids* (2001); lavishly photographed books on ancient civilizations and ruins in Barnes & Noble bargain aisles; www.ancientlives.org; www.ancient-art.com/bargbox.htm; www.vcoins.com/ancient/

Archaeology (continued)—Egyptian Hieroglyphs

2-letter hieroglyphs

aw	*ak*	*wj*	*mw*	*nb* lord/all
ab	*aj*	*ba*	*mn*	*nm*
akh	*o/wa*	*bh*	*mr* love	*nh*
iw	*wa*	*pa*	*mh*	*nkh*
im	*wp*	*pr* house	*ms*	*ns*
in	*wn*	*ph*	*mt*	*nj*
ir rites	*iwn*	*ma*	*mt*	*rw*
is	*wr*	*mi* like/as	*nw*	*ra* sun
aa great	*wd*	*mi*	*nw*	*di* give
ha	*kha*	*sa*	*shs*	*ti*
hw	*khw*	*sw* king	*shd*	*tm*
hm	*kht*	*sn*	*kd*	*tja*
hm	*kha*	*sn*	*ka* spirit	*dja*
hn	*khn*	*sk*	*kp*	*djw*
hr	*khn*	*st*	*km*	*djr*
hs	*khr*	*sha*	*gm*	*djd* enduring
hj	*sa* son	*shw*	*gs*	*nekh*
kha 1000	*sa*	*shn*	*ta*	

Some 3-letter hieroglyphs

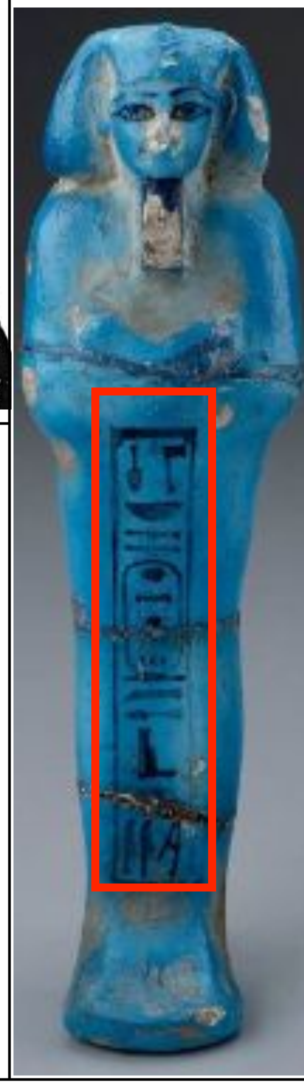
iwn	*nfr* good	*htp* offering	*shma*	*maa* true
ankh live/life	*ntr* god	*khpr* being	*kap*	
aha	*njm*	*khnt*	*tyw*	
wah	*rwj*	*khrw* voice	*djam/was* power	

Archaeology cont'd

Experiment 5: Rosetta Stone Discovered in 1799 in Rashid, Egypt. Now in British Museum, London.

Experiment 6: Stele of Ahmose Now in Museum of Fine Arts, Boston.
Egyptian New Kingdom, Dynasty 18, 1550–1295 B.C.

Experiment 7: Ushabti
Discovered 1902 in a Valley of the Kings tomb in Thebes, Egypt. Now in Museum of Fine Arts, Boston.



Experiment 8: Vase Discovered 1922-23 in a Valley of the Kings tomb in Thebes, Egypt. Now in Egyptian Museum, Cairo.

Astronomy

Experiment 9: Lunar geography

Astronomers study planets, stars, and other space stuff and get rather cranky if you call them astrologers. To try out astronomy for yourself, go look at the moon. No, really. Binoculars are helpful but not required. The white areas are called the highlands; they are largely made of anorthosite, sort of like granite (p. 13). The dark areas are called seas (maria in Latin), but are really basalt, iron-rich lava that has spilled out from inside the moon and hardened. Six manned Apollo missions landed on the moon. Use the moon map on p. 7 to identify the landing sites. Note that the moon always keeps the same face to the earth as it orbits the earth. Watch the moon as it goes through its monthly phase--the shadows can make some features more visible at certain phases.

Experiment 11: Meteor showers

Comets have left trails of debris throughout the solar system. As earth orbits the sun each year, it passes through different debris trails. Some of the debris enters and burns up in our atmosphere, creating meteor showers at certain times of the year. Each meteor shower is named after the constellation in the direction from which the meteors appear to come (see blue list below). Check www.imo.net or www.space.com for more detailed information on upcoming meteor showers. Step outside way before dawn on the appropriate date, let your eyes adjust to the darkness, look toward the right constellation (see Expt. 12), and enjoy the show. You don't need binoculars or a telescope--just your eyes. If you see a really big one coming, call Bruce Willis.

Experiment 10: Satellites

Look at the sky for 30-60 minutes soon after sunset or before sunrise when only a few stars are out. During these times, sunlight shines on satellites but not on you. Binoculars are helpful but not required. Satellites will look like bright slowly moving stars. Most travel from west to east within minutes. Klaatu barada nikto! To identify what you have seen, or to find out when you can see really impressive satellites like the International Space Station, see:

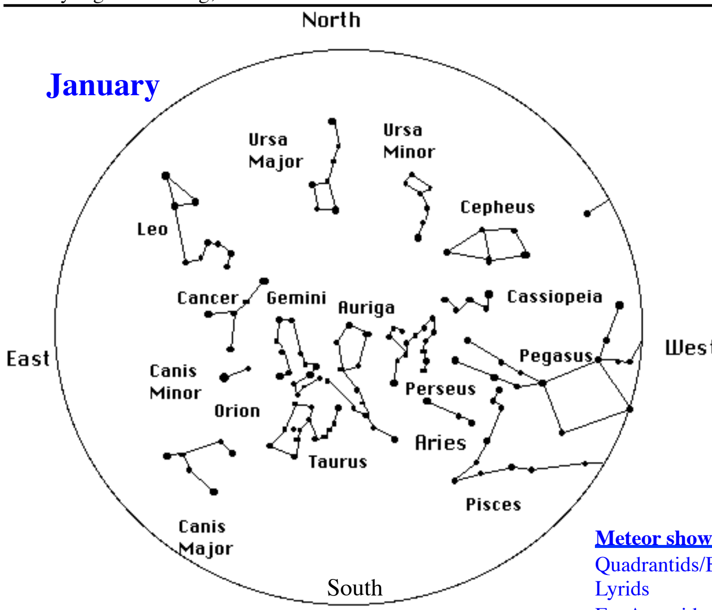
www.satobs.org www.heavens-above.com

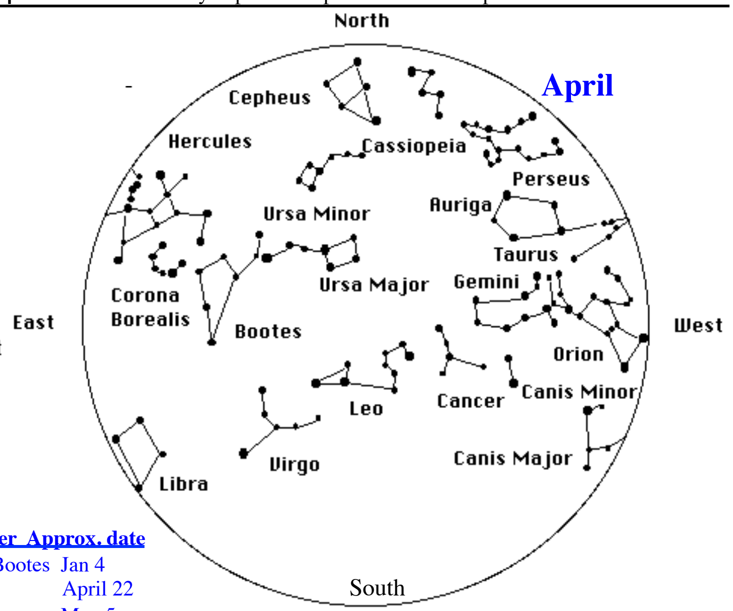
Experiment 12: To infinity and beyond!

To identify stars in the night sky more easily, we arbitrarily group certain bright stars together as constellations. As the earth rotates each day and orbits the sun each year, different sets of constellations are visible from the northern and southern hemispheres. The star maps below are for the northern hemisphere; use whichever one is closest to the current month. How many constellations can you identify? With binoculars or a small telescope, you can see Jupiter and its four largest moons, other planets, the Andromeda galaxy, and nebulae. To know where to look, check the latest edition of one of these:

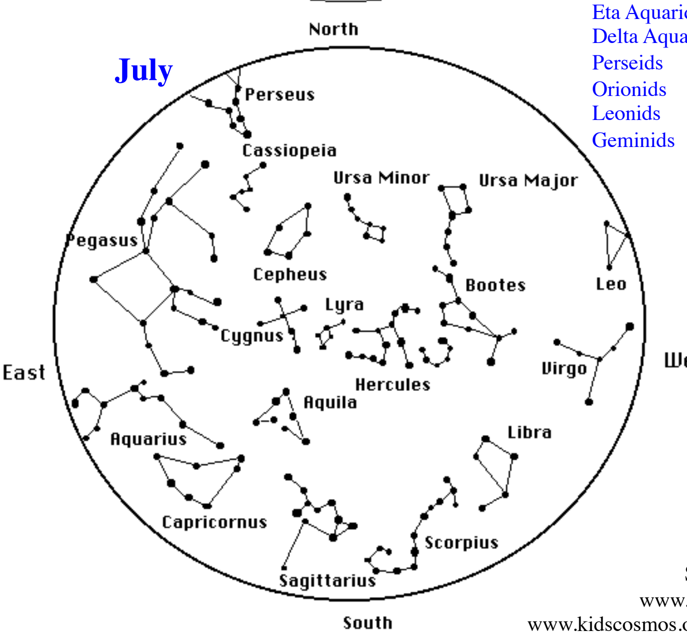
Terence Dickinson, *NightWatch* Philip S. Harrington, *Star Watch*
Guy Consolmagno & Dan M. Davis, *Turn Left at Orion*

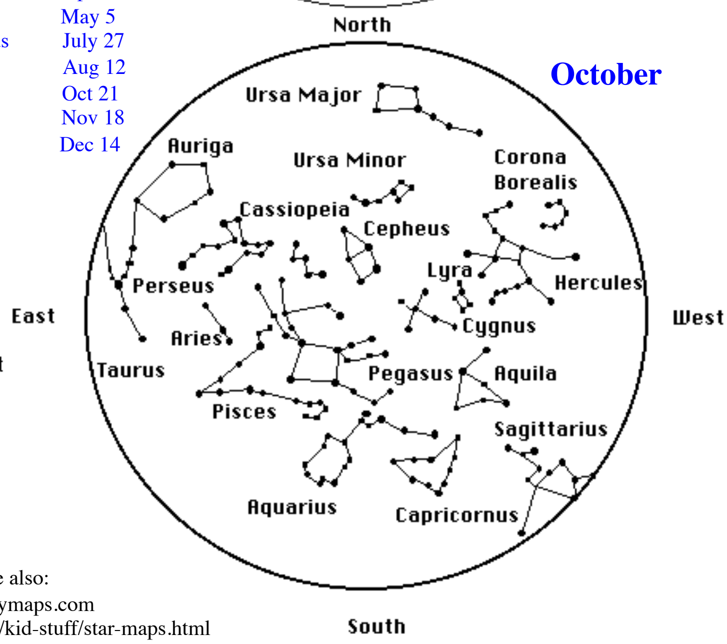
Also check www.skymaps.com to print a detailed map each month.





Meteor shower	Approx. date
Quadrantids/Bootes	Jan 4
Lyrids	April 22
Eta Aquarids	May 5
Delta Aquarids	July 27
Perseids	Aug 12
Orionids	Oct 21
Leonids	Nov 18
Geminids	Dec 14

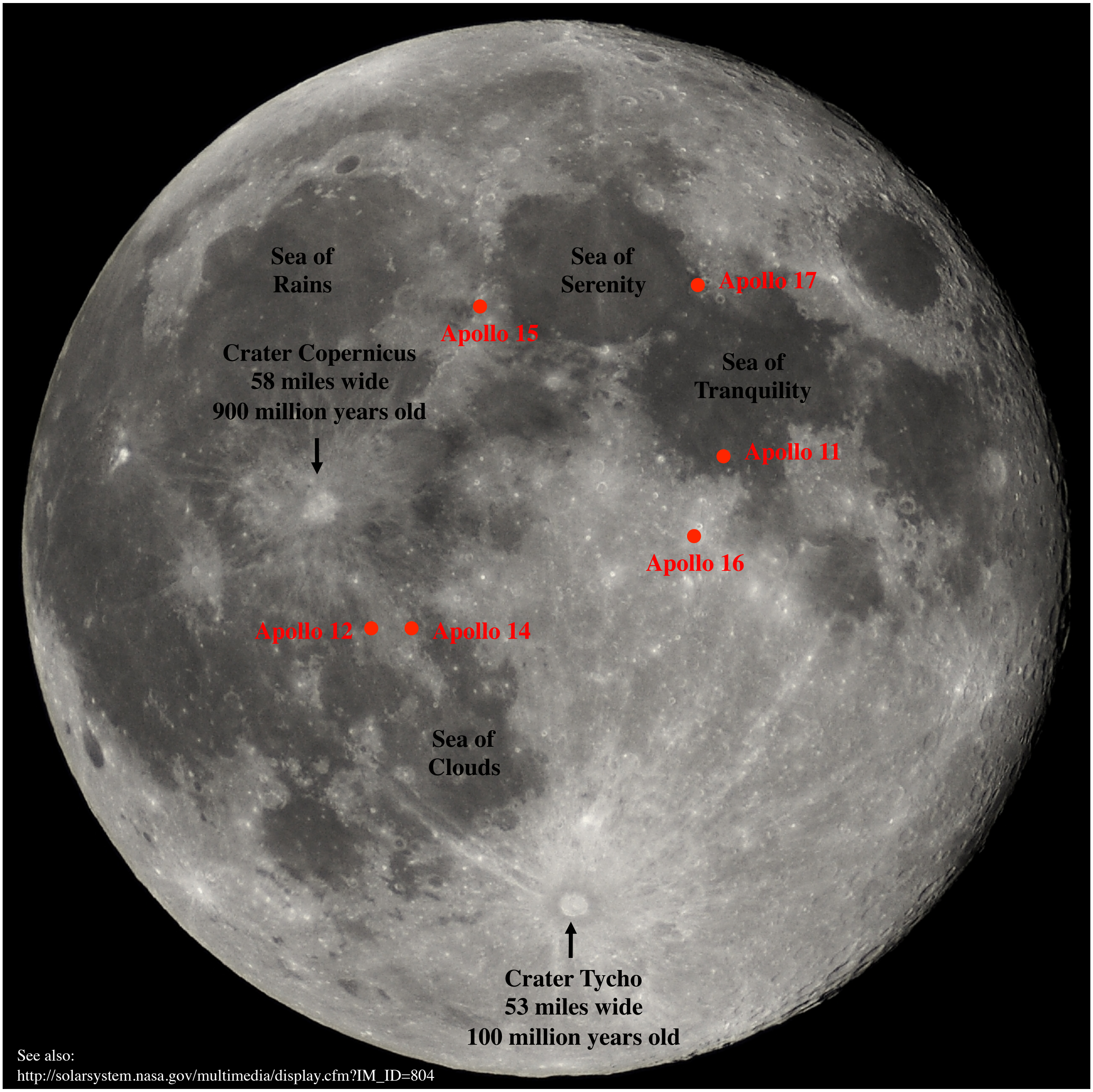




See also:
www.skymaps.com
www.kidscosmos.org/kid-stuff/star-maps.html

Explore further: Latest editions of: Terence Dickinson, *NightWatch* and *Backyard Astronomer's Guide*; Consolmagno & Davis, *Turn Left at Orion*; H.A. Rey, *The Stars* and *Find the Constellations*; telescopes at www.telescope.com & www.opticsplanet.com (avoid cheap telescopes in stores and catalogs—they are useless); www.hometrainingtools.com/space-astronomy/c/20/ & www.hometrainingtools.com/telescopes-accessories/c/128/

Astronomy (continued)--Moon Map



Basalt from dark-colored "seas" or maria

3.6-3.9 billion years old

(Apollo 11)

Anorthosite from light-colored highlands

4.4-4.5 billion years old

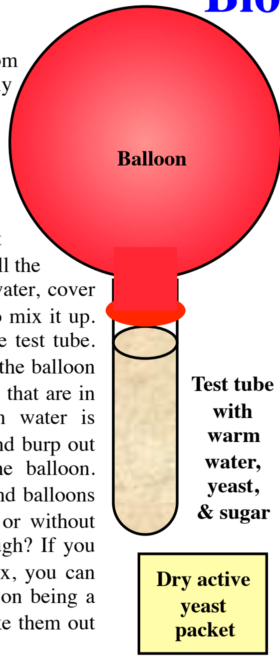
(Apollo 16)

Biology

Experiment 13: Yeasty beasties

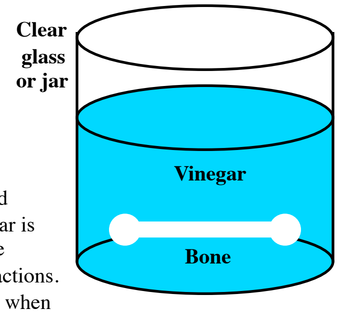
Kit provides: Balloons, test tubes

You provide: Bread yeast packets, sugar, water



Biologists study how living organisms work, from bacteria to plants to people, and get to genetically engineer the occasional monster when research funding permits. To try some biology, stretch the balloon so it can inflate easily. Pour a packet of bread yeast and one tablespoon of sugar into a clean test tube. (Optional: With adult assistance, a metal coat hanger can be bent into a rack to hold several test tubes upright.) Fill the tube with very warm (but not painfully hot) water, cover the top with your thumb, and shake the tube to mix it up. Stretch the deflated balloon over the top of the test tube. Over the course of several minutes or an hour, the balloon should inflate. Yeast cells are simple organisms that are in "suspended animation" in the packet. When water is added, they come back to life, eat the sugar, and burp out carbon dioxide (CO_2) gas, which inflates the balloon. Repeat the experiment using other test tubes and balloons with hotter or colder water, or without yeast or without sugar. Why are yeast cells added to bread dough? If you have a microscope that magnifies at least 100x, you can see the individual yeast cells. Congratulations on being a new pet owner, and you don't even have to take them out for a walk.

Experiment 14: *The Joy of Vinegar*



Kit provides: Test tubes, balloon, pipette (plastic eyedropper)

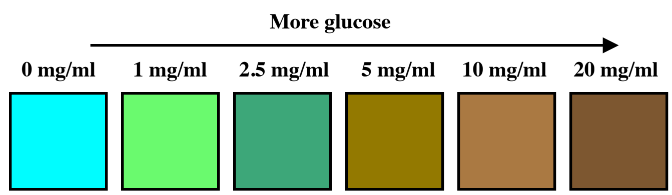
You provide: White vinegar, cooked chicken bone, hard-boiled egg in the shell, skim milk, clear glass or jar

Now let's cook up some things that would horrify Julia Child. Ordinary white vinegar is a mild acid (dilute acetic acid) that can be used for several different biochemical reactions. It also smells bad, which is always a plus when you are doing mad science experiments:

(A) Fill a clean test tube nearly full with skim milk. Use the pipette to add several drops of vinegar to the tube. After several minutes to an hour, solid chunks should form in the milk. Casein is a polymer (long chemical molecule) and a protein (like meat) that is normally dissolved in milk, but the vinegar makes it precipitate or clump together to form solid chunks. Casein used to be widely used to make paints and glue.

(B) Take a cooked chicken bone, such as a wishbone, and clean it thoroughly. Notice that it is stiff and difficult to bend. Put the bone in a clear glass and add enough vinegar to cover the bone. Each day pour out the old vinegar and cover the bone with fresh vinegar. After a few days, the bone should be very rubbery and flexible. Bones are made of rubbery protein plus chalk-like calcium. The vinegar removed all the calcium from the bone, leaving only protein.

(C) Repeat the bone experiment, but use a hard-boiled egg instead of the chicken bone. The shell of an egg is also made of protein and calcium, and the vinegar will remove the calcium. See if you can squeeze the egg into a bottle without cracking the egg!



Experiment 15: Enzymes

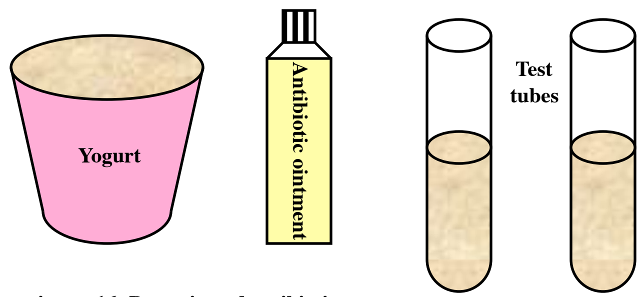
Kit provides: 6 glucose test strips (narrow white plastic with light blue glucose test pad on one end), plastic test tubes, straw

You provide: Regular milk (or Parmalat/Lil' Milk for Expt. 16), Lactaid milk, lactase tablets (e.g., Lactaid), scissors, pliers, cups, foil

Enzymes are little molecular machines that do certain jobs inside you. Your body can easily use simple sugars like glucose as energy sources. However, milk mainly contains lactose, two simple sugars (glucose and galactose) glued together. Therefore, your body (especially when you are young) makes the enzyme lactase, which breaks lactose into its two parts. If people don't have enough lactase, milk can upset their stomachs, but modern medicine has rushed to the rescue. Lactase tablets provide the enzyme for you, and Lactaid milk comes with all the lactose already broken down.

