TERRIFIC SCIENCE
EMPOWERING TEACHERS THROUGH INNOVATION

2018 MAARS Summer Workshop

High School Teachers

Jackson State University

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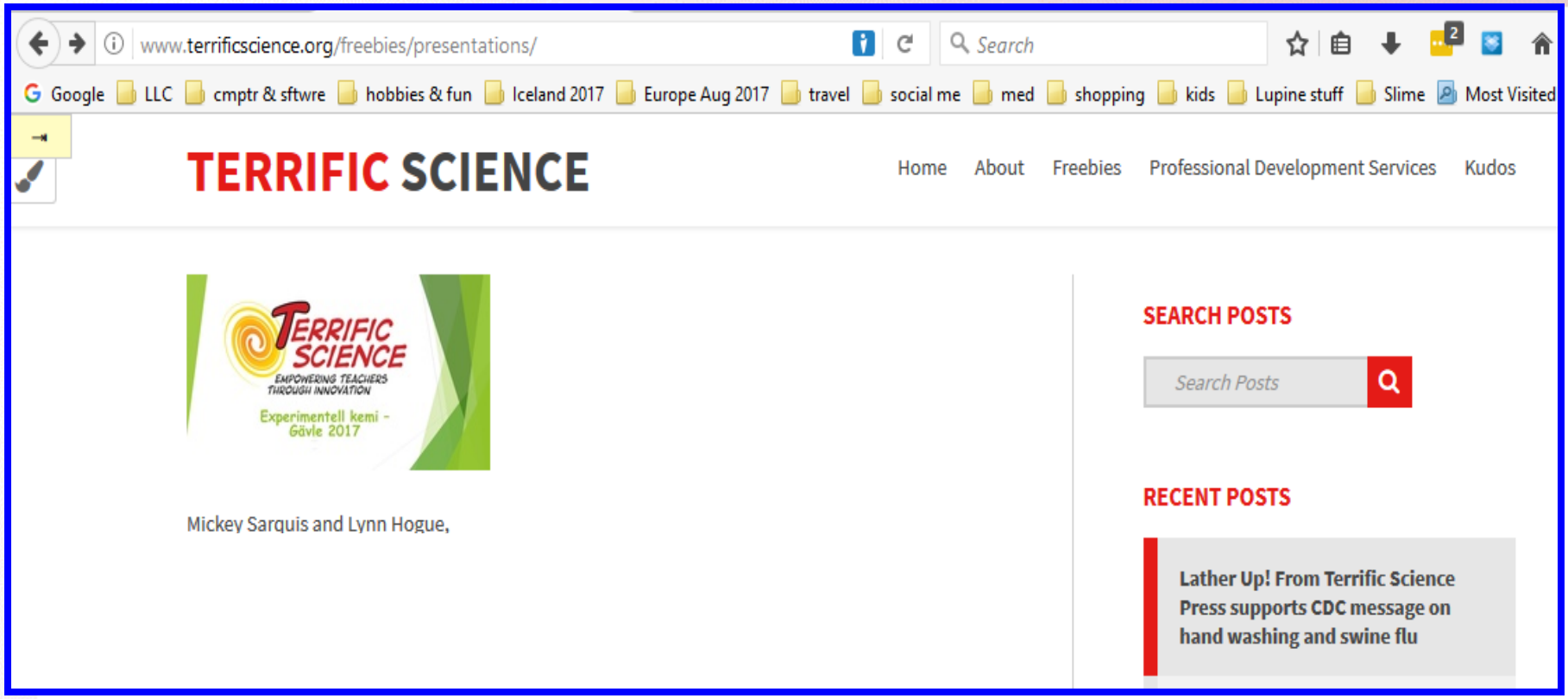
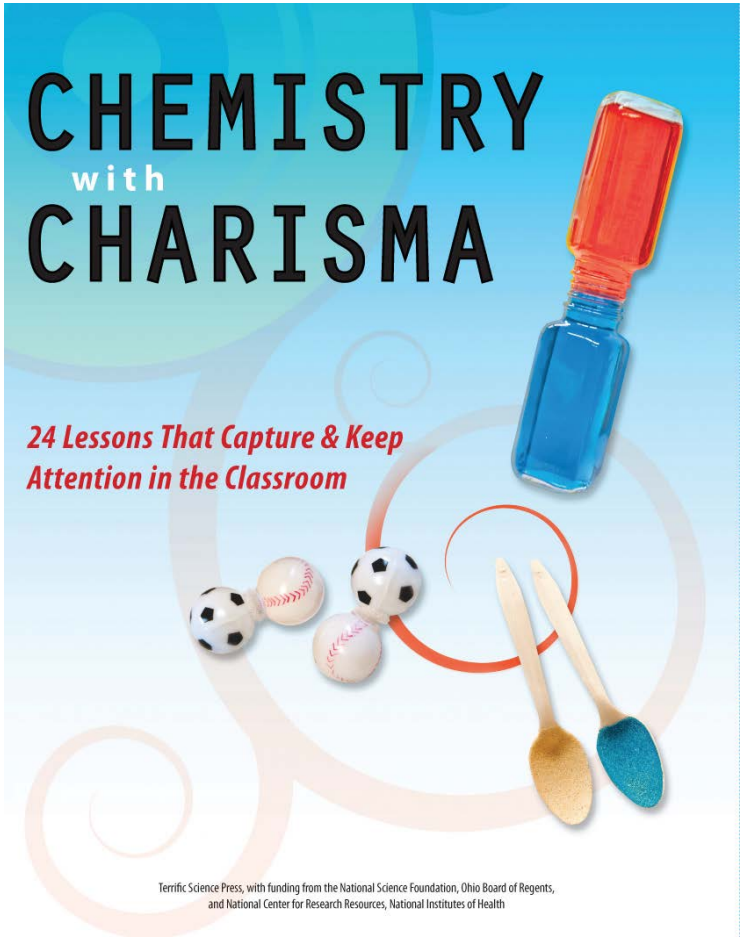
www.terrificscience.org