To watch enzymes in action, cut each glucose test strip lengthwise into two pieces. Now you can do up to 12 tests. Fill two test tubes 2/3 full with regular milk. Get an adult to crush a Lactaid tablet in pliers. Dump the pieces into one tube and mix carefully with a straw. Label which tube is which and cover both with foil. Keeping the tubes upright, hold their lower two-thirds in a cup of warm water for 5 minutes. Dip a half glucose test strip into one tube for a few seconds, then gently brush it against the inside rim of the tube to wipe off milk. Let the strip dry for 30 seconds, then compare the color with those above. How much glucose is in the milk? Test the other tube with a fresh half test strip. What happened? Be warned that most lactase tablets contain a small amount of glucose themselves. To be sure that isn't confusing your results, wash out the test tubes and repeat the experiment with a tube of water and a tube of water plus crushed lactase tablet. Also repeat the experiment with Lactaid milk.

If you are in the mood to be gross, experiment with your own saliva! (Use only your own drool, and dispose of it properly when finished.) Saliva contains amylase, an enzyme that breaks down starch into glucose. Crumble a cracker in water in a cup. Chew another cracker for 30 seconds, then spit it into a second cup. Test both cups for glucose. Incidentally, even the test strips use enzymes, glucose oxidase and peroxidase. Enzymes run the world!



Experiment 16: Bacteria and antibiotics

Kit provides: Plastic test tubes (must be clean), straws

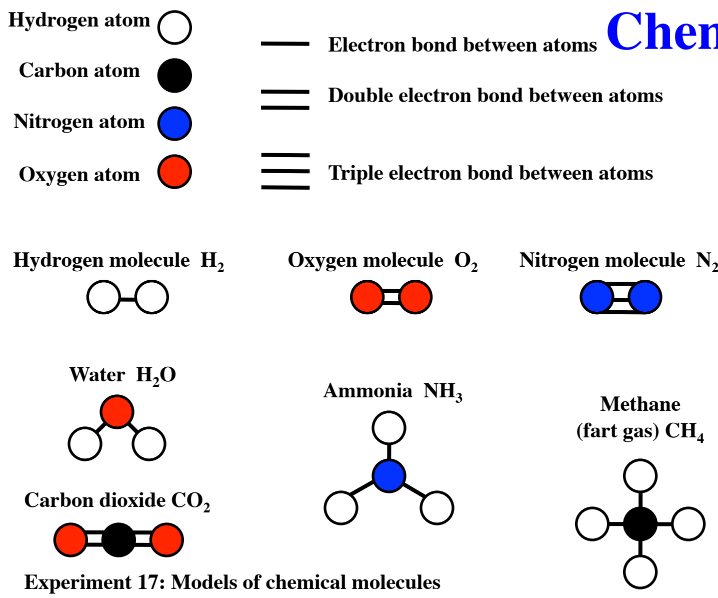
You provide: Yogurt, Parmalat or Lil' Milk, triple antibiotic ointment, foil

Certain safe bacteria cause milk to solidify to become yogurt. Buy a small rectangular box of Parmalat or Lil' Milk at the grocery store. Unlike normal milk, Parmalat/Lil' Milk is ultra-high-temperature pasteurized to kill all bacteria in it, so it does not need refrigeration until it is opened. Insert its little plastic straw, use the milk box as a squeeze bottle, and fill two test tubes halfway with milk. Using a straw or long toothpick, add a healthy booger-sized blob of yogurt to each tube. Using a fresh straw or toothpick, add a similar blob of triple antibiotic ointment (e.g., Neosporin or similar generic version) to one tube, and label which tube is which. Cover the top of each tube with aluminum foil. Tape the tubes to the side of a box so they stay upright, and leave them in the warmest room in your house. After 2-3 days at 75°F (or overnight at 99°F), carefully tilt the tubes to the side. Why is there a difference? **To be safe, don't eat the yogurt you have made.** In fact, knowing what you do now, you may decide never to eat yogurt again…

Optional: Make an inexpensive water bath incubator. Fill an ice chest with water, insert an aquarium heater and a thermometer in the water, and adjust until the water temperature holds constant at 99°F. Seal test tubes of milk + yogurt with plastic wrap and partially immerse them in the water overnight.

Explore further: Janice VanCleave, *Biology for Every Kid*, *Human Body for Every Kid*, *A+ Projects in Biology*; Sea Monkeys (Walmart); Luann Columbo, *Uncover the Human Body*; Human Body Inside Out Smart Lab; Joanna Cole, *The Magic School Bus Inside the Human Body*; www.ncbe.reading.ac.uk/NCBE/MATERIALS/DNA/menu.html; www.hometrainingtools.com/microscope-comparison-chart/a/1348/ (buy any of these, but avoid scopes in catalogs & stores—virtually all give badly distorted images); www.hometrainingtools.com/microscope-accessories/c/19/; www.hometrainingtools.com/microscope-slide-sets/c/151/; www.hometrainingtools.com/dissection-kit-advanced/p/DE-KIT02/

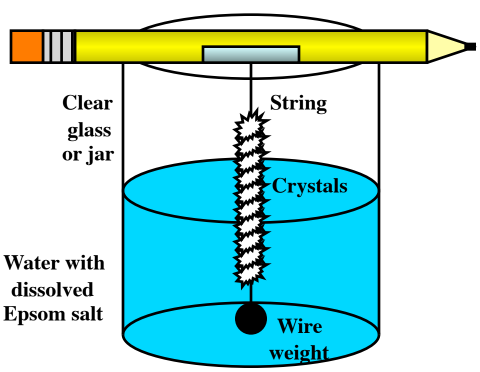
Chemistry



Experiment 17: Models of chemical molecules

Kit provides: Chemical model sheet (page 32)
You provide: Scissors, glue stick and cardboard (optional)

Pure chemical elements like hydrogen, carbon, and oxygen are made of tiny pieces called atoms. Chemical compounds like water, sugar, and sand are made of molecules, or combinations of different atoms joined together. Chemists deal with elements, compounds of elements, and chemical reactions that change one compound into another. To make models of chemical molecules, cut out the model atoms on p. 32. Real atoms are too small to have colors, but our model atoms are white for hydrogen (H), black for carbon (C), red for oxygen (O), and blue for nitrogen (N). Electrons (shown as black lines) can form bonds between atoms to create molecules. Different types of atoms like to have different numbers of bonds: one bond for hydrogen, two for oxygen, three for nitrogen, four for carbon, etc. Most bonds are single bonds (one electron line between atoms), but some are double bonds (two electron lines) or even triple bonds (three lines). See how many different molecules you can create.



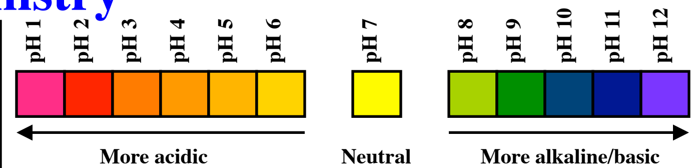
Experiment 19: Growing crystals

Kit provides: Plastic spoon, wire
You provide: Epsom salt, clear glass or jar, cotton string, water

Cut a ~2-inch piece of wire and ball it up to make a weight. Tie one end of cotton string or yarn to the wire weight. Cut the string so it is as tall as a clear glass or jar. Tape the other end of the string to a pencil.

Fill the glass halfway with very warm water. Slowly add Epsom salt while constantly stirring; keep adding it until no more salt will dissolve. Let the string hang down in the water and leave the glass for a week.

After a week, take the string out of the water. You should see Epsom salt crystals along the string. Use a Leeuwenhoek microscope (Expt. 52) to examine the crystals more closely. Repeat the experiment with table salt, sugar, or borax and then examine those crystals. Now it can look like Christmas year-round, no matter how much global warming may occur.



Experiment 18: Acids and bases

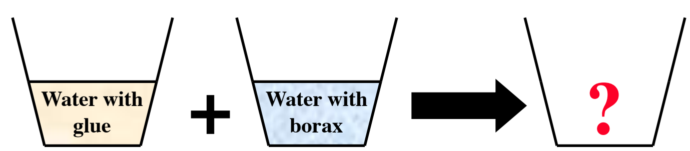
Kit provides: 4 strips pH paper (narrow pinkish-orange paper strips), test tubes, balloon, mini plastic beakers
You provide: Safe household acids and bases (lemon juice, vinegar, Tums, baking soda, Windex, etc.), scissors, tweezers

Acids are chemicals that have too many protons (hydrogens) and want to get rid of some of them. Bases, sometimes called alkali, have too few protons and want to steal some from other chemicals. Neutral chemicals are happy with their number of protons. pH is a number that measures how acidic or alkaline a chemical is. Neutral chemicals have pH 7, acids have pH values lower than 7, and bases have pH values higher than 7. pH paper starts off pinkish-orange, but changes color when dipped into a liquid chemical. The color scale above indicates approximately what color corresponds to each pH value.

To measure as many samples as possible, cut a strip of pH paper into several smaller pieces. Pour a little water into a mini plastic beaker. Grab a small piece of pH paper with tweezers, dip it into the water for a few seconds, and then pull it out. What is the pH of water? Get an adult to help you pour some safe household acids and bases into other mini beakers--try lemon juice, orange juice, vinegar, baking soda dissolved in water, Tums/Rolaids/etc. dissolved in water, and Windex. Test each one with a new small piece of pH paper. Wipe off the tweezers after each sample. Which ones are acids and which are bases? What is the strongest acid? What is the strongest base?

Fill a test tube almost full with vinegar or lemon juice. Break a Tums/Rolaids tablet in half and drop it in. Quickly seal the top of the test tube with a balloon. Notice the bubbles forming in the liquid. Within 10-20 minutes, the balloon should inflate with carbon dioxide (CO_2) gas. Once the fizzing stops, test the pH of the liquid. What happened? Now you know how to spell relief. For extra messy fun, combine some bubble solution from Expt. 36 with a Tums + vinegar or baking soda + vinegar reaction.

To make your own pH indicator, cut a small, relatively dry piece of red cabbage. Soak it in Windex for a few minutes. What happens to the color? If you want to be fancier, get an adult to help chop red cabbage, boil it in water, and collect the colored water once it is cool. What happens if you mix the colored water with safe acids and bases such as those you tested above?



Experiment 20: Polymers

Kit provides: Plastic spoon or other stirring utensil
You provide: Elmer's glue, box of borax powder (check laundry detergent aisle), water, measuring cups and spoons, disposable cups, food coloring

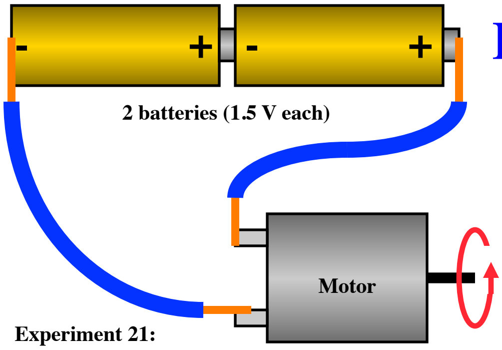
In one cup, mix ¼ cup water, 2 drops food coloring, and ¼ cup Elmer's glue. Stir with a plastic spoon or other utensil. Wash off the spoon with water and dry it. In a second cup, mix 1/4 cup of water and 1 tablespoon of borax. Stir with the **clean** spoon. Wash off the spoon with water and dry it. Pour equal amounts of both mixtures into one large **disposable** plastic or paper cup. Stir with the plastic spoon for a minute. What does the mixture turn into? Can you fish it out of the cup? Can you gross out your favorite relative? Can you make a ball?

Glue contains polymers, which are very long yarn-like molecules that can slide past each other (see also Expt. 14A). Borax crosslinks the polymers, tying them to each other so that they can no longer move as easily, like a very tangled ball of yarn. Plastics and rubber are good examples of crosslinked polymers.

For more more slimy fun, get an adult to help you mix ¼ cup rubbing alcohol + ¼ cup dishwasher detergent containing sodium silicate (Costco Kirkland dishwasher detergent works well) and squeeze out the excess liquid, or see: www.hometrainingtools.com/slime-recipes-project/a/1660/

Explore further: Thames & Kosmos chemistry sets, especially C3000 (all other modern chemistry sets are useless; search for best price online); www.hometrainingtools.com/chemistry/c/3/; Magic Rocks (Toys R Us and other toy stores); Janice VanCleave, *Chemistry for Every Kid* (1989) and *A+ Projects in Chemistry* (1993); Robert Bruce Thompson, *Illustrated Guide to Home Chemistry Experiments* (2008)

Electrical Engineering

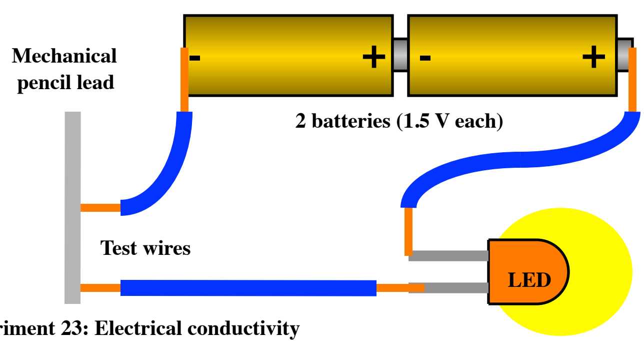


Experiment 21:
Electric motor
Kit provides: Motor, wires   You provide: 2 AA batteries, tape, scissors

Electrical engineers play with electric circuits, such as those here that use batteries, wire, motors, light bulbs, etc. Get an adult to cut three 6-12” pieces off the long wire included in the kit. The adult can strip 1/2” of insulation off each end of each wire. If a wire cutter/stripper is not available, scissors or even a nail clipper works well. To remove the insulation without cutting through the wire, don’t bring the blades all the way together; then use your fingernails to pull off the cut insulation. If necessary, you can even use strips of aluminum foil as wires.

Get two AA batteries. The end with the metal bump is positive (+), and the other end is negative (-). Put the batteries together, + end to - end as shown above, and tape them together. Tape two wires to the free ends of the batteries and touch them to both terminals on the motor. The motor should whir and its shaft should turn. To more easily see that the shaft is turning, you can put a broad piece of tape across the shaft. When the motor turns, it will spin the tape. What happens if you reverse which motor terminals the wires connect to? What happens if you only use one battery? Tune an AM radio to the static between stations. Bring the motor close to the radio. Connect and disconnect the motor. What happens and why? Wanna operate a pirate radio station?

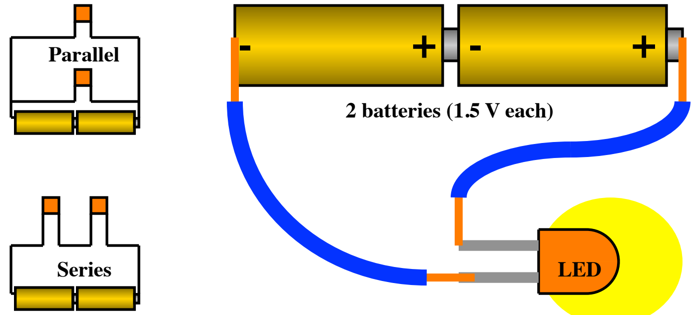
With the motor disconnected from wires, bring the motor close to steel paperclips. What must be inside the motor? To make your own motor, see: www.hometrainingtools.com/build-motor-project/a/1605/



Experiment 23: Electrical conductivity
Kit provides: LEDs or motor, wires, mini beaker (plastic cup)
You provide: 2 AA batteries, tape, scissors, mechanical pencil lead, salt

Use two AA batteries to power an LED or electric motor as in Expts 21 and 22, but force the electricity to go through two test wires to get from the negative (-) battery terminal to the LED or motor. If the test wires are connected directly to each other, electricity is conducted through the wires to the LED or motor. If the test wires do not touch each other, there is no electrical conductivity—electricity cannot get to the LED or motor. Touch the test wires to different metals, plastic, glass, paper, etc. to test the electrical conductivity (how well electricity can flow through) of those substances. Electrical conductors have good conductivity, and electrical insulators do not conduct electricity.

Now test the conductivity of mechanical pencil lead (graphite) by putting the test wires close together or far apart on the pencil lead. Graphite conducts electricity, but not well, so the further the electricity has to travel through the graphite, the dimmer the light gets or the slower the motor runs. Light dimmers and volume knobs work this same way. Put the test wires in a mini beaker filled with water. Is water a conductor? What happens if you add salt to the water? How conductive is dry human skin? How about the skin of someone who is sweating? Now you might have to subject your parents to a lie detector test…

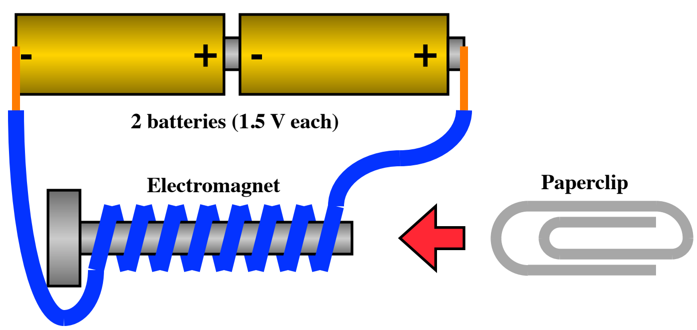


Experiment 22: Light emitting diodes (LEDs)
Kit provides: 2 LEDs (small clear plastic parts with 2 wires each), wires
You provide: 2 AA batteries, tape, scissors, paperclips, rubber bands

LEDs may get hot--please use caution. Tape two AA batteries together, then tape wires to each end as shown. Touch the wires to the two leads of an LED. If the LED doesn’t light up, reverse which LED leads the battery wires connect to. Yes, we know the LED is orange. Nobody loves orange, so we got these for a song. Note that one LED lead is shorter than the other. Which is positive and which is negative? What happens if you only use one battery?

Tape the two batteries together again. Connect two LEDs in parallel--one battery wire goes to the short lead of both LEDs, and the other battery wire goes to the long lead of both LEDs. Now connect the LEDs in series--the short lead of one LED contacts the long lead of the other LED, the free lead on one LED goes to the + battery wire, and the free lead on the other LED goes to the - battery wire. Are the LEDs brighter in series or in parallel?

For an improved battery holder, use a rubber band to hold a metal paperclip on each end of a battery, then attach your wires directly to the paperclips.



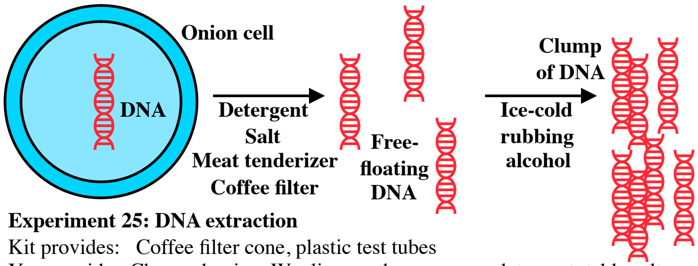
Experiment 24: Electromagnet
Kit provides: Wire, steel bolt, steel washers
You provide: Steel paperclips, 2 AA batteries, tape, scissors

Bring the steel bolt close to steel paperclips. Is the bolt magnetic? Now strip ~1/2” of insulation off the ends of the remaining long wire. Make an electromagnet by wrapping the wire around the bolt as many times as possible (keep wrapping in the same direction around the bolt), only leaving fairly short ends that can be connected to the batteries as shown above. Use tape to connect the wire to the batteries and the batteries to each other. Is the bolt magnetic enough to pick up several paperclips at once? How many? Notice that the batteries get warm from this short circuit, so don’t keep the electromagnet on for very long. Disconnect one wire from the batteries before your parents complain that you are eating batteries. Now how many paperclips can the bolt pick up?

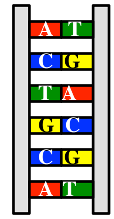
Electromagnets and permanent magnets (Expt. 58) can attract some metals (not all) by temporarily aligning the atoms in the metal to make the metal magnetic. In addition to paperclips, try to pick up the steel washers in this kit, as well as aluminum foil, various U.S. and foreign coins, or other metals you may have.

Use a compass (Expt. 31) to study the magnetic field of the electromagnet when it is on, off, and with or without the steel bolt inserted in the coil.

Explore further: Alligator clip leads and battery holders (Radio Shack, www.sciplus.com, or www.hometrainingtools.com) make Expts. 21-24 easier; Rudolf Graf, *Safe and Simple Electrical Experiments* (1973); Hexbug robots (amazon.com and Target); Lego Mindstorms (Toys R Us and online); Snap Circuits kits and 130 in 1 Electronic kit (search online for best prices); www.hometrainingtools.com/technology/c/9/



Forensic Science



Experiment 25: DNA extraction
Kit provides: Coffee filter cone, plastic test tubes
You provide: Chopped onion, Woolite or other common detergent, table salt, meat tenderizer, drug store 91% isopropyl alcohol, measuring cups & spoons

Forensic scientists use fingerprints, DNA, and other evidence to solve crimes. You can use household materials to remove the DNA from cells and gather enough to see with your own eyes. A hot detergent solution dissolves cell membranes as it would kitchen grease. Ions from table salt neutralize charged DNA molecules so they don't repel each other. Meat tenderizer chews up enzymes that might break down the DNA. A coffee filter lets DNA and other molecules pass through but blocks all large debris. And alcohol is nonpolar, forcing the polar DNA and salt to form large clumps for self defense.

Before beginning, put an unopened bottle of 91% isopropyl alcohol in a sealed Ziploc bag in the freezer for a few hours. Make an adult cry--get one to chop an onion into pieces and put it in a medium-sized Tupperware-style container. In a cup or bowl, put 3 oz water and add 2 teaspoons of detergent, 1/2 teaspoon of salt, and 1/2 teaspoon of meat tenderizer. Mix these together slowly with a spoon, then pour the mixture into the container with the chopped onion and reseal the container. Get an adult to put the container in a sink full of very hot water for 10-15 minutes, run cold water over it for a few minutes to cool it, and then give it back to you. Open the coffee filter into a cone shape and hold it point downward over a clean measuring cup. Slowly pour some of the onion mixture into the coffee filter, being careful not to let any onion mixture fall directly into the measuring cup. Only filtered onion mixture should go into the cup.

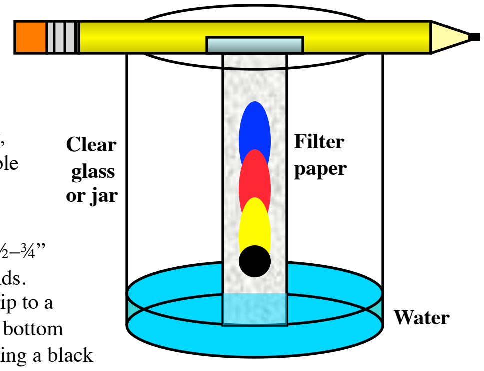
Fill one test tube 1/3 full with filtered onion mixture. Get an adult to fill another test tube 1/3 full with cold alcohol. Now pour the contents of the onion tube into the alcohol tube. The alcohol is less dense and should stay in the upper half. Within the clear alcohol, you will see DNA clump together, going from looking like a milky cloud to spider web threads to a little DNA booger within minutes. Now frizz your hair and shout, "Give my creation life!"

Experiment 28: Fingerprints Kit provides: This sheet
You provide: Pencil, blank paper, clear tape, cocoa or talcum powder, cosmetic brush, your parents' permission for you to make a big dusty mess
Everyone's fingerprints are unique, but can generally be classified as arches, loops, or whorls. Go over and over the same square inch of paper with a pencil until the square is covered with graphite. Roll someone's finger in it, stick clear tape on the finger, then put the tape on clean paper. Get prints from all 10 fingers, label the sheet with the person's name, then move on to your next suspect. Touching a hard smooth surface leaves invisible skin oils in the form of fingerprints. To see the fingerprints, use a cosmetic brush to ***very softly*** dust light surfaces with cocoa powder or dark surfaces with talcum powder. Then "lift" fingerprints with tape, stick the tape to light or dark paper, and compare with your fingerprint files until you find the right suspect.

Experiment 26: DNA replication
Kit provides: DNA models (pp. 32-34)
You provide: scissors, cardboard & gluestick (optional)

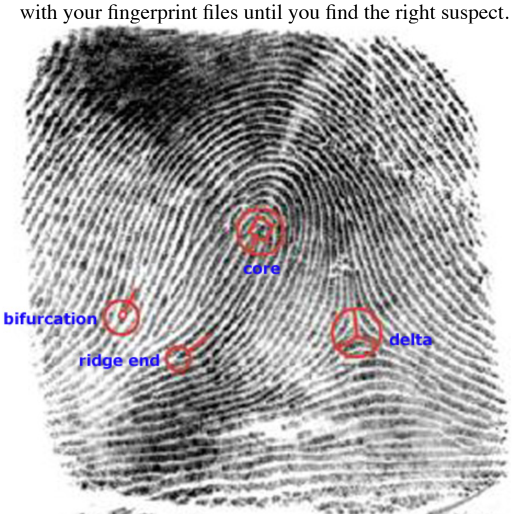
Just as you can string together various combinations of letters to write an instruction book, a strand of DNA uses four chemical letters or nucleotides, designated A, C, G, and T, strung together in various combinations to spell out the instructions for making all the parts for viruses, bacteria, plants, and animals. DNA normally has two strands, with each A on one strand connected to a T on the other strand, and each C on one strand connected to a G on the other strand. Critters replicate or copy their DNA by separating the two strands and joining individual nucleotides to each to make new strands. Once scientists extract DNA from a crime scene (or dinosaur DNA from amber…), they have to artificially replicate the DNA to make enough to use or analyze. This process is called polymerase chain reaction (PCR), in which one DNA double strand becomes two, which then become four, then eight, etc. You can simulate PCR by cutting out the DNA strands and nucleotides on pp. 32-34. Put the two strands together on a flat table, then pull them apart and add nucleotides to make two identical double-stranded DNA sections.

Experiment 27: Chromatography
Kit provides:
Coffee filter
You provide:
Scissors, clear glass or jar, tape, pencil, black washable marker (**Vis-à-Vis wet erase pen works well**)



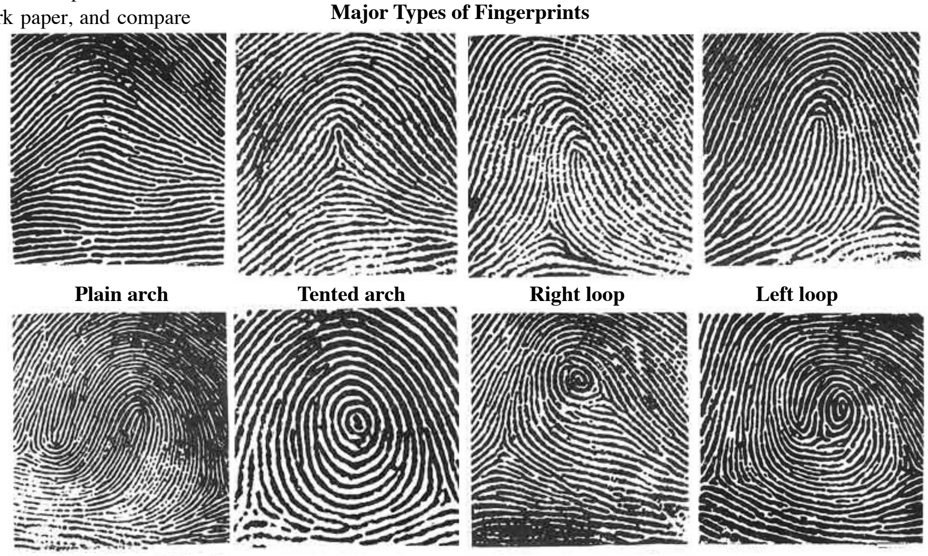
Cut one coffee filter into ½–¾" wide strips with square ends. Tape one end of a long strip to a pencil. About 1" from the bottom of the strip, make a dot using a black washable marker. Suspend the paper strip in a clear glass or jar as shown. Add just enough water to the glass that the bottom ~1/2" of the strip will be in the water. The water level must be below the black dot. Watch the paper for 10-20 minutes, then take it out of the jar. Repeat the experiment with a new strip of paper and other types of ink.

As water spreads up the paper, it carries the ink with it. Many inks are composed of several different colored chemical molecules, some of which move more slowly through the paper than others. Chromatography, separating chemical molecules of different sizes by forcing them through paper or other materials, is a widely used lab technique for purifying or analyzing various chemicals. Granted that it seems more exciting with CSI music playing… See also: www.hometrainingtools.com/leaf-chromatography-science-project/a/1548



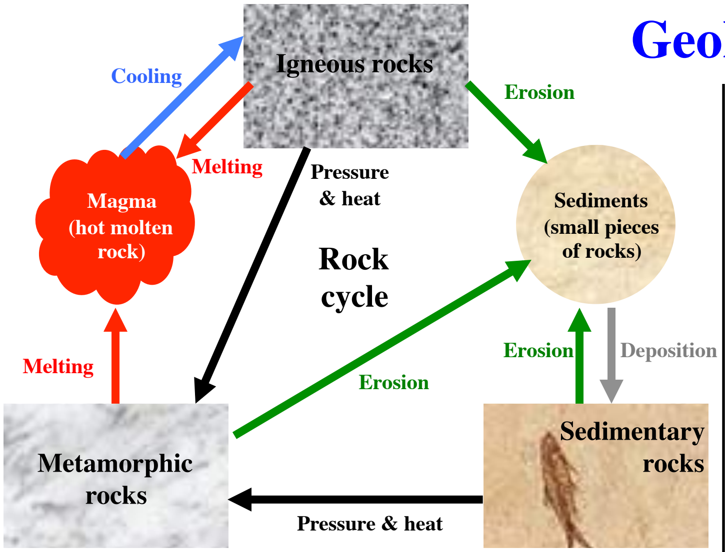
Small Features of Fingerprints

Major Types of Fingerprints



Explore further: www.hometrainingtools.com/search.asp?ss=forensic&x=0&y=0, forensic kits at www.amazon.com and Toys R Us

Geology

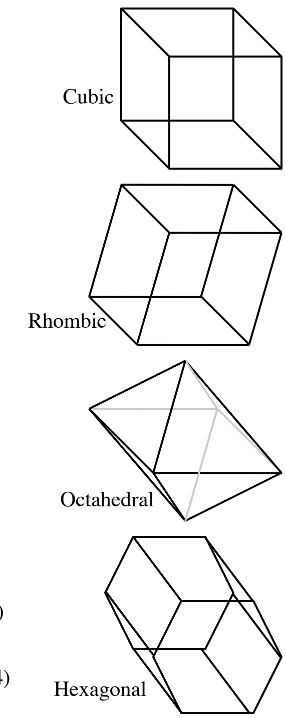


Mohs' scale of hardness.
A softer mineral can be scratched by a harder one:

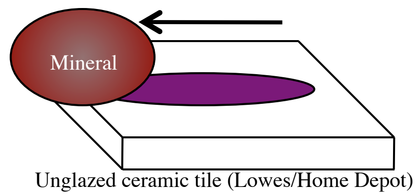
Increasing hardness of mineral

1: Talc
2: Gypsum ← 2.5: Fingernail
3: Calcite ← 3.5: Coins
4: Fluorite
5: Apatite ← 5.5: Steel nail clipper
6: Feldspar
7: Quartz
8: Topaz, beryl
9: Corundum/ruby/sapphire
10: Diamond

Some crystal shapes:



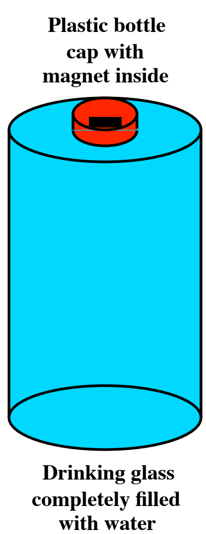
Streak test. Streak color may be different than surface of mineral and is a better identifier.



Experiment 29: "Life is like a box of rocks…"
Kit provides: Rock identification sheet (p. 13)
You provide: Rocks!
Geology concerns what the earth is made of, which means rocks and minerals. Minerals are fairly pure chemical substances, like sulfur, gold, quartz (silicon dioxide), etc. (see Expt. 30). Rocks are mixtures of minerals (just as you mix pure ingredients together to bake a cake or cookies). For example, granite rock is made of three minerals mixed together: quartz, mica, and feldspar. Rocks can be divided into three categories: (A) Igneous rocks solidified from hot liquid materials (like volcanic lava) and may have flow marks, gas bubbles, or crystals (if they cooled slowly). (B) Sedimentary rocks were deposited as sediments at the bottom of rivers, lakes, or oceans and then hardened. They may crumble easily, have flat deposited layers, or contain visible chunks or fossils. (C) Metamorphic rocks began as igneous or sedimentary rocks but then were changed by extreme pressure and heat (but not melting) deep underground. They are stronger and denser (heavier) than sedimentary rocks and may have wavy layers from the pressure. Any of these three types of rock can be turned into either of the other types by the processes in the rock cycle shown above. Collect rocks from where you live or vacation, and use the rock sheet (p. 13) or the books below to identify them.

Experiment 30: Collecting minerals
Kit provides: Mineral identification sheet (p. 14)
You provide: Minerals!
Minerals are the pure ingredients that are mixed together to make rocks. You may be lucky enough to find a crop of pure minerals where you live or vacation. If you can only find rocks, you can order minerals from the suppliers listed below. Or go find some table salt—you have your first mineral! Some minerals can be identified simply based on how they look (see mineral sheet on p. 14). Others may require you to conduct tests such as those shown above in order to identify them. See the books below for more detailed information.

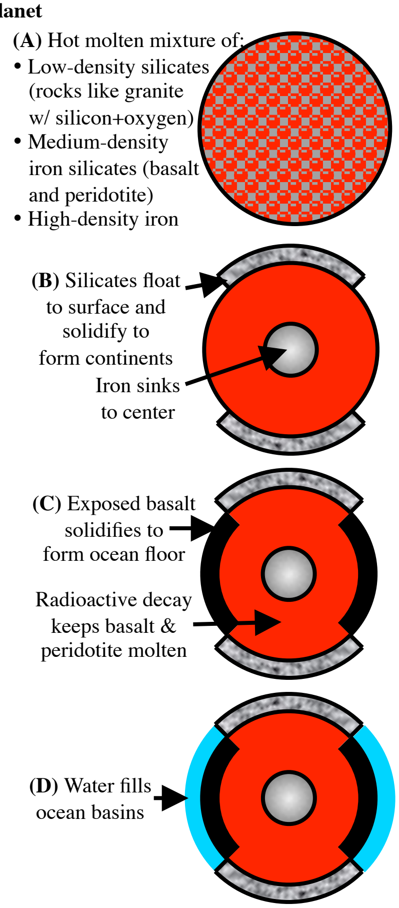
Experiment 31: Making a magnetic compass
Kit provides: Magnets
You provide: Plastic bottle cap, glass of water, tape
Fill a drinking glass full to overflowing with water and gently float an inverted plastic bottle cap in the water like a boat. Due to surface tension effects in the water, if the glass is not completely full, the cap will get stuck on the side of the glass, but if the glass is completely full, the cap will float somewhere in the center, which is what this experiment requires. Gently put one of the magnets in the center of the cap. The cap should be free to turn in any direction it would like. Bring one end of the other magnet near the glass, and see if the magnet and cap rotate to point toward the magnet. Flip the magnet you are holding to the other end, and see if the floating magnet rotates so that its other end faces your magnet. Now put the second magnet very far away from the glass. The floating magnet should settle down with one end pointing north and the other end south. Consult a map to figure out which is which, then use a small piece of tape to mark which end of your compass points north.



Due to a lot of iron at the center or core of the earth (Expt. 32), the earth acts like a giant magnet with poles at the north and south. Compasses such as the one you have made detect the earth's magnetic field and indicate directions. Now that you have a good compass, you are ready to set off into the wilds to hunt and gather good fast food.

Experiment 32: Build your own planet
Kit provides: Test tubes, pipette
You provide: Vegetable oil, food coloring, honey or corn syrup
About 4.5 billion years ago, particles surrounding the newly formed sun condensed to form the earth and the other planets. Initially the earth was a hot molten mixture of rocks of different densities or heaviness. Iron had the highest density and sank to the center of the earth. Low-density silicates (rocks like granite containing silicon and oxygen) floated on top and solidified to form the continents. Medium-density iron silicates (basalt and peridotite) were in between.

To show how the layers of the earth separated, mix water and food coloring in one test tube. Fill another test tube ¼ full with honey or corn syrup. Gently add ¼ test tube of colored water on top of that. Then gently add ¼ test tube of vegetable oil on top of the water. Honey/corn syrup has the highest density, water has medium density, and oil has the lowest density, so they don't mix. The density of a material relative to the density of water is called the specific gravity (SG) and is given for various minerals on p. 14.



Explore further: www.geoed.com; www.djminerals.com; www.hometrainingtools.com/catalog/earth-space-science/cat_rocks-minerals.html; Shaffer & Zim, *Rocks, Gems and Minerals* & Frank Rhodes, *Geology* (Golden Guides); Chris Pellant, *Smithsonian Handbooks: Rocks and Minerals*; Prinz, Harlow, & Peters, *Simon & Schuster's Guide to Rocks and Minerals*; Janice VanCleave, *Earth Science* books; Cole, *Magic School Bus Inside the Earth*

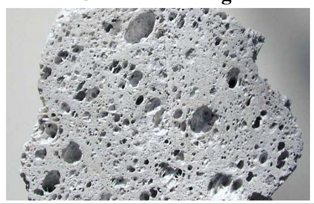
Dr. Rider's Guide to Pet Rocks

Igneous rocks

Solidified from hot liquid materials.
May have flow marks, gas bubbles, or crystals (if cooled slowly).

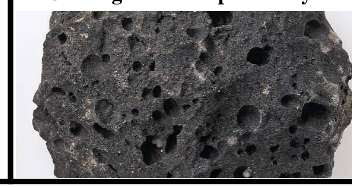
Granite
Particles of black, white, pink, clear
Hard, foundation of continents
Used for counters, monuments
Called rhyolite if uniformly mixed

Pumice
Gray, floats in water (trapped air)
Hardened volcanic foam
Used for sanding

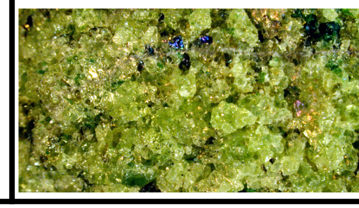


Obsidian
Shiny black and sharp (careful!)
Volcanic glass
Used for arrowheads

Basalt
Black, dense, may have bubbles
Volcanic lava that cooled
Forms the sea floor
Called gabbro if separate crystals



Peridotite
Greenish, dense
Forms mantle of earth
Source of peridot (olivine) gems

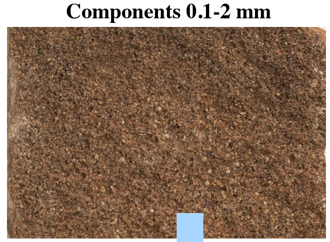


Sedimentary rocks

Deposited as sediments and hardened. May crumble easily,
contain visible chunks or fossils, or have flat deposited layers.

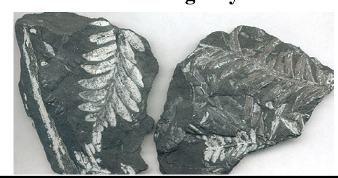
Conglomerate
Round pebbles glued together
Looks like concrete
Components >2 mm
Called breccia if pebbles are sharp

Sandstone
Grains of sand glued together
Components 0.1-2 mm



Shale
Mud that hardens to rock
Components <0.1 mm
May contain fossils
More organic matter → darker

Coal
Black, burns—used for fuel
Compressed decayed plants
Bituminous coal is dull & crumbly
Anthracite coal is glossy & harder

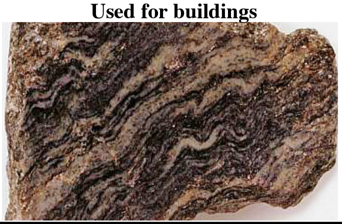


Limestone
Rough, fizzes in vinegar
Compressed little seashells
Used for chalk, buildings

Metamorphic rocks

Other rocks changed by pressure or heat (but not melting). Stronger
& denser than sedimentary rocks; may have wavy layers from pressure.

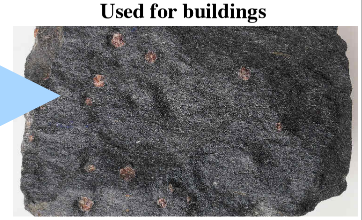
Gneiss ("Nice")
Layers of black,white, pink, clear
Formed from granite
Used for buildings



Quartzite
Dense glassy sand
Formed from sandstone
Used for buildings

Slate
Dense black/gray/green, fine layers
Formed from shale
Used for blackboards, tile

Schist
Grayish with glittery, wavy layers
Formed from slate + more pressure
Used for buildings



Marble
Dense, polished, fizzes in vinegar
Formed from limestone
Used for countertops, tile

Dr. Rider's Brief Bestiary of Minerals

Minerals that are common components of rocks:

Quartz
Clear/white hard hexagonal crystals
SiO_2, hardness 7, SG 2.65
In sand, granite
Color: amethyst/rose/smoky quartz
Microscopic xtals: flint/agate/onyx

Feldspar
White/pink shiny hard "rock"
$(Na,K,Ca)AlSi_3O_8$, hard: 6, SG ~2.6
Types: microcline, plagioclase, etc.
In granite

Mica
Flat, shiny, brittle, thin sheets
Silicates, hard: 2.5-4, SG ~2.8
Biotite if black, muscovite if silver
In granite, schist, etc.