In addition to things we do with you
check out our resources at

www.TerrificScience.org/freebies/


CHEMISTRY
with
CHARISMA
24 Lessons That Capture & Keep
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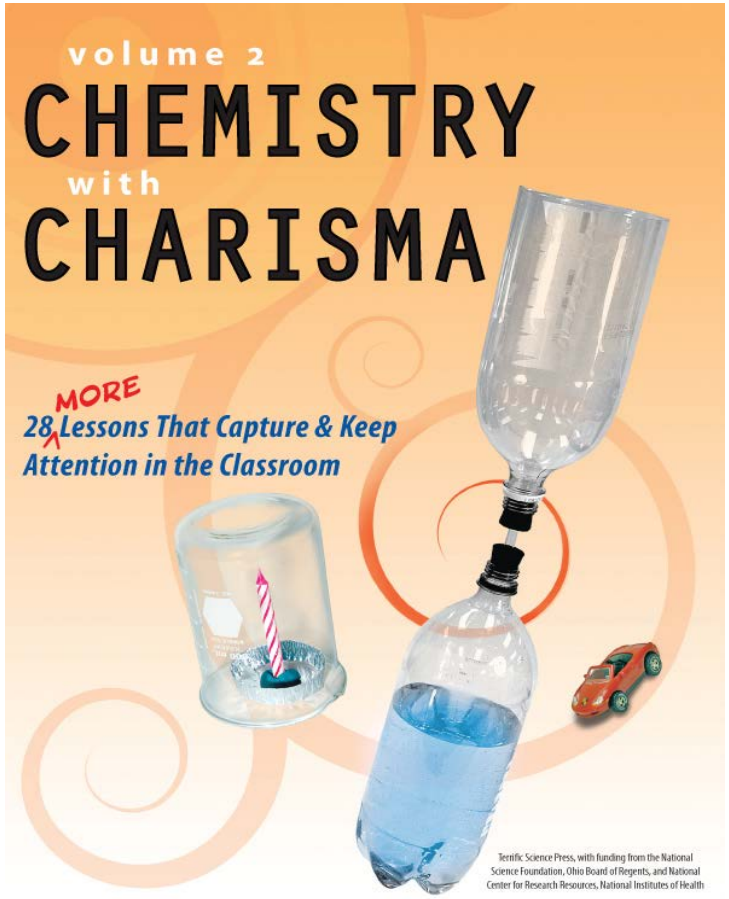
volume 2
CHEMISTRY
with
CHARISMA
MORE
28 Lessons That Capture & Keep
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Center for Research Resources, National Institutes of Health

Play *is learning without punishment!*

If I were to present myself before you with an offer to teach you some new game—
If I were to tell you an improved plan of throwing a ball,
of flying a kite, or
of playing leapfrog
Oh, with what **attention** you would listen to me!

Well, I am going to teach you many new games.
I intend to instruct you in a science full of

interest, wonder, and beauty

a science that will afford you amusement in your youth, and riches in your more mature years.

In short, I am going to teach you the science of **CHEMISTRY!**

— Dr. Scoffern, Devonshire, England,
Chemistry No Mystery, 1848

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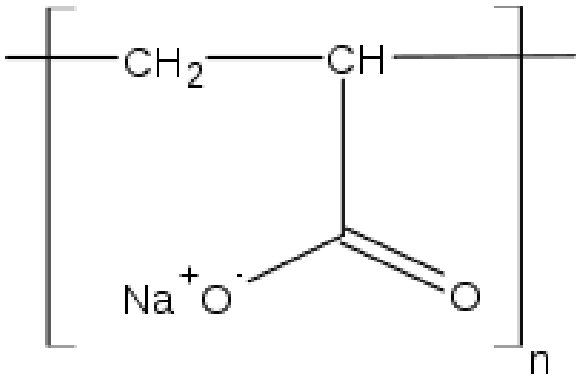
The old shell game.