Calcite
Causes double images if clear
May be white or colored; not cubic
$CaCO_3$, hardness 3, SG 2.71
In caves, limestone, marble

Augite
Black shiny crystals/layers
$(Ca,Mg,Fe)SiO_3$, hard: 5.5-6, SG ~3.4
In basalt
Hornblende is similar

Minerals that are major sources of metals:

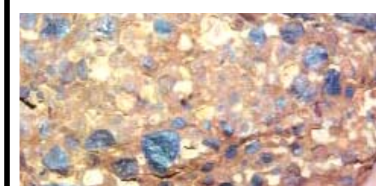
Magnetite
Black, heavy, magnetic
Fe_3O_4, hardness 5.5-6.5, SG 5.2
Source of iron for magnets, steel
Hematite (Fe_2O_3) is similar but
reddish (rusted) and not magnetic

Pyrite
Heavy golden cubes or clusters
"Fool's gold"—not really gold
FeS_2, hardness 6-6.5, SG 5.0
Source of iron and sulfur

Malachite
Greenish cluster of round pieces
$Cu_2CO_3(OH)_2$, hardness 3.5-4, SG 4.0
Source of copper for wires, pipes
Azurite is similar but bluish crystals

Bornite
Shiny red/blue/purple metal
"Peacock copper ore"
Cu_5FeS_4, hardness 3, SG 5.0
May have yellow/green chalcopyrite

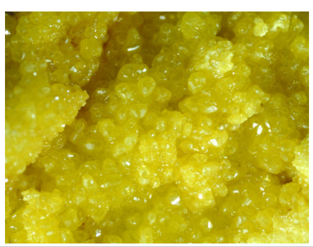
Bauxite
Gray/tan with round pieces inside
Breathe on it → smells like wet clay
$Al(OH)_3$, etc., hardness 1-3, SG ~2.5
Aluminum for foil, pots, etc.



Minerals that are major sources of non-metals:

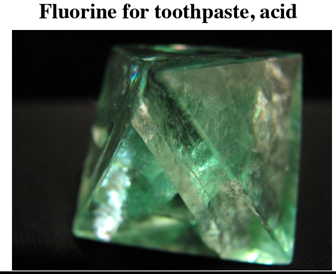
Graphite
Silvery black, soft, fine layers
2D carbon atoms, hard: 1-2, SG ~2.2
Used in pencils, circuits, lubricant
Diamond is 3D carbon atoms

Sulfur
Yellow, soft, smells bad
S, hardness 1.5-2.5, SG ~2
Used in rubber, explosives, acid



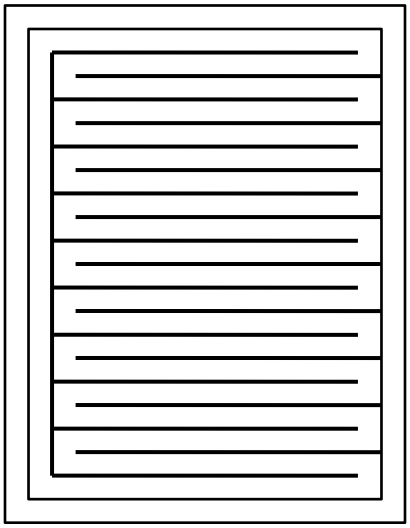
Halite
Clear or whitish cubic crystals
NaCl, hardness 2, SG ~2.15
Left when ancient oceans dried up
Used for table salt, road salt

Fluorite
8-sided crystals, various colors
CaF_2, hardness 4, SG 3.2
Fluorine for toothpaste, acid



Gypsum
White/brown fragile crystals/"roses"
$CaSO_4 \cdot 2H_2O$, hardness 2, SG 2.32
Used for plaster, wallboard

Mathematics

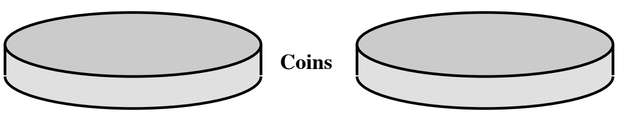


Pattern sheet (p. 27)
Cut along the lines but nowhere else

Experiment 33: Walk through a sheet of paper
Kit provides: Pattern sheet (p. 27)
You provide: Scissors

Mathematics is much more than adding, subtracting, multiplying, and dividing numbers. Those numbers are just ways to describe sizes, shapes, probabilities, and physical laws, and we will explore some examples in Experiments 33-36.

Can you step through a standard-sized (8.5x11 inch) sheet of paper? Use the pattern sheet on p. 27 and cut along all the lines but nowhere else. (You may find it easier to fold the paper in half before you begin to cut.) You should be able to spread out the paper to form two loops, one the same size as the original sheet and one large enough you can walk through. The solid paper still has the same surface area it always did, but you have increased its perimeter by cutting so many lines. Area and perimeter or linear length are very important in mathematics. In principle, you could use the same paper to make a loop with a perimeter of several miles if you made the cut lines close enough together. Now you can make your allowance look bigger!



Experiment 35: E pluribus nerdum
Kit provides: Instructions
You provide: Coins

An important field of math is probability, or calculating the chances that various outcomes may happen. You can do experiments with probability using coins.

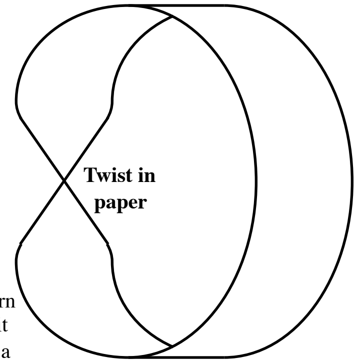
If a coin is evenly balanced and you flip it, on average it should come up heads half the time and tails half the time. Flip a coin 2 times and write down the result each time. Did it come up heads once and tails once? Flip it a couple more times to make 4 total flips, and write down the results. Was that two heads and two tails? How many heads and tails do you get if you do 8 flips total, or 16, or 32? Probability can only predict what the coin will do *on average*, not necessarily what it will actually do. However, the more flips you do, the closer the actual outcome should be to the expected average of heads half the time and tails half the time. If a coin has been coming up heads for several flips, does that mean the next flip is more likely to be tails to balance things out? (No, the coin doesn't remember what it has done, so each new flip could go either way.)

Now flip two coins, preferably of two different types so you can tell them apart. How often should both come up heads at the same time? Flip both 32 times, write down the results, and check. How often should both come up tails? Check that too. How often should one (either coin) come up tails and the other come up heads? Test that.

Test for other possible outcomes, try larger numbers or runs, or try three coins.

If you get bored with coins, try predicting and testing probability with dice. If you get good at this, see how much money you can win from your parents.

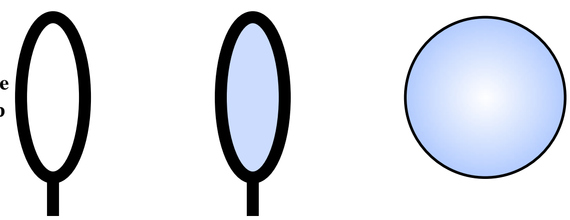
Experiment 34: Möbius strips
Kit provides: Instructions
You provide: Paper, scissors, tape, pencil



Cut a sheet of paper into long rectangular strips. Make a loop out of one strip, but twist one end by half a turn (flip it over) before you tape it to the other end. This creates a Möbius strip, named after the German mathematician August Möbius. You started with paper that had two sides, a front and a back. Use a pencil to draw a line around the Möbius strip until you come back to where you started. You just demonstrated that the Möbius strip only has one side! Try making more strips with no turns before you tape them together, one full turn, one and a half turns, two turns, two and a half turns, etc., and draw lines around each one. What determines how many sides each one has? Now draw a line down the end of each strip until you return to where you started. How many edges does each strip have?

Use a Möbius strip with one half turn, and cut it the long way down the middle all the way around but nowhere else. What happens? What happens if you cut again all the way around? Try cutting the long way down the middle all the way around strips with one full turn, one and a half turns, two turns, two and a half turns, etc. Do this with red tape and you could have a promising career in government.

See http://mathssquad.questacon.edu.au/mobius_strip.html for additional ideas. For even stranger mathematical shapes, see Klein bottles:
http://plus.maths.org/content/os/issue26/features/mathart/index
http://en.wikipedia.org/wiki/Klein_bottle



Experiment 36: Soap bubble geometry
Kit provides: Wire
You provide: Dishwashing soap, glycerin (from drug store) or light corn syrup, bowl, your parents' permission to make a big, wet, slippery, foamy mess

Make your own bubble solution using:

¼ cup dish soap   1 cup warm water   2 tablespoons glycerin or corn syrup

Stir it for several minutes to mix thoroughly. If the bubble solution doesn't work well, try using different soap brands or water (tap, spring, or distilled), or try adjusting the amounts of each ingredient. Pour the bubble solution into a shallow bowl. If you would like to store the solution, use an airtight container.

Make a loop with the wire included in this kit, or with a metal coat hanger and an adult's help. Dip the loop briefly into the bubble solution. Notice that the bubble solution clinging to the loop wants to minimize its surface area by forming a flat membrane across the loop, due to surface tension, or the way the rubbery soap membrane pulls on itself. Now blow gently through the loop. Initially the bubble solution stretches way out, but once it releases from the loop, it forms a ball or sphere, which again minimizes its surface area. Try making membranes and blowing bubbles with other wire shapes—triangles, squares, etc. If you are feeling ambitious, make a wire cube, dip it in the bubble solution, and see what happens! If you don't need a pipette for other experiments, you can cut off half of the pipette bulb, dip that end briefly in bubble solution, then blow into the stem of the pipette to blow bubbles.

To make more bubbles than Lawrence Welk, combine some bubble solution with a Tums + vinegar or baking soda + vinegar reaction from Expt. 18. For additional ideas, see: http://mathssquad.questacon.edu.au/bubbles.html and www.hometrainingtools.com/super-soap-bubble-solution/a/1704/

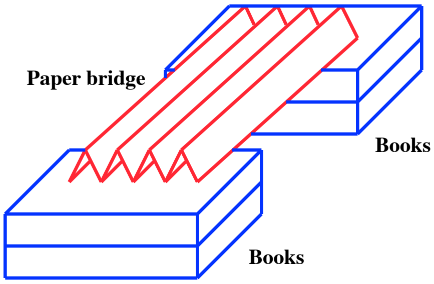
Explore further: Overholt & Kincheloe, *Math Wise!* (2nd ed.); Muschla, *Hands-On Math Projects with Real-Life Applications*; Brunetto, *MathART Projects and Activities*; Janice VanCleave, *Math for Every Kid, Play and Find Out About Math,* and *Teaching the Fun of Math;* http://mathssquad.questacon.edu.au

Mechanical Engineering

Experiment 37:
Paper bridge

Kit provides: Paper bridge pattern sheet (p. 28)

You provide: Books, pennies; toothpicks and soft gumdrops (optional)



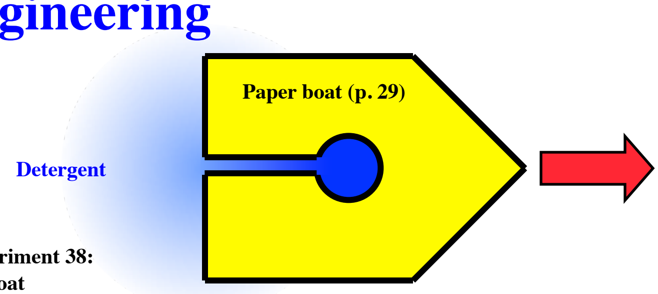
Mechanical engineering involves building stationary or moving structures for bridges, automobiles, ships, submarines, power plants, etc.

How strong is paper? Make two stacks of books the same height, with about an 8” gap between the two stacks. Drape the paper bridge pattern sheet between the two stacks. How many pennies can you put in the middle of the bridge before it sags all the way down?

Now fold the paper bridge pattern sheet along the vertical lines like an accordion, creasing each line to bend up or down as indicated on the sheet. Put the bridge back on the two book stacks, with the creases steep enough that the sheet has less than half of its unfolded width. Now how many pennies will the bridge support? Corrugated cardboard used in large shipping boxes uses this same principle to make it stronger.

Engineers use similar principles to design strong bridges, buildings, cars, and aircraft. An object’s strength depends not only on the material it is made from, but also on how cleverly that material is shaped to endure the forces that the object will experience.

Optional: You can build more elaborate bridges and other structures using toothpicks joined together by soft gumdrops. If you like this experiment, you could have a bright career repairing a lot of bridges.



Experiment 38:
Jet boat
Kit provides: Paper jet boat pattern sheet (p. 29)
You provide: Crayons, scissors, liquid detergent (not concentrated), sink or bathtub, foil and pennies (optional)

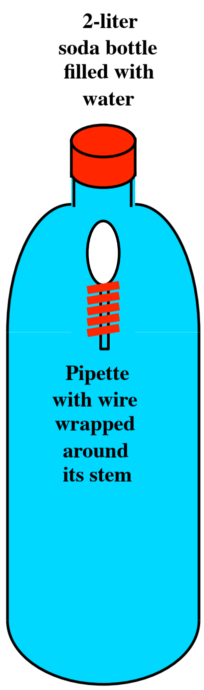
Page 29 contains several paper boats. (See also www.paperairplanes.co.uk/rocket.php.) To help waterproof the paper boats, it is helpful (but not absolutely essential) to color the boats completely on both sides with crayons. Color **before** cutting! Then cut out a boat, including the central hole. (You can also cut boats of similar shapes from thin cardboard, such as an empty cereal box.)

Fill a sink or bathtub with water. Gently place the boat in the water. It should float on the surface. Add a drop of **regular or diluted** liquid detergent to the central hole. (Concentrated detergent just falls through the hole to the bottom.) The boat should zoom immediately forward as the detergent diffuses out the back. This effect ceases within a few seconds once a thin film of soap has spread across all the surface of the water, so bathtubs work better than sinks. Kiss your rubber duckie goodbye.

Normally the surface tension of water molecules pulls at all edges of the paper boat. When soap leaks out the back of the boat, it reduces the surface tension there. With normal surface tension in front and little tension in back, the boat is pulled forward. You can also try this with cooking oil instead of detergent.

If you are feeling very nautical, make different designs of boats out of aluminum foil and see how many pennies they can hold before they sink.

Experiment 39: Cartesian diver
Kit provides: Pipette (plastic eyedropper), wire
You provide: Empty 2-liter soda bottle, scissors

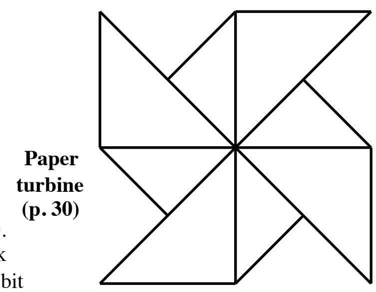


Remove the label from a soda bottle. Put a pipette in a glass of water and notice that it floats due to the air inside its bulb. Keep the pipette full of air but wrap wire around the stem to make it heavy enough it just barely floats. You can cut the stem to shorten it if you don’t need the pipette for other experiments. Fill the soda bottle to the very top with water, put in the wire-wrapped pipette, and screw the lid tightly back on the soda bottle.

The pipette should still float near the top of the bottle. Now gently squeeze the bottle. What happens? The pipette floats due to the buoyancy of the air inside it, since the air is less dense (lighter) than the surrounding water. Squeezing the soda bottle creates extra pressure which squeezes the air inside the bulb, reducing the volume of air and its buoyancy. By squeezing and releasing the bottle, you can make the pipette sink and rise—this is called a Cartesian diver, named after René Descartes, a French scientist and all-around champion nerd.

Fish naturally have a gas-filled swim bladder that they use in a similar manner to control their buoyancy when they want to move higher or lower in the water. Submarines have ballast tanks that can be filled with air, water, or a mixture of the two to control the submarine’s buoyancy to make the sub sink deeper or rise toward the surface. Time to rent *Das Boot*!

Experiment 40: Turbine
Kit provides: Paper turbine pattern (p. 30), electric motor
You provide: Scissors, tape, voltmeter (optional, inexpensive ones available at Walmart, Lowes, Home Depot, Radio Shack)



Use the paper turbine pattern on p. 30. (Optional: Trace the pattern onto thick paper or poster board, which works a bit better than the thin paper.) Cut along all of the solid black lines but nowhere else. Do not cut on the dotted lines! Curve the corners with red dots over into the center, but do not crease or fold them flat. Each red dot should lie in the exact center of the pattern. Tape the layers of paper together in the center. Press the center onto the shaft of the motor. Use more tape or modeling clay to keep it from slipping if necessary. Blow on it from the front and from the side to test which way works best. You have made a simple turbine. Turbines are used inside jet engines. In power plants, heat from burning fossil fuels or from nuclear fission (Expt. 48) boils water to make steam, and the steam blows through turbines and makes them spin. The spinning turbines turn electrical generators to make electricity.

Optional: Get an adult to help you connect the leads of the motor to a voltmeter to measure the voltage and current. Sending electricity into the motor’s leads makes the motor spin (try Expt. 21 with the turbine on the motor). Forcibly spinning the motor shaft (by blowing on the turbine attached to it, in this case) makes electricity come out of the motor’s leads. In other words, a motor can be used “backwards” as an electrical generator. See how much voltage and current you can generate by spinning the motor shaft with the wind turbine or with your fingers. If you are feeling really ambitious, can you make enough electricity to make an LED glow? (See Expt. 22. It might be dim, so do this in a dark room and try the LED with the leads connected in one direction and then with the leads connected in the other direction.) Better save your breath for power outages.

Explore further (search for best prices online, see www.homesciencetools.com, or check Costco, Walmart, or Target in December): Erector Set Special Edition (and similar sets in a suitcase), K’NEX (especially Deluxe Simple Machines set), Thames & Kosmos Physics Workshop and Physics Pro; Lego Technic (Toys R Us); *Lego Crazy Action Contraptions* (Klutz book, amazon.com and Barnes & Noble)

Meteorology

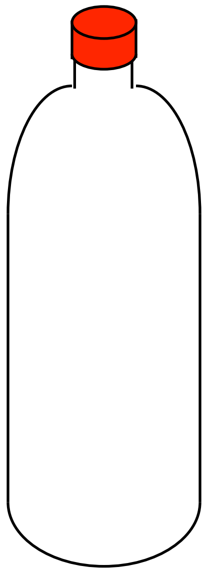
Experiment 41: Air pressure

Kit provides: These words of wisdom

You provide: Empty 2-liter soda bottle, sink, freezer

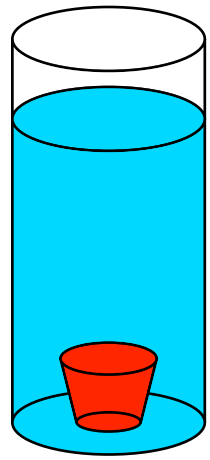
Meteorologists study the atmosphere (air) and weather, and some of them even get to point at things on TV. Although air is invisible, it is all around us and has pressure, meaning that it is constantly pushing on everything. To demonstrate this, remove the label from an empty 2-liter soda bottle and take the cap off (but save the cap). Have an adult run very hot water over the bottle in a large sink for a few minutes, in order to heat the air inside the bottle while getting as little water inside the bottle as possible. Keep the bottle upside down so the hot air doesn't escape, then quickly put the cap back on the bottle, tighten it, and put the bottle in a freezer for a few minutes. What happens to the bottle?

Air expands and has more pressure when it is heated, and it contracts and has less pressure when it is cooled. The hot air perfectly fills the bottle initially, but after a few minutes in the freezer the air in the bottle has cooled and has much lower pressure—it doesn't do a good job of filling the bottle anymore. The air outside the bottle is still at its normal full pressure, though, so it crushes the bottle. Air pressure plays an important role in meteorology, the science of weather, and it can be measured using an instrument called a barometer. Usually the air pressure decreases when a storm is on the way.



2-liter soda bottle

Clear drinking glass full of cold water



Mini beaker full of hot water with red food coloring, covered with plastic wrap

Experiment 42: Show a little convection

Kit provides: Mini beaker

You provide: Tall clear drinking glass, plastic wrap, red food coloring, salt, steak knife **(with adult assistance, careful!)**

Fill a mini beaker with hot water, add a couple drops of red food coloring, and cover it with plastic wrap. Set it inside an empty drinking glass, facing up. Fill the drinking glass with very cold water, then get an adult to use a steak knife to puncture the plastic wrap on the mini beaker. What happens?

Hot water is less dense (lighter) than cold water, so it wants to rise to the top. This is called convection. In meteorology, convection is important both in the ocean and in the atmosphere.

In the ocean, similar effects arise from differences in salt concentration as well as differences in temperature. You can demonstrate this by dissolving as much salt as possible in a drinking glass of tap water (normal temperature). Fill the mini beaker with red-colored tap water (same temperature) without salt, and cover it with plastic wrap. Put it at the bottom of the drinking glass and again have an adult puncture the plastic with a steak knife. Fresh water is less dense (lighter) than salt water, so it rises to the top.

Experiment 43: Tornado

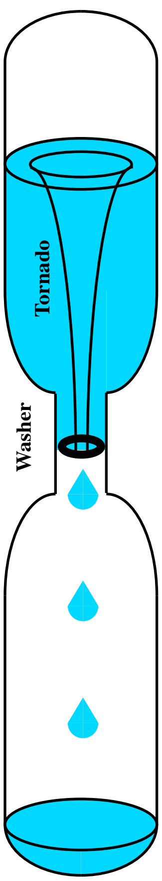
Kit provides: Metal washer

You provide: Two empty 2-liter soda bottles, duct tape, flying cows or little dogs named Toto (optional)

Let's do an experiment to see how tornadoes work. To continue with our theme of torturing soda bottles, peel the labels off two bottles and do this experiment in a large sink or bathtub. Fill one of the bottles 3/4 full with water. Dry off the top of the bottle and invert the other bottle above it with the washer sandwiched between the mouths of the two bottles to create a small hole between the two bottles. Join the bottles firmly together in this configuration using plenty of duct tape. (It's okay if it leaks a bit.) Turn the bottles upside down, so that the one with the water is on top, and vigorously swirl them. The swirling motion should start a tornado in the water that is flowing from the upper bottle to the lower one. Stop moving the bottles, and the tornado will continue to swirl, since it very efficiently allows the water from the upper bottle to go down (around the edges) and the air from the lower bottle to go up (through the center) without letting them run into each other. To see how inefficient the process can be when the air and water do run into each other, repeat the experiment but without swirling the bottles to form a tornado.

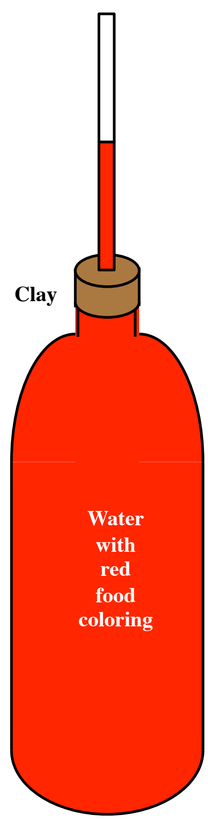
Real tornadoes are similar. If heavier cool air coming from the north flows above lighter warm air coming from the south, the heavier cool air will want to go down, and the lighter warm air will want to go up. They can do that more efficiently if they begin a swirling motion. In most cases, this just leads to thunderstorms with winds blowing in various directions at different locations and altitudes, but occasionally the swirling motion becomes so severe that a tornado forms. The swirling wind in a tornado can blow at 100-200 miles per hour and can do a lot of damage if it reaches all the way to the ground.

Soda bottle



Soda bottle

Straw



Soda bottle

Experiment 44:
Gilligan's Island weather station

Kit provides: Straw, test tubes, pipette

You provide: Empty 2-liter soda bottle, red food coloring, modeling clay, tape, marker

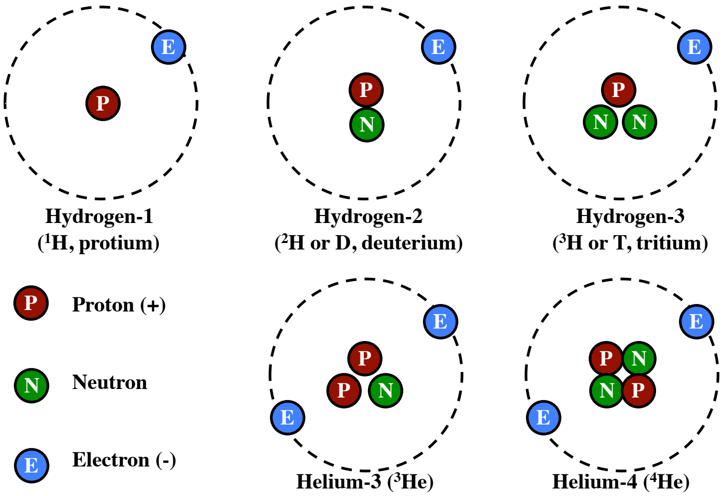
The Professor on Gilligan's Island was a science nerd role model—he was able to build anything from an electrical generator to a radiation suit with bamboo, coconuts, and rope. (Too bad he didn't know anything about boats…) You can use similar techniques to make your own instruments for measuring weather conditions.

To make a thermometer, use a clear two-liter soda bottle with no label, add a few drops of red food coloring, and fill it completely full with lukewarm water. Lower a clear drinking straw 1-2 inches into the bottle and thoroughly seal the top of the bottle around the straw with modeling clay. If necessary, use a pipette to add enough red water to come half way up the straw. Mark the current water level on the straw. Set the bottle in a sink full of hot water, wait a few minutes for the water to rise in the straw, and mark the new water level on the straw. Then put the bottle in a sink full of ice water, wait for the water level to stop going down, and mark the position on the straw. Your thermometer works because water expands as it becomes hotter and contracts as it cools. Real liquid thermometers work the same way, although instead of water they usually use nastier chemicals that expand and contract even more when they are heated and cooled. When you are done with the thermometer, this experiment also makes a great water gun **(outdoors only, please!)**.

You can also use a test tube as a rain gauge. Attach it securely outside, then check it after each rain to see how much rainfall there was. If you would like to make or buy more sophisticated weather instruments, see the suggestions at the bottom of this page.

Explore further: Mary Kay Carson, *Weather Projects for Young Scientists* (2007); Janice VanCleave, *Janice VanCleave's Weather* (1995); Brian Cosgrove, *DK Eyewitness Weather* (2007); Joanna Cole, *The Magic School Bus Inside a Hurricane* (1996); Storm Dunlop, *Guide to Weather Forecasting* (2008); www.hometrainingtools.com/weather-study-kit/p/KT-WESTUDY/

Nuclear Engineering

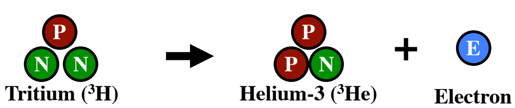


Experiment 45: Models of atoms and nuclei

Kit provides: Proton, neutron, and electron models (p. 31)
You provide: Scissors, cardboard and glue stick (optional)

No, we didn't pack any plutonium in your science kit. But we did include models you can use to demonstrate nuclear reactions. (Optional: use a glue stick to glue p. 31 to a piece of cardboard first.) Cut out all of the protons, neutrons, and electrons.

All material is made of atoms. Each atom has protons (P, with a positive electric charge) and uncharged neutrons (N) in the center or the **nucleus**, and negatively charged electrons (E) running in circles around the nucleus. Build models of the five atoms shown above. Notice that atoms have the same number of electrons as protons, so that their charges completely cancel each other. The number of neutrons can vary, but is usually comparable to the number of protons. Make more atoms: lithium-6 (3P, 3N), lithium-7 (3P, 4N), beryllium-9 (4P, 5N), boron-10 (5P, 5N), boron-11 (5P, 6N), carbon-12 (6P, 6N), nitrogen-14 (7P, 7N), and oxygen-16 (8P, 8N). Notice that the numbers in each name are the total number of protons and neutrons in the atom. Chemical reactions (p. 9) involve rearranging the electrons in atoms, but nuclear reactions involve rearranging the protons and neutrons and release about a million times more energy than chemical reactions. Since nuclear reactions involve the protons and neutrons, we often don't bother to show the electrons. Nuclear engineers use nuclear reactions to study radioactivity (Expt. 46), produce energy in power plants (Expts. 47-48), and create giant monsters in bad movies.



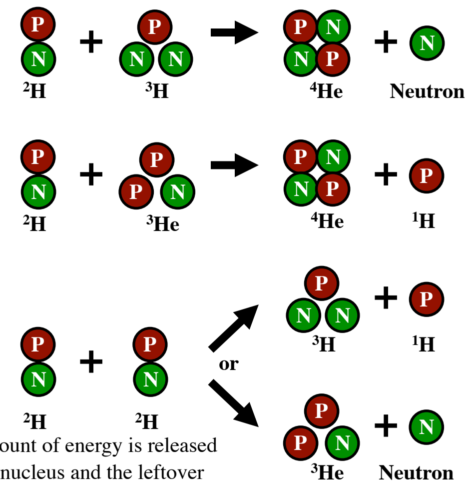
Experiment 46: Half life

Kit provides: Proton, neutron, and electron models (p. 31)
You provide: Watch or clock

Sometimes a nucleus is unhappy, so it will undergo radioactive decay to rearrange itself. For example, a tritium (hydrogen-3) nucleus would rather be a helium-3 nucleus, so one of its neutrons splits into a proton plus an electron (to maintain neutrality). You never know quite when a nucleus will decay, but on average half of them decay within one half life. Tritium decays to helium-3 with a half-life of about 12.3 years.

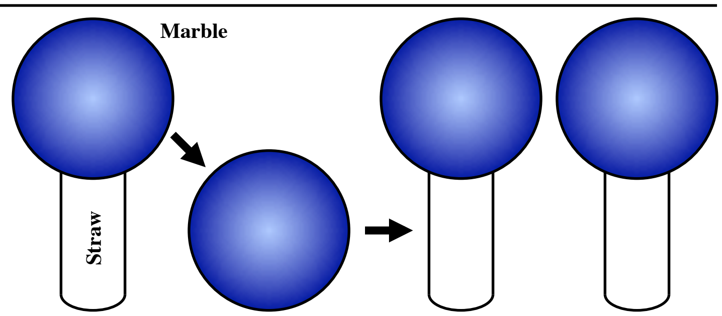
Make 8 model tritium nuclei and use a watch to pretend that their half life is one minute. After one minute, convert four (half) of them to helium-3. After another minute, convert two more (half of the remaining tritium nuclei) to helium-3. After another minute, convert one more (half of the remaining tritium). Eventually the last tritium will also become helium-3.

Do well with these, and maybe your parents will buy you real radioactive materials for your next birthday…



Experiment 47:
Fusion reactions
Kit provides: proton & neutron models, magnets
You provide (optional): Old cathode ray tube TV

Nuclei really want to be medium-sized, and they are willing to pay you lots of energy to get there. In nuclear fusion, two small nuclei join or fuse together to form a larger nucleus, usually with one proton or neutron left over. A large amount of energy is released as kinetic energy as the new nucleus and the leftover proton or neutron fly apart. The fusion reactions that happen most easily are shown above. Use your paper models to demonstrate each one. Note that fusing two deuterium nuclei together can result in either of two outcomes. The positive charges on protons make two nuclei repel (push against) each other. (The electrons are too far away to help.) Nuclei must be given lots of energy—equivalent to a temperature of millions of degrees—to make them bash together hard enough to overcome this repulsion and fuse. Material that hot is called a plasma, a glowing gas in which the electrons have so much energy that they no longer circle the nuclei, but wander freely and conduct electricity. Lower-energy plasmas are found inside fluorescent light tubes and decorative plasma globes. Scientists are trying to create fusion reactors that use hot plasma to produce fusion energy. To keep the hot plasma from touching material walls and cooling down or escaping, the plasma is trapped in a magnetic bottle or force field. To demonstrate how magnetic fields can herd charged particles, get your parents' permission to bring your magnets near the screen of an old TV while it is on. (Warning: this may permanently damage the TV picture if you do it too long. You can also use iron filings from www.hometrainingtools.com to see the effects of magnetic fields.) The picture is made by electrons hitting the screen, and your magnets bend the paths of the electrons. So far scientists have not been able to make a magnetic bottle that is good enough for a fusion reactor. If you can figure out how to do that, you could be Tony Stark.

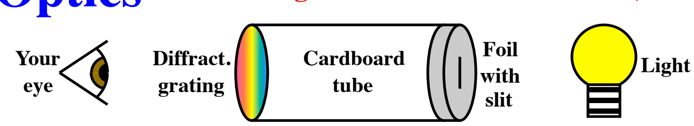


Experiment 48: Fission chain reaction, or losing your marbles
Kit provides: Straws You provide: Scissors, marbles
Cut one or two straws into many pieces about ¾" long, each with flat ends so they will stand up. Put them all close together on a table and put a marble on top of each one. If you roll a marble into this setup, it should knock one or more marbles off their straws, and each of those marbles in turn will knock off one or more marbles. This is an example of a chain reaction. (For a different example, DNA polymerase chain reaction, see Expt. 26.) In nuclear fission, a large nucleus (such as uranium or plutonium) fissions or splits to form two medium-sized nuclei plus a couple of loose neutrons. As in fusion, the resulting nuclei and neutrons fly apart with lots of energy. In your experiment, marbles on straws represent uranium nuclei before fission, and rolling marbles represent loose neutrons after fission. If a loose neutron from one uranium fission event hits another uranium, it can make that uranium fission too. If enough uranium atoms (marbles on straws) are close together, you have a critical mass, such that each loose neutron triggers another fission, and you get a chain reaction—all the marbles fall down. In fission reactors, the trick is to control the chain reaction, so that it neither gets out of hand nor dies out. Looking for the perfect science fair project? Build your own nuclear bomb!

Explore further: Hazel Richardson, *How to Split the Atom* (2001); Ira Freeman, *All About the Atom* (1955); plasma globe (Spencer's in many malls—avoid all the kinky aisles and head straight for the science nerd aisle; turn on the globe and bring a fluorescent light bulb near it); cloud chamber (http://sciencekit.com/cloud-chamber-set/p/IG0023989/); spinthariscope (www.unitednuclear.com/index.php?main_page=index&cPath=2_12)

Optics

Warning: Don't ever look at the sun, laser beams, or other bright lights that could damage your eyes.



Experiment 49: Spectroscope
Kit provides: Diffraction grating (clear plastic square that makes rainbows)
You provide: Toilet paper or paper towel tube, aluminum foil, tape, scissors

Optics is the study of light. Look at lights through the diffraction grating. You should see more rainbows than Dorothy. The diffraction grating is clear plastic covered with parallel lines that are too small to see and very close together, almost as close as the wavelength of visible light. Different colors of light have different wavelengths (shortest for violet, longest for red) and are bent by different amounts when they hit the lines in the diffraction grating. Thus what normally looks like white light gets broken up by the diffraction grating into its many different component colors. The same thing happens to light bouncing off a CD or DVD. The surface features used to record data on CDs and DVDs are very closely spaced lines and act like the diffraction grating.

To see the component colors of lights more clearly, you can make a simple spectroscope. Cover each end of an empty cardboard tube with aluminum foil. Get an adult to use scissors or a knife to cut a very narrow slit in one end and a small square hole in the other end. Put the diffraction grating across the square hole, taping the outer edges in place.

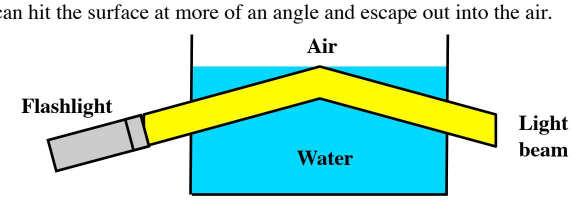
Close one eye, hold the diffraction grating end near your other eye, and point the tube's slit at a light. You should see the rainbows more clearly on either side of the slit within the dark interior of the tube. If necessary, rotate the foil slit while holding the grating end fixed. White lights contain all the colors, but some colored lights will only contain one or a few colors. Try looking at TV/computer screens, parking lot lights, LEDs (Expt. 22), and other light sources. Scientists use similar but more sophisticated spectroscopes to look for small shifts in the wavelength (color) of laser light, to identify chemical elements that emit or absorb certain wavelengths (colors), and for other uses.

Experiment 51: Fiber optics
Kit provides: Optical fiber (looks like fishing line or clear thread)
You provide: Flashlight (esp. Maglight); clear fish tank/bowl/glass of water

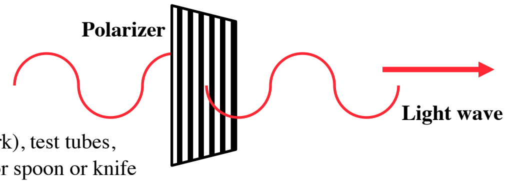
In a darkened room, shine a flashlight (or the LED from Expt. 22) into one end of the optical fiber and bend the fiber into a gentle U shape so that you can look into the other end. That end should glow with light. Optical fibers act like pipes for light, carrying light long distances and around corners. Many computer and phone networks use fiber optics to transmit data in the form of laser pulses.

Keep shining the flashlight into one end of the optical fiber, but now bend the fiber into a sharp V shape in its middle. Light should stop coming out the other end of the fiber, and in a dark room you may be able to see light escaping at the sharp turn of the V shape. An optical fiber can channel light around corners, but only if the fiber doesn't bend too sharply.

To demonstrate what keeps light inside an optical fiber, shine a narrowly focused flashlight beam into a clear fish tank, bowl, or glass filled with water. If you have fish, you can leave them in, but they may not fully appreciate the experiment. Hold the flashlight just below the top of the water, pointing slightly upward so that the light strikes the surface of the water at a grazing angle. The light should bounce off the surface and go back down into the water and out the other side of the container. However, if you angle the light beam upward more, it will break through the surface and not bounce back down into the water. Light travels more slowly in water or inside an optical fiber than in air, and its path bends when it passes from the water to the air. If the light beam grazes the surface at a shallow enough angle, the bending is enough to send the light back into the water. Likewise, inside the optical fiber, light hitting the wall at a shallow angle is bent back into the fiber. But if the fiber is kinked into a V shape, light can hit the surface at more of an angle and escape out into the air.



Experiment 50: Polarized light
Kit provides:
2 polarizers (plastic squares, transparent but dark), test tubes, clear plastic fork or spoon or knife

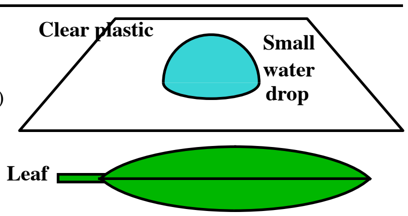


You provide: Molded clear plastic CD case or cassette tape case; LCD screen
Note: The polarizers may have a blue protective film on each side that is very difficult to peel off. You can do everything below without removing the film, but if you can remove the film, the polarizing effects will appear brighter.

A light wave moving forward is composed of electric and magnetic fields wiggling side-to-side or up-and-down, like waves on a vibrating string or Slinky (Expt. 61). It is very easy to stop the wiggling electric field (and thus the light wave) if it runs into something. Polarizers are covered with parallel lines, but the lines are much closer together than the lines on diffraction gratings. If the electric field of a light wave wiggles in the same direction as the lines in a polarizer, the light can squeeze through the polarizer. But if the light wave's electric field wiggles in the wrong direction, it runs into the lines and the polarizer stops the light. Light from most sources has some light wiggling the right way and some the wrong way to get through, so the polarizer makes those light sources look dimmer. Many (but not all) sunglasses use polarizers. Unlike most other sources, most LCD screens only have light of one polarization. Hold a polarizer over an LCD computer monitor, TV screen, or calculator. If you turn the polarizer the right way, much of the light gets through. But if you rotate the polarizer by 90°, virtually all the light is blocked. Stick a bit of tape on one edge of each polarizer to indicate which side needs to be up to see the LCD screen. Hold sunglasses over an LCD screen and rotate them to see if the lenses are polarizers or just plain darkened plastic.

Put your two polarizers together with the tape in the same direction. Light should pass through both polarizers, since all their little lines go the same direction. Now rotate one polarizer 90° relative to the other one. No light should get through, since light wiggling the right way to pass through one polarizer will be wiggling the wrong way to pass through the other polarizer. Get one of the plastic test tubes, or use a clear molded plastic fork/knife/spoon or CD case lid. Sandwich it between the two polarizers and look through the stack. As you rotate one polarizer relative to the other, you should see colors in the plastic item, especially in areas where the plastic is bent. When plastic is stretched, its long molecules can line up in parallel and act somewhat like a polarizer, rotating the polarization of light. The rotation affects different wavelengths (colors) of light differently, so you see colors in areas of the plastic that were stressed during the manufacturing process. Sometimes engineers use similar but fancier techniques to analyze stress patterns in materials to make sure things won't break unexpectedly. You might even know some people who turn colors when they get stressed.

Experiment 52: Leeuwenhoek microscope
Kit provides: Clear plastic bag
(**keep away from young children**)
You provide: Scissors, water, newspaper, leaves, ants, etc.

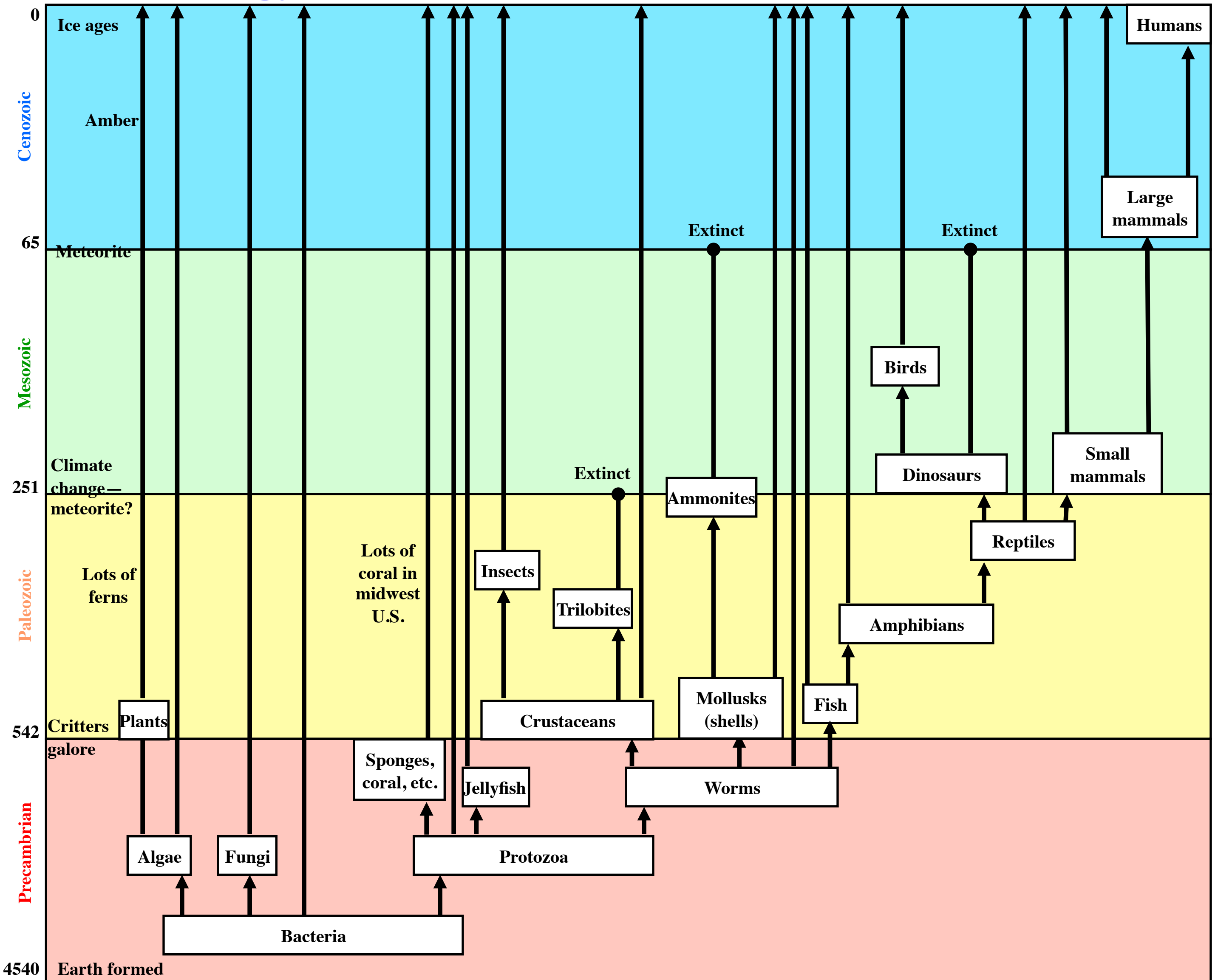


In the 1600s, the Dutch scientist Anton van Leeuwenhoek made the earliest known microscope, a tiny round glass drop through which he was able to see microorganisms. You can make a similar microscope with a water drop. Cut a small square (6x6" is a good size) out of plastic wrap or a clear plastic bag. Adjust a faucet until only an occasional drop comes out, and let one drop of water fall on the plastic. The drop should form a hemispherical shape which makes a good lens. Keep the drop in the center of the plastic. Don't touch the water or center of the plastic with your fingers--oil from your skin can mess up the shape of the water. In a well-lit area, hold the plastic and water drop close to a newspaper. Do the letters look larger? Briefly touch the drop with a paper towel to soak up part of the water. As the drop becomes smaller, its curvature and thus its magnification become greater. With a small enough drop, you can see the tiny dots that many printers use to form letters and images. Use water drops of various sizes to examine leaves, insects, someone's hand, human or animal hair, and other samples. Can you find structures that you hadn't realized were there? After a while, you may start to feel like *Horton Hears a Who!*

Explore further: Levine & Johnstone, *The Optics Book* (1999); Cobb, *Light Action!* (2005); try all kinds of magnifiers, Fresnel (flat plastic magnifier) lenses, eyeglasses (treat them with care!), etc.; www.hometrainingtools.com/light-optics/c/27/ www.sciplus.com/category.cfm/subsection/21 www.scientificsonline.com/optics.html Thames & Kosmos Scope Constructor

Paleontology

Dr. Rider's Family Tree (numbers indicate millions of years ago)



Experiment 53: Fossil identification

Kit provides: Fossil guide (pp. 21-22) You provide: Fossils

Paleontologists dig up and study fossils, the hardened remains of animals and plants that lived long ago. Fossils of different types and ages are found in different areas—e.g., dinosaur tracks in parts of New England, seashells in the midwest U.S., and dinosaur bones in parts of the western U.S. Use www.fossilsites.com to see what you can find where you live or vacation, or buy fossils online or at museum gift shops. Use the fossil guide or books below to identify each fossil, how old it is, and how that animal or plant lived. Now you can tell your parents what you really want for your birthday is a dinosaur coprolite, otherwise known as Jurassic poop or dino doo-doo.

Experiment 55: Fossilize your toothbrush

Kit provides: Instructions You provide: Flour, salt, sand, alum, food coloring

Most fossils are critters that fell into mud, which turned into rock. Make your own "mock rock" mud and bury an object in it before it hardens. Then excavate the "fossilized" object, just as paleontologists do. Here is the mock rock recipe:

1 cup flour	5 drops red food coloring	½ cup water
1 cup sand	3 drops yellow food coloring	2 tsp. alum (in
½ cup salt	3 drops blue food coloring	grocery spice aisle)

Mix everything thoroughly, insert the object of your choice, and put the blob in a warm place for at least a week to dry into a hard mock rock. Then excavate it with whatever tools your parents will let you use. **(Wear eye protection if you get energetic.)** If you get desperate, soak the mock rock in water to soften it.

Experiment 54: Molds and casts

Kit provides: Instructions You provide: Modeling clay, coin, white glue

After animal or plant remains were buried in mud, over time the mud hardened into shale, creating a hard **mold**. Eventually the remains decayed away, and minerals from the ground filled the empty space inside the mold. Over time those minerals became a **cast** that looks like the original remains. Dinosaur bones in museums are generally not the dinosaur's actual bones, but minerals that formed a cast shaped like the original bones. To demonstrate this, use a coin as "animal remains" and modeling clay as mud. Press the coin into the clay, then remove it to pretend the remains decayed away. Now fill in the clay mold with glue and let it dry a few days. Gently peel off the dried glue. The glue is a fossil cast of the original coin, and the clay is a fossil mold of the coin.

Experiment 56: Dinosaur-flavored Jello

Kit provides: Yup, just these instructions You provide: Tall narrow drinking glass, different colors of Jello, different types of Gummi bears or similar candy

Fossils are buried in layers, with newer layers of fossils on top of older layers. Paleontologists can tell how old a fossil is by what layer it was in. Show this by mixing up several batches of Jello, each of a different color, and using different types of Gummi bears or similar candy. Pour one color of Jello into the bottom of a tall clear glass, mix in one type of candy, and let that layer solidify in a refrigerator. Pour another color of Jello on top, mix a second type of candy in that layer, and again let it solidify. Repeat to make several layers, then excavate with a spoon to investigate how Gummi bears evolved over time.

Explore further: www.twoguysfossils.com (50 fossils for $67, click Paleo-Sets at upper left); www.rocksandminerals.com; Nash dinosaur tracks (www.roadsideamerica.com/attract/MASOUnash.html); Cyril Walker & David Ward, *Fossils* (DK, 2002); Rhodes, Zim, & Shaffer, *Fossils* (St. Martin's Press Golden Guide, 2001); Chris McGowan, *Make Your Own Dinosaur Out of Chicken Bones* (1997) and *T-Rex to Go* (1999)

Dr. Rider's Prehistoric Bestiary (Part 1)

Plants:

Algae (Stromatolite)
Single algae cells piled up to form stromatolite mounds in the ocean
Look like swirls/rings in rock
3 billion years ago to present

Coal Ferns
Compressed dead ferns formed coal
360-300 million years ago

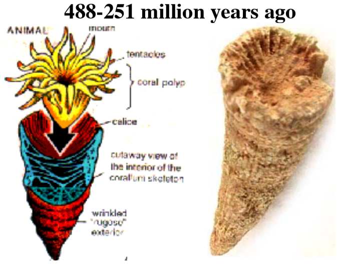
Leaves
Leaves from trees/bushes left impressions in mud that hardened
360 million years ago to present

Petrified Wood
Tree trunks or branches that have been replaced by minerals
300 million years ago to present

Amber
Hardened tree sap (like maple syrup)
May contain insects, leaves, etc.
40 million years ago to present

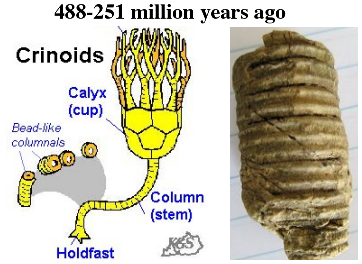
Simple stationary sea animals that looked like plants:

Horn (Rugose) Coral
Simple animal; mouth at large end
Often mistaken for a horn or tooth
488-251 million years ago

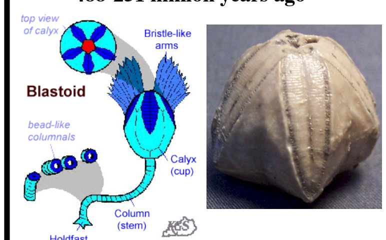


Colonial Coral
Cluster of coral animals that lived together
542 million years ago to present

Crinoid
Flower-like sea animal
Often only the stem is found
488-251 million years ago



Blastoid
Flower-like sea animal
Often only the 5-sided bud is found
488-251 million years ago



Bryzoan
Stems/spirals made of millions of microscopic sea animals
488 million years ago to present

Animals that lived in shells:

Brachiopod
Clam-like animal
Left & right sides of shell look same
542 million years ago to present

Pelecypod
Clam-like animal
Left/right sides of shell look different
542 million years ago to present

Gastropod
Snail that lived in shell
Shell is usually cone-shaped spiral
542 million years ago to present

Orthoceras
Squid-like animal
Lived in cone-shaped shell
488-200 million years ago

Ammonite
Squid-like animal
Lived in spiral shell
425-65 million years ago

Dr. Rider's Prehistoric Bestiary (Part 2)

Arthropods:

Trilobite
Underwater crustacean related to horseshoe crabs and lobsters
542-251 million years ago

Crawling insect
Beetles, etc.--Related to underwater crustaceans like trilobites, but evolved to live on land
~416 million years ago to present

Flying insect
Many species from small flies to giant dragonflies
Usually preserved in amber, or in mud that hardened to shale
~320 million years ago to present

Fish:

Shark tooth
Teeth were harder and preserved much better than other shark parts
~420 million years ago to present

Complete fish
Dead fish sank into mud at bottom of lake/ocean; mud hardened to shale
~510 million years ago to present

Dinosaurs:

Dinosaur bone
May look like petrified wood, but dinosaur bone is porous inside
251-65 million years ago

Dinosaur tooth
Meat-eating dinosaurs had sharp pointed teeth; plant-eating dinosaurs had dull flat teeth
251-65 million years ago

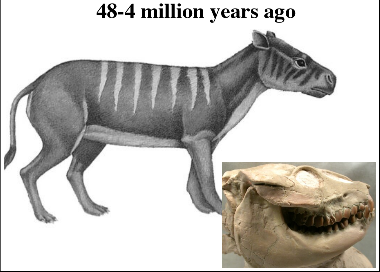
Dinosaur gastrolith
"Gizzard stone" swallowed by dinosaur to grind up food in stomach
Round and smooth from grinding
251-65 million years ago

Dinosaur eggshell
Eggshell pieces of hatched eggs, or whole unhatched eggs, could become fossilized
251-65 million years ago

Dinosaur coprolite
Dino doo-doo, or Jurassic poop
251-65 million years ago

Mammals:

Oreodont
Pig-like plant-eating mammal
Lived in North America
48-4 million years ago



Mammoth
Sometimes frozen/preserved in ice
Hair & tusk pieces widely available
5 million – 10,000 years ago

Horse
Horses evolved in North America, gradually getting bigger
Horse teeth are easy to recognize
40-50 million years ago to present

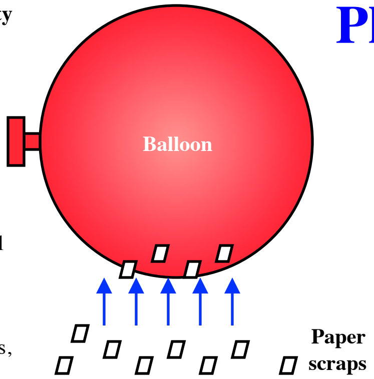
Whale
Gradually evolved from land animals
Whale ear bones easy to recognize
~45 million years ago to present

Humans
Left fossil skeletons, as well as stone tools and arrowheads
~2.5 million years ago to present

Experiment 57: Static electricity

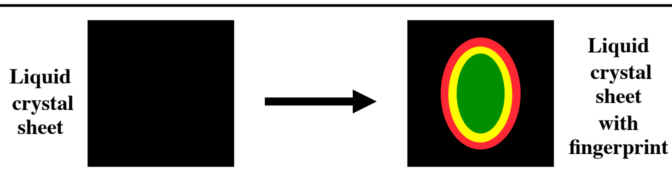
Kit provides: Balloons

You provide:
Your head or carpet for friction, tiny paper scraps, salt and pepper



Physicists study various types of energy (such as moving or kinetic energy, stored or potential energy, heat energy, etc.) and different types of forces (such as electric force, magnetic force, gravitational force, nuclear forces, and the strong force that tries to keep you in bed early on a school day). To experiment with electric force, blow up a balloon if you haven't already. It may be easier if you stretch the balloon with your hands for a while before you try to blow it up. To prevent the air from coming out, keep the end of the balloon pinched in your hand. Rub the balloon back and forth against your hair or on a carpet. Then hold the balloon close over tiny scraps of paper. The paper should fly up and stick to the balloon. Or hold the balloon over your head for mad scientist hair. Mix a little salt and pepper together—can you separate them by holding the balloon over them?

Normally materials are electrically neutral—they have the same number of negatively charged electrons as positively charged protons (Expt. 45). But rubbing two different materials together (like the rubber balloon and your hair) can make electrons hop off one material onto the other one, leaving one material negatively charged (too many electrons) and the other one positively charged (too few electrons). Opposites attract, so a negatively charged object and a positively charged object will attract each other, but two negatively charged or two positively charged objects will repel each other. A charged object can even attract an uncharged neutral object (like the paper scraps) by making some of the electrons in the neutral object run to one side, so that one side is negatively charged and the other side is positively charged. If you don't need two balloons for other experiments (**do Expts. 3, 13, and 18 first!**), you can blow them up, tie off their ends, charge up both of them by rubbing them against your hair, and then see how they interact with each other or when placed on a wall. Alternatively, rubbing a comb through your hair is a great way to produce a static charge on the comb. Charge up a comb or balloon, bring it near a thin stream of water falling from a faucet, and see if the path of the water bends. If these experiments don't work well, try them again in a warm room during the winter, when the air contains little water vapor that could let the electrons sneak back home and make everything neutral again.



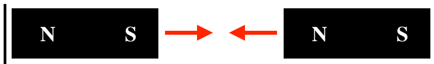
Experiment 59: Liquid crystals

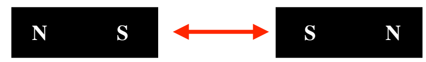
Kit provides: Liquid crystal sheet (thin, shiny, black plastic)

You provide: Your thumb; other warm or cool objects

One side of the liquid crystal sheet changes color when it is warmed above room temperature. (The other side always stays black.) Press a warm fingertip against the liquid crystal sheet for a few seconds. Notice how the colors gradually fade to black as the sheet cools back to room temperature. Make a nose print, breathe on the sheet, expose it to sunlight, or try other warm sources (but no flames or ovens!). Try cooling the sheet more rapidly by putting it in a refrigerator. If you have a thermometer, which colors correspond to what temperatures?

Liquid crystals are composed of rod-shaped molecules that, guess what, act as if they are halfway between being a liquid (like water) and being a crystal (like ice). As liquid crystals are warmed, the alignment of the molecules changes and their effect on light changes, hence the change in reflectivity for different colors of light. In electronic liquid crystal displays (LCDs), similar changes are produced by electric fields instead of temperature changes.





Experiment 58: Magnets

Kit provides: 2 magnets, steel bolt and washers

You provide: Other magnets, paperclips, foil, coins

Yes, we know you have already been playing with the magnets, but now we'll do it officially. Every magnet has a north (N) pole and a south (S) pole. The N pole of one magnet will attract the S pole of another magnet (opposites attract). However, two N poles will repel each other (push each other away), and two S poles with repel each other. Test the two provided magnets with each other or with any other magnets you have.

Magnets can attract some metals (not all, sorry Magneto!) by temporarily aligning the atoms in the metal to make the metal magnetic. Test your magnets on the steel bolt and washers in this kit, as well as on paperclips, aluminum foil, various U.S. and foreign coins, or other metals you may have.

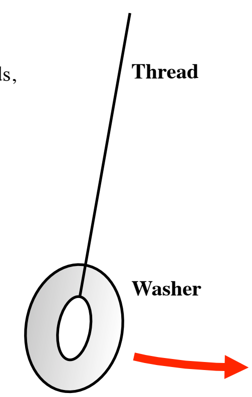
You can permanently magnetize a steel paperclip by stroking it several times in the same direction with one end of a magnet. This permanently aligns the atoms in the paperclip to make it a real magnet. Test that the paperclip is magnetized by seeing if it will attract another paperclip. If not, stroke it some more.

You can also use a magnet to make a compass (see Expt. 31).

Experiment 60: Pendulum

Kit provides: Thread and washers

You provide: Stopwatch or clock that shows seconds, or better yet fractions of seconds



Tie one washer to a very long piece of thread. Let the washer swing gently back and forth as a pendulum. Use a stopwatch to determine the period of the pendulum—the time required for the pendulum to swing from one side to the other and return to the side where it started.

Now let's do experiments to figure out what things affect the period of the pendulum. To be scientific, change one thing in each experiment, but keep everything else exactly the same:

(A) If you increase or decrease the amplitude of the swings (how far the washer swings), how does that affect the period?

(B) If you increase the mass of the pendulum by tying 2, 3, or 4 washers to the string, how does that affect the period?

(C) If you increase or decrease the length of the pendulum by holding the thread at different distances from the washer(s), how does that affect the period?

Borrow an adult and a calculator and compare your results with the results of this formula:

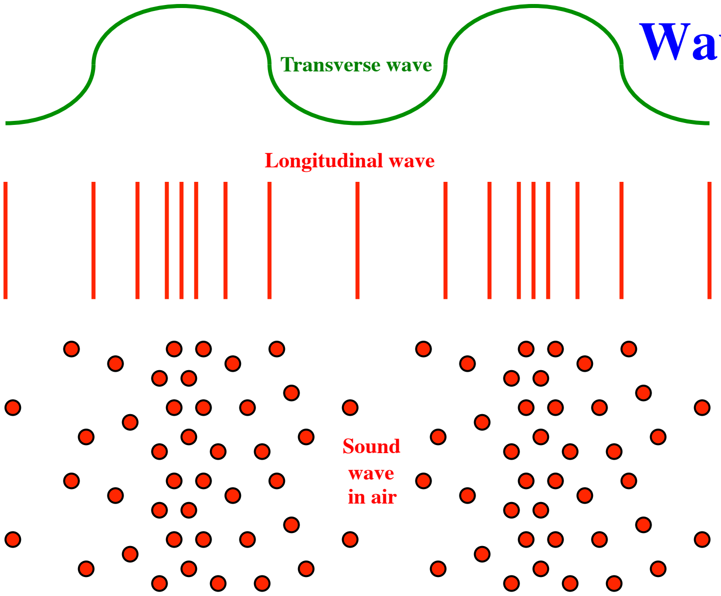
$$\text{Period (in seconds)} = 0.32 \times \sqrt{\text{pendulum length (in inches)}}$$

If you are curious where that formula came from, go grill a high school physics teacher or a physicist. (If you ask a physicist a question, you'll always get an answer. You may not get the right answer, but you will always get an answer…)

Try the pendulum in front of your parents. "You are getting very sleepy... When you awake, you will feel the urge to buy me lots of science toys…"

Explore further: Janice VanCleave, *Physics for Every Kid* (1991), *Energy for Every Kid* (2005), *A+ Projects in Physics* (2003), and *Magnets* (1993); drinking bird (www.scientificsonline.com and www.sciplus.com; put a cup of cold water at the head AND a cup of hot water under the tail); radiometer (www.scientificsonline.com and www.sciplus.com); www.hometrainingtools.com/physical-science-physics/c/4/

Waves and Acoustics



Experiment 61: Waves on a Slinky and on rubber bands
Kit provides: These instructions
You provide: Slinky (Walmart, Target, Toys R Us, etc.), rubber bands

Acoustics is the study of sound waves, which means you now get to make lots of noise for the sake of science. To see how waves work, stretch a Slinky out to several feet between you and another person. If you wiggle the Slinky up and down or side to side, you can make transverse waves. Light (p. 19) and radio waves are transverse waves made of wiggling electric fields (Expt. 57) and wiggling magnetic fields (Expt. 58).

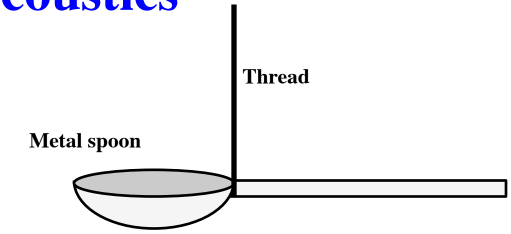
If you hold the stretched Slinky straight and give one end a sudden shove, you can make longitudinal waves—parts of the Slinky are alternately compressed and stretched. Sound is longitudinal waves in air (or other materials); particles of air are alternately compressed and rarified as they bump into each other in a sound wave. Sometimes you see lightning several seconds before you hear the corresponding thunder, so you know that light waves travel much faster than sound waves.

Stretch a rubber band between your fingers and pluck it. Are the vibrations longitudinal or transverse waves? How does the length to which you stretch the rubber band affect the sound when it is plucked? Try different thicknesses of rubber bands if you have them. A vibrating rubber band vibrates the air around it and makes sound waves that come to your ears. Musical instruments such as guitars, violins, and pianos make sound using vibrating strings similar to the rubber band. A longer rubber band or string can make longer waves, which correspond to sound waves with lower pitches or frequencies.

Experiment 63: Straw kazoo
Kit provides: Drinking straws You provide: Scissors, soda bottles of all sizes

Flatten one end of a straw and use **clean** scissors to cut the corners of that end to form a shape like a bird beak. Stick that end in your mouth (the flattened beak shape must be inside your mouth, not between your lips) and blow as hard as you can. You may need to adjust the shape and flatness of the cut end, how you blow, and how hard you blow, but sooner or later the straw should work as a kazoo. You'll know you have succeeded when your parents are annoyed. What happens to the sound pitch (frequency) if you cut off part of the opposite end of the straw? The beak-shaped end of the straw acts like the reed in a woodwind instrument such as a clarinet or saxophone. A longer straw can make longer sound waves, which have lower pitches or frequencies.

You can also make sounds by blowing horizontally across the top of an empty soda bottle. (Try bottles of various sizes, from 8 or 12 ounces to two liters.) If you partially fill a bottle with water, there is less air inside for sound waves, and the waves should get shorter with higher pitches or frequencies when you blow. Musical instruments like flutes, trumpets, and trombones adjust the length of air-filled tubes to control what pitch they produce.



Experiment 62: Silverware symphony

Kit provides: Thread

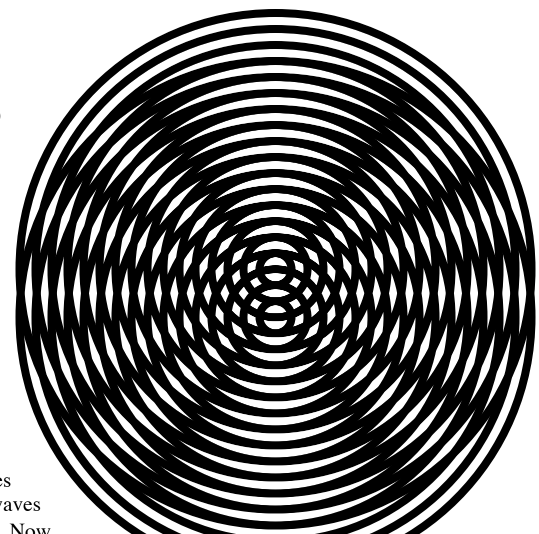
You provide: Metal spoons and pot lids of different sizes or metals **(get your parents' permission before you start banging on them)**

Tie a piece of thread around a spoon and hold the spoon by the thread. Gently tap the spoon with another spoon. The hanging spoon vibrates, which vibrates the air around it and makes sound waves. Why is the thread important—what happens if you hold onto both spoons instead of hanging one by a thread? How does the sound change if you hit the same hanging spoon (carefully!) with different objects or materials? How does the sound change if you use a hanging spoon that is larger or smaller or made of a different metal? Metal pot lids work very well too. Musical instruments like triangles, cymbals, and xylophones work the same way. As with rubber bands and strings, larger objects can make longer waves, which correspond to sound waves with lower pitches.

Experiment 64: Wave interference

Kit provides: Wave pattern sheet (p. 25)

You provide: Water, coins, photocopier, two clear overhead transparencies



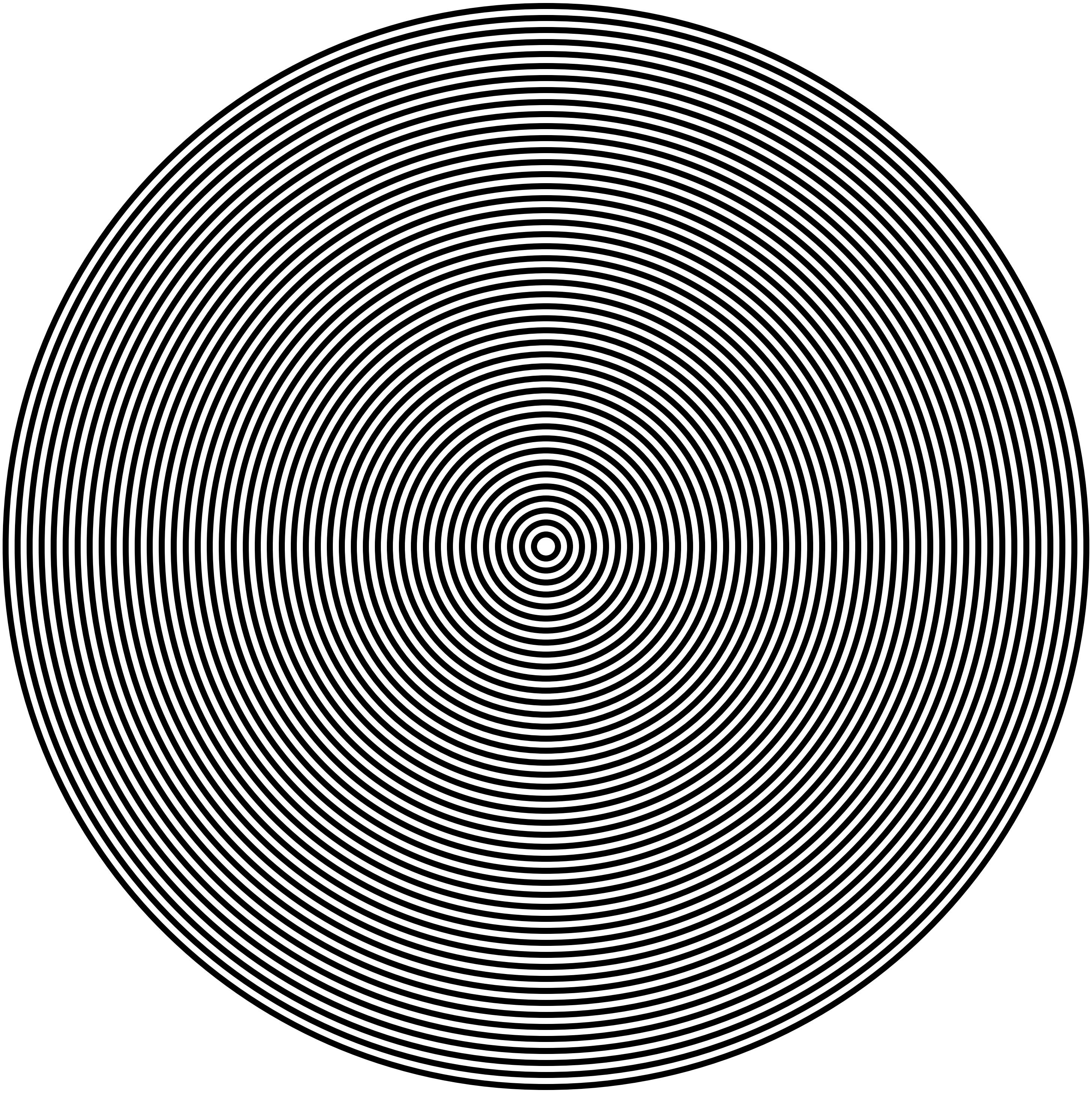
Drop a small object such as a coin into a bowl, sink, or tub full of water **(don't let it go down the drain!)**. Notice that the object makes circular ripples or waves that spread outward. Now drop two coins at the same time but a few inches apart. Notice that the waves interfere with each other. Where the waves from both coins are going up at the same time and down at the same time, they add together to make bigger waves, which is called constructive interference. But where the waves from one coin are going up at the same time the waves from the other coin are going down, the waves cancel each other out, which is called destructive interference. Drop the coins at the same time again, but closer together or further apart, and see how that affects the interference patterns.

To do more experiments with interference patterns, have an adult make two identical photocopies of the wave pattern sheet (p. 25) on clear overhead projector transparencies. If the two transparencies are perfectly overlapped, you just see circles. But if you slowly slide one transparency over the other, you see constructive and destructive interference. This effect is called a Moiré pattern and would impress even Timothy Leary. Notice that in order to get good interference between two wave sources, the waves need to have the same wavelength or distance between successive waves. Constructive and destructive interference can be used to direct sound waves, laser beams, and radar beams in particular directions but not in others. Good to know if you are building a death ray for your science fair project!

Explore further: Levine & Johnstone, *Science Experiments with Sound & Music* (2002); Melissa and Doug Deluxe Band Set and Band in a Box (amazon.com and toy stores); www.hometrainingtools.com/sound-wave-motion/c/28/

Moiré Wave Pattern Sheet

Make 2 identical photocopies of this page on overhead transparencies
Overlap them exactly, then gradually slide one relative to the other

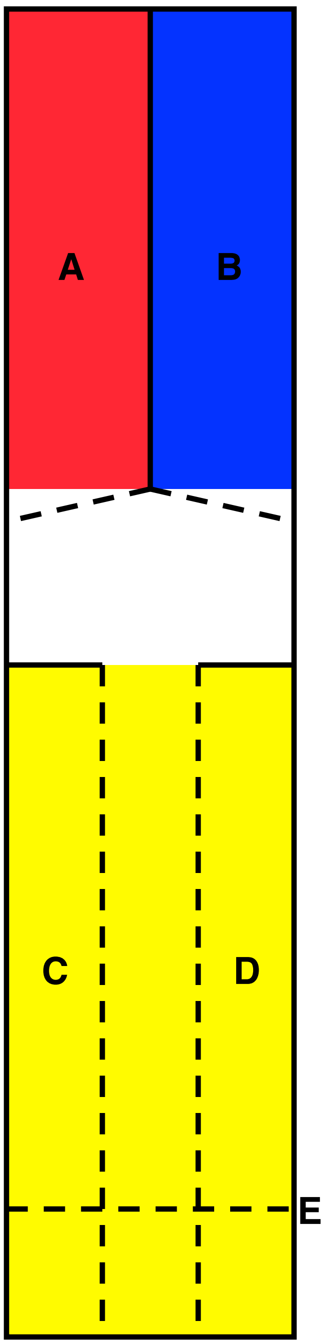


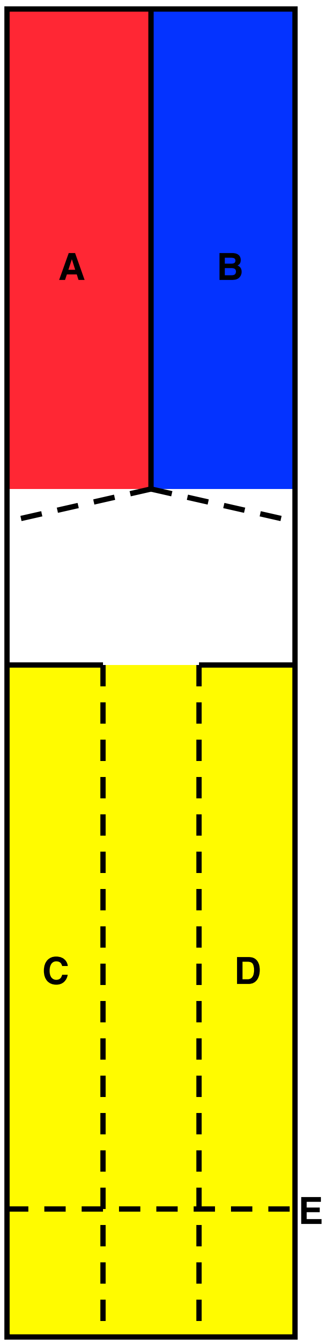
Paper Helicopters

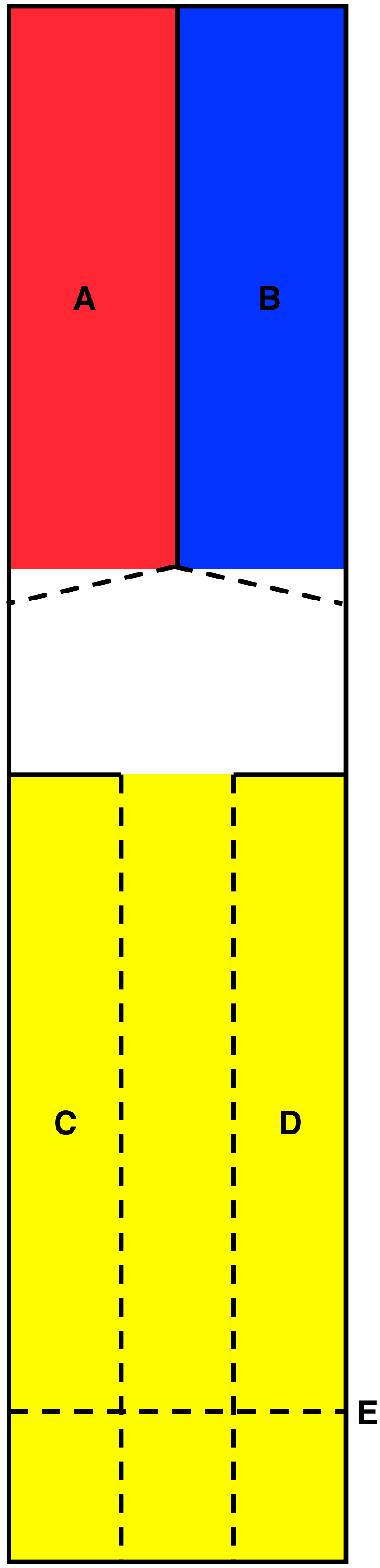
Photocopy this page if you want to do the experiment more than once

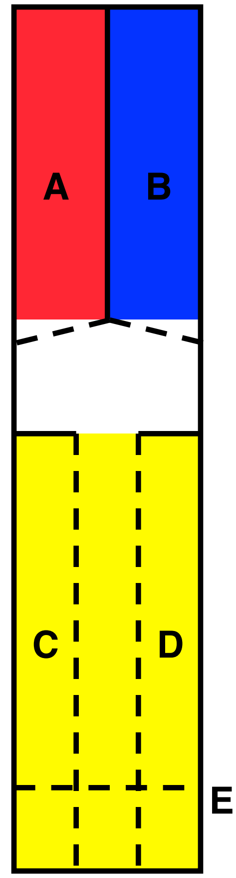
Cut **on all the** ***solid*** **lines**

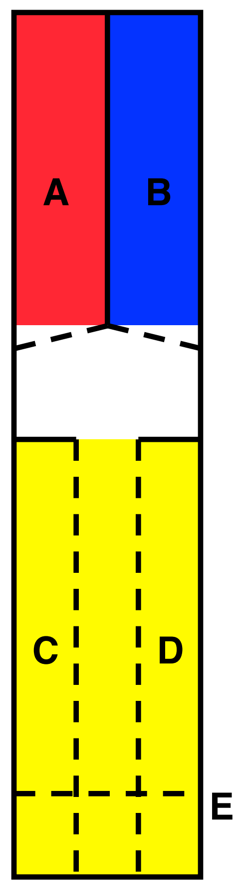
Fold **on all the** ***dotted*** **lines**











Walk Through a Sheet of Paper

Photocopy this page if you want to do the experiment more than once

Cut along all black lines *but nowhere else*

Paper Bridge

Photocopy this page if you want to do the experiment more than once

Fold so this line sticks up

Fold so this line sticks down

Fold so this line sticks up

Fold so this line sticks down

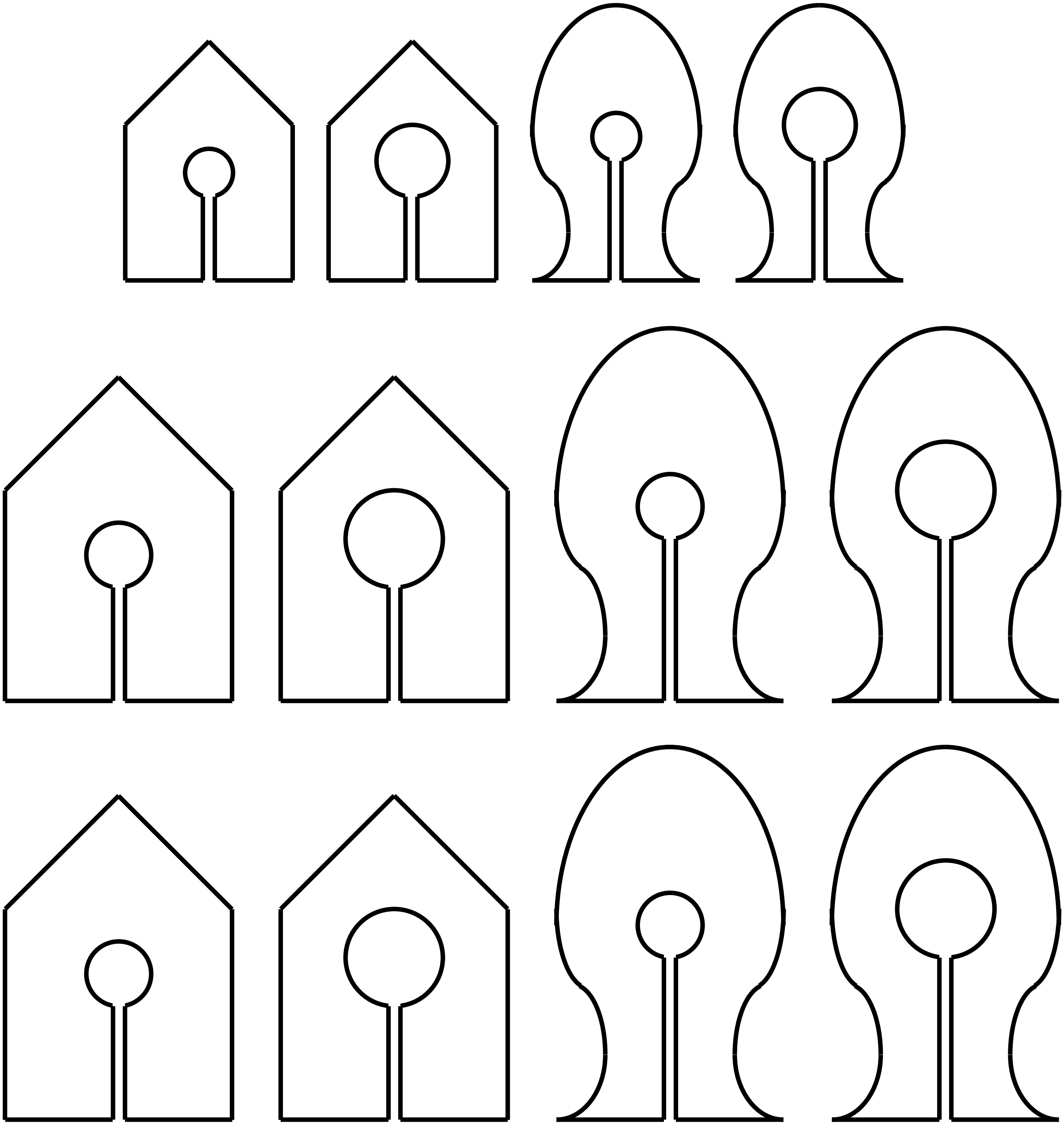
Fold so this line sticks up

Fold so this line sticks down

Fold so this line sticks up

Paper Jet Boats

Photocopy this page if you want to do the experiment more than once



Answers to Expts. 5-8

5: Made ca. 196 BC for Ptolemy V (Ptolmys)

King of upper
& lower Egypt
P
T
O
L
M
Y
S
live
forever
Ptah's
beloved

6: Made ca. 1550-1295 BC

The king
gives
an offering
to Osiris
the good god
so that he may give
a voice offering

7: Made ca. 1390 BC for Thutmose IV

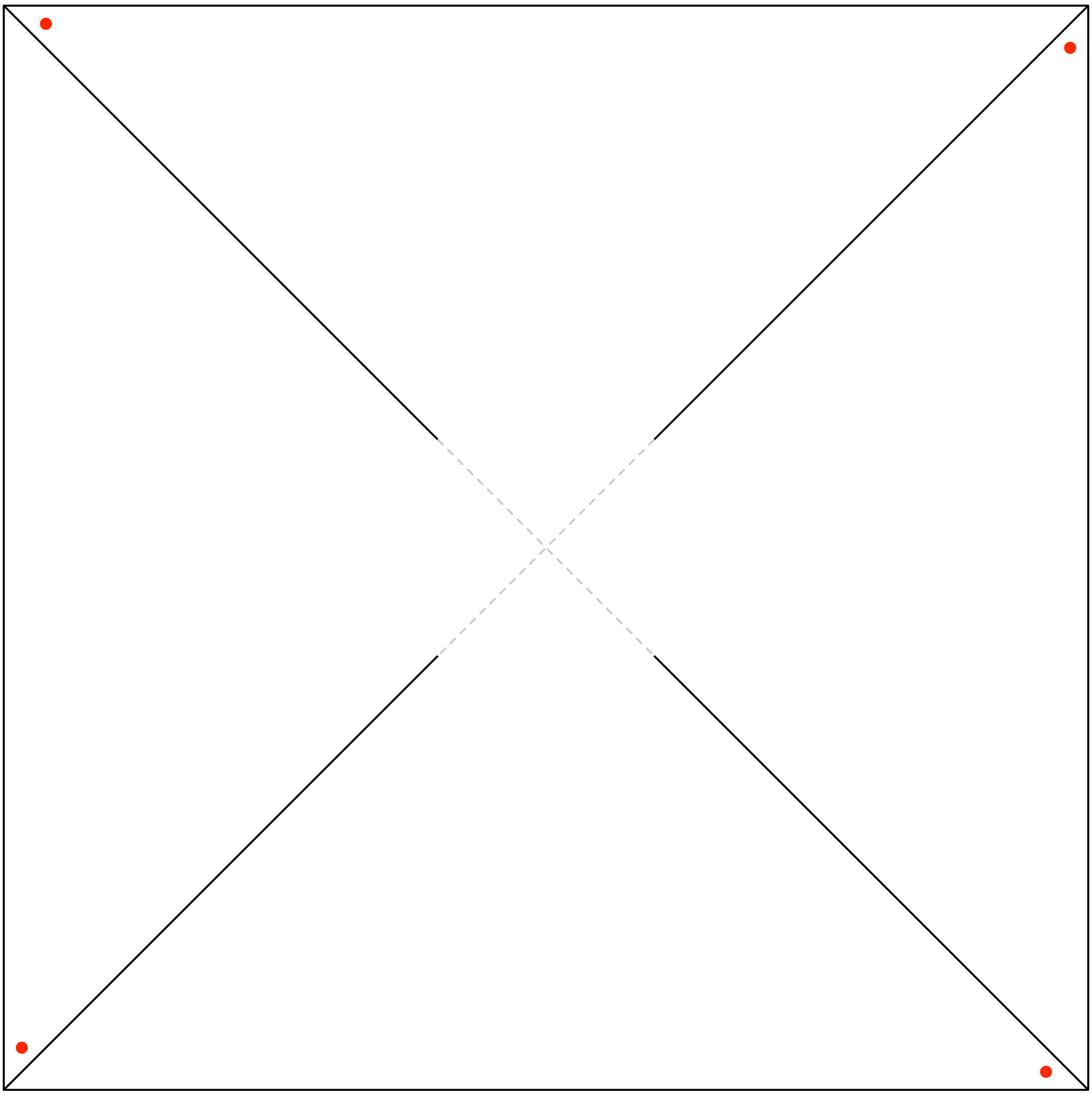
The good god,
lord of the two lands,
Men-kheper-ra [Thutmose IV],
true of voice [deceased],
Osiris's
beloved

8: Made ca. 1336-1327 BC for Tutankhamun

Son of Ra Tutankhamun Ruler of Thebes Forever	King of Upper & Lower Egypt Neb-Kheper-Ra Given life	Amun-Ra Lord of thrones & the two lands Lord of heaven Beloved [of Amun-Ra]

Turbine Pattern

Photocopy this page if you want to do the experiment more than once. Cut along all of the solid black lines but nowhere else. (Do not cut on the dotted lines!) Fold the corners over so that the red dots are exactly in the center. Tape the layers of paper together in the center. Press the center onto the shaft of the motor. Use more tape or modeling clay to keep it from slipping if necessary.

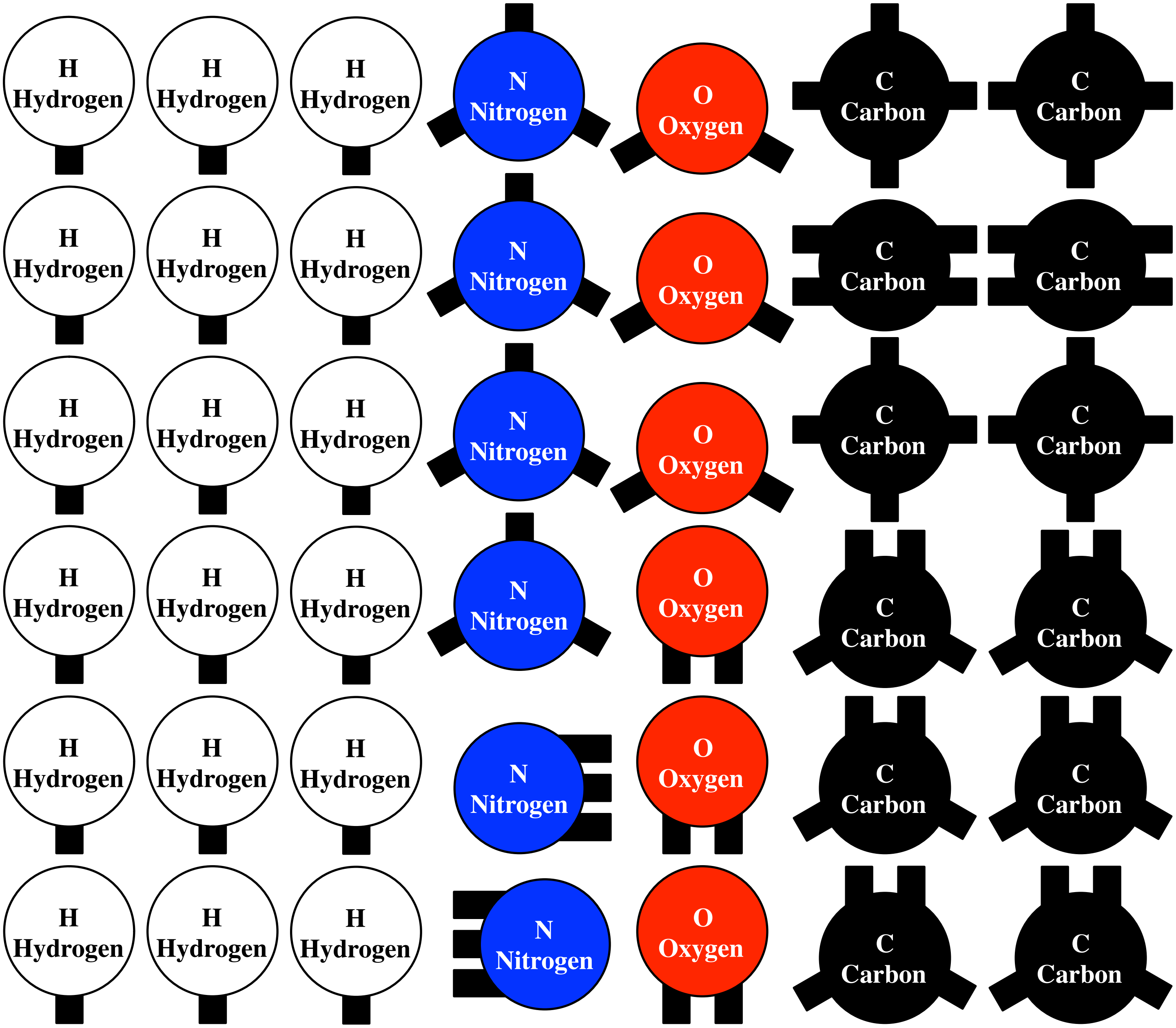


Proton, Neutron, and Electron Models

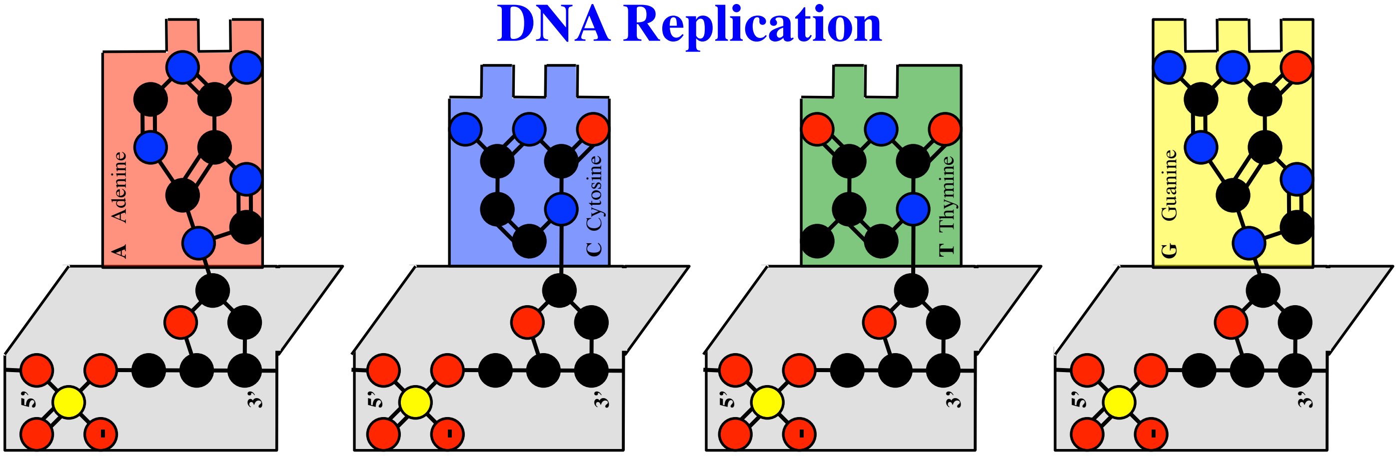
Photocopy this sheet if you want more. Optional: Use a glue stick to glue this sheet to cardboard before cutting out the models.

Chemical Models

Photocopy this sheet if you want more. Optional: Use a glue stick to glue this sheet to cardboard before cutting out the models.



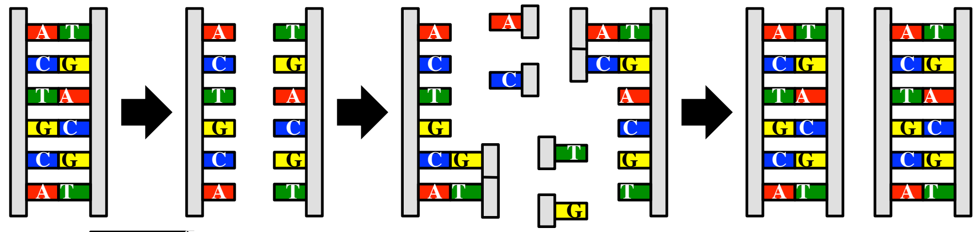
DNA Replication

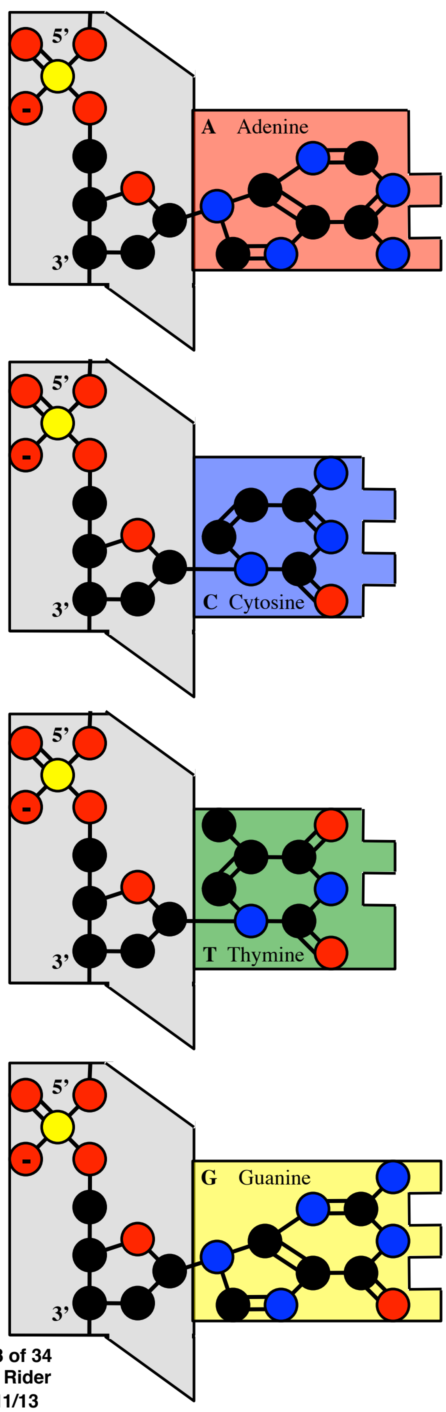


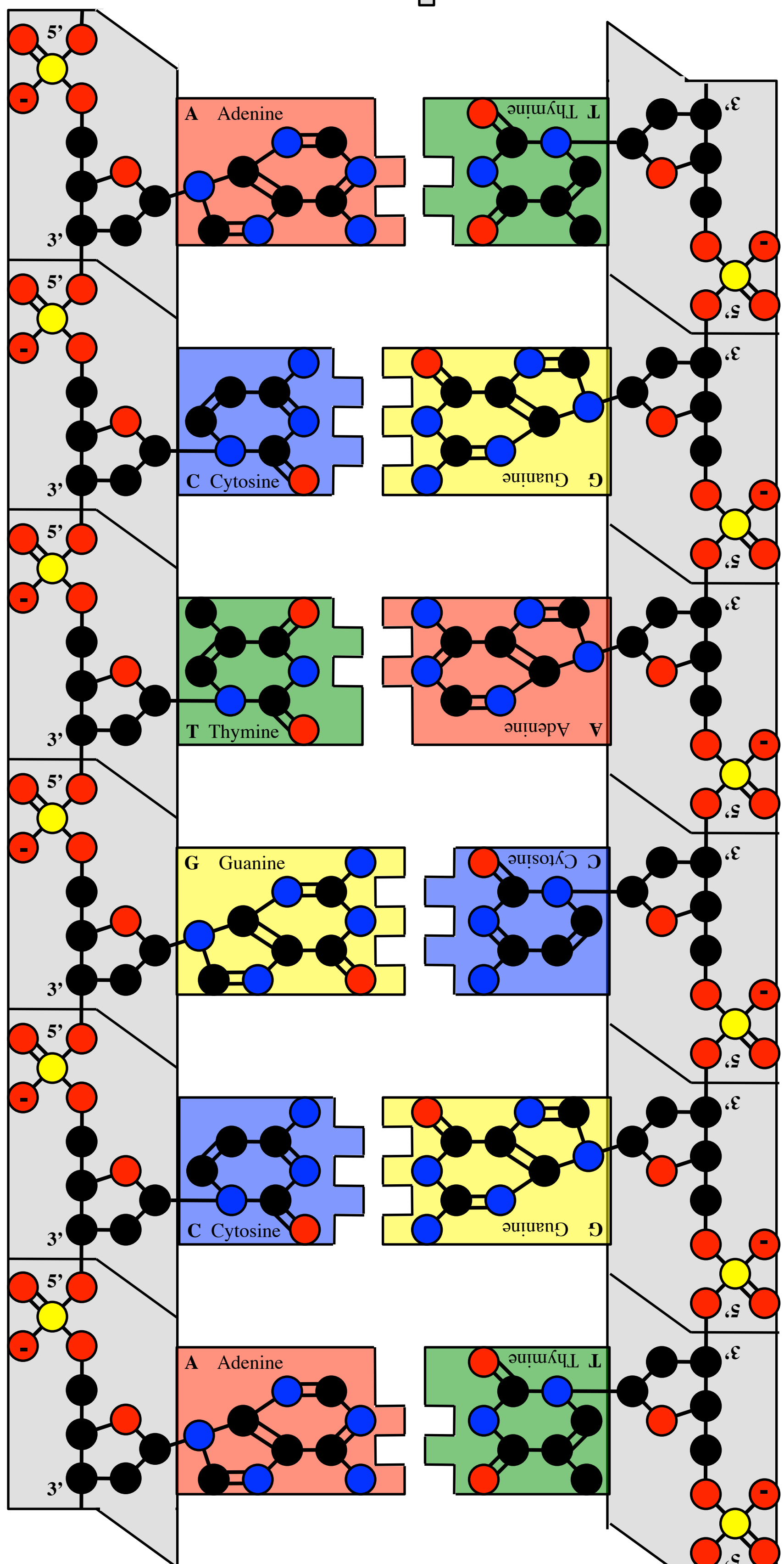
Todd H. Rider
2019/11/13

DNA Replication

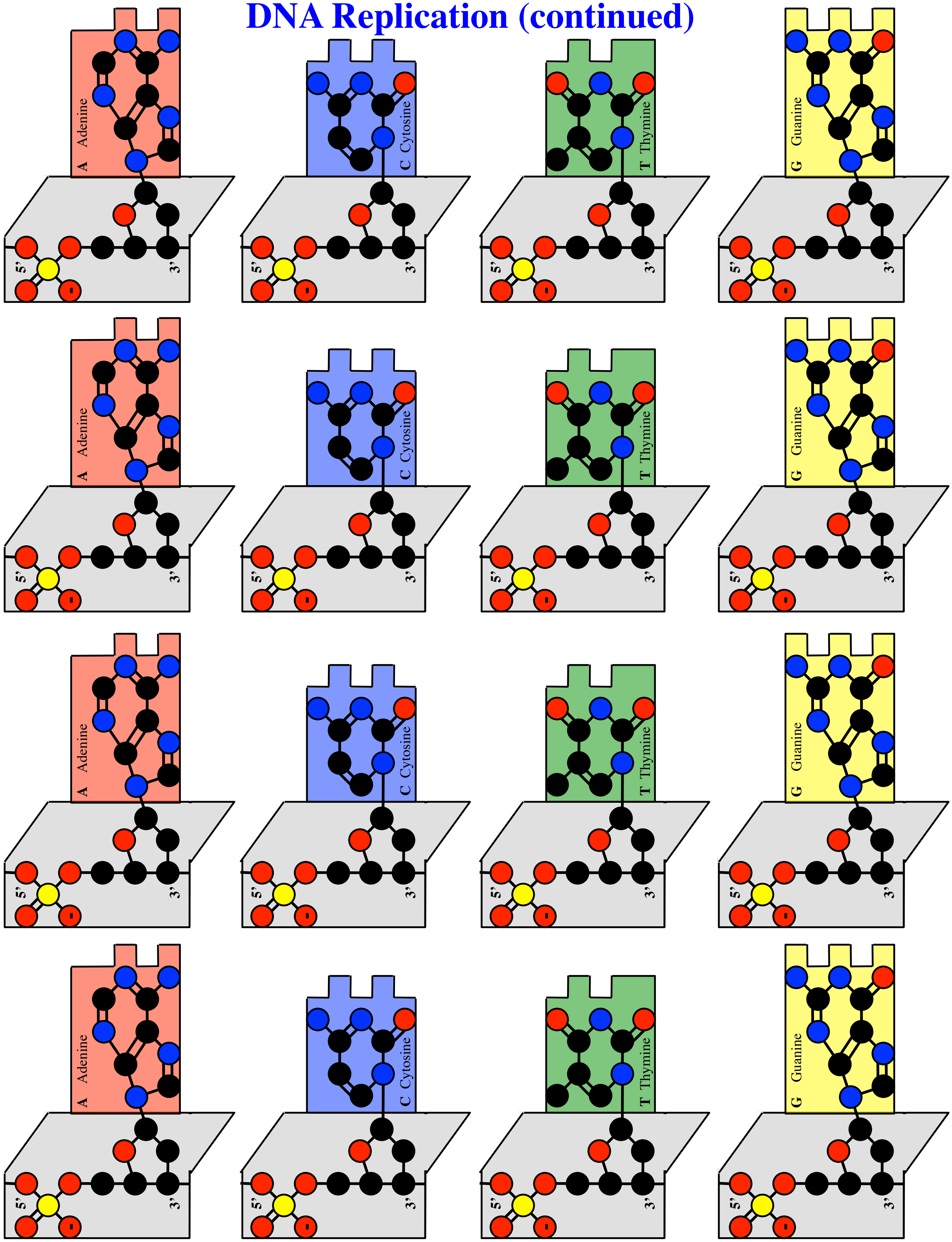
Photocopy pp. 32-34 if you want more or would like to enlarge them. Optional: Use a glue stick to glue pp. 32-34 to cardboard. Cut out the complete DNA strands and the component nucleotides and help replicate the DNA as shown (above right). For simplicity, hydrogen atoms in DNA are not shown. All nitrogen atoms have three electron bonds and all carbon atoms have four bonds; any bonds not shown connect to hydrogen atoms. Oxygen atoms with a – sign have only one bond and a negative electric charge. Scientists use the terms 5' and 3' to indicate which direction a DNA strand goes. New nucleotides are added to the 3' end of each strand.







DNA Replication (continued)



Hydrogen atom (not shown)
Carbon atom
Nitrogen atom
Oxygen atom
Phosphorus atom
Electron bond between atoms