How keen are your powers of observation?

“Super Slurper” (Sodium Polyacrylate)



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Students do it *All*

- ***do*** an activity or observe a demonstration
- ***form*** testable questions
- ***devise*** an experiment to answer their testable question
- ***make*** observations and collect data
- ***interpret*** data to provide evidence
- ***develop*** a claim about the system they are investigating
- ***use*** evidence to substantiate their claims

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So Your Challenge is to:

make observations
formulate testable questions
design an experiment
collect evidence
formulate a claim

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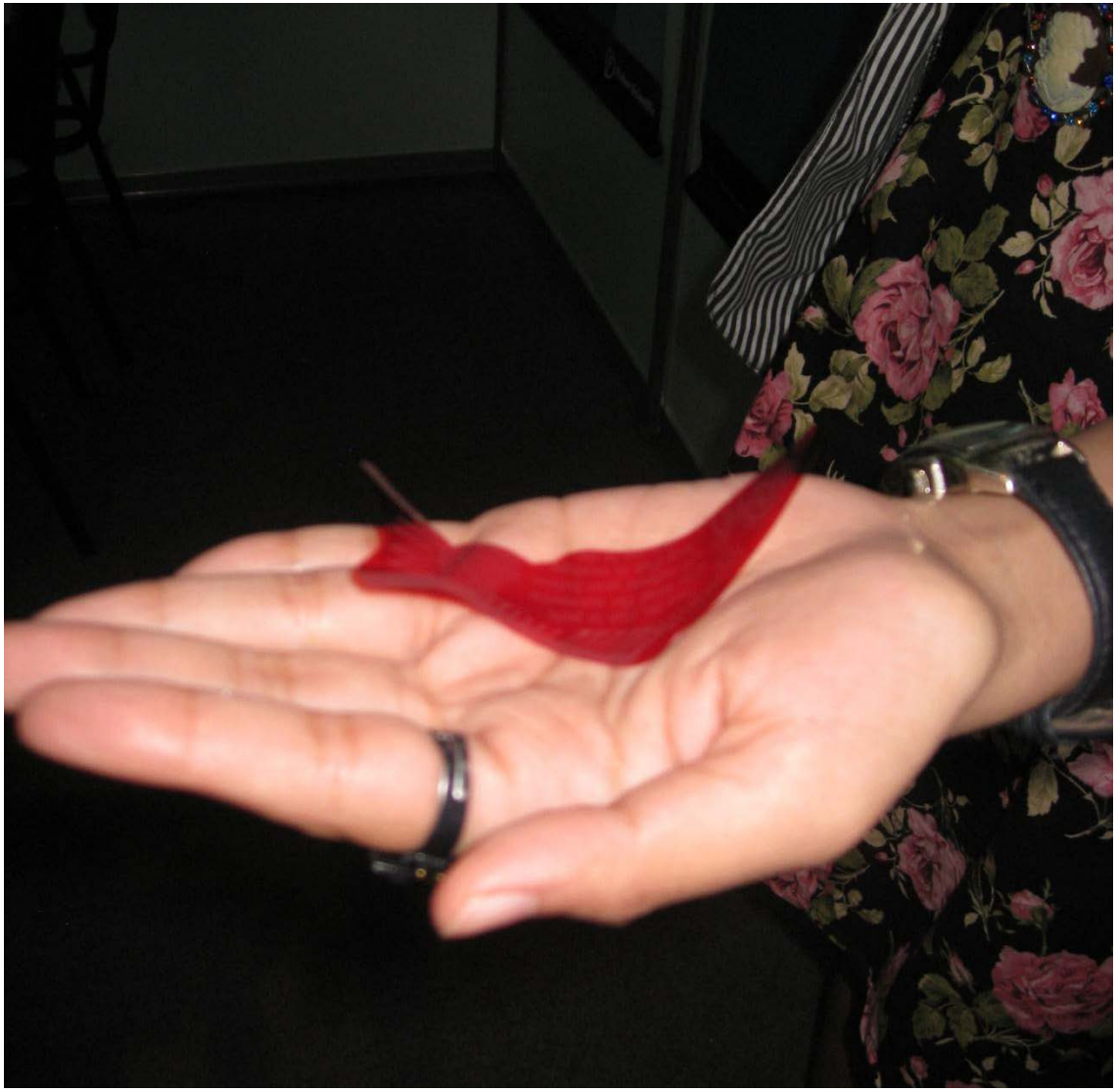

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Reusable Heat Packs

Crystallizing

supersaturated solution of aqueous sodium acetate

- How much of the sodium acetate remains in solution after this crystallization process?
- Design an experiment to determine the amount of heat required to recrystallize this solid.

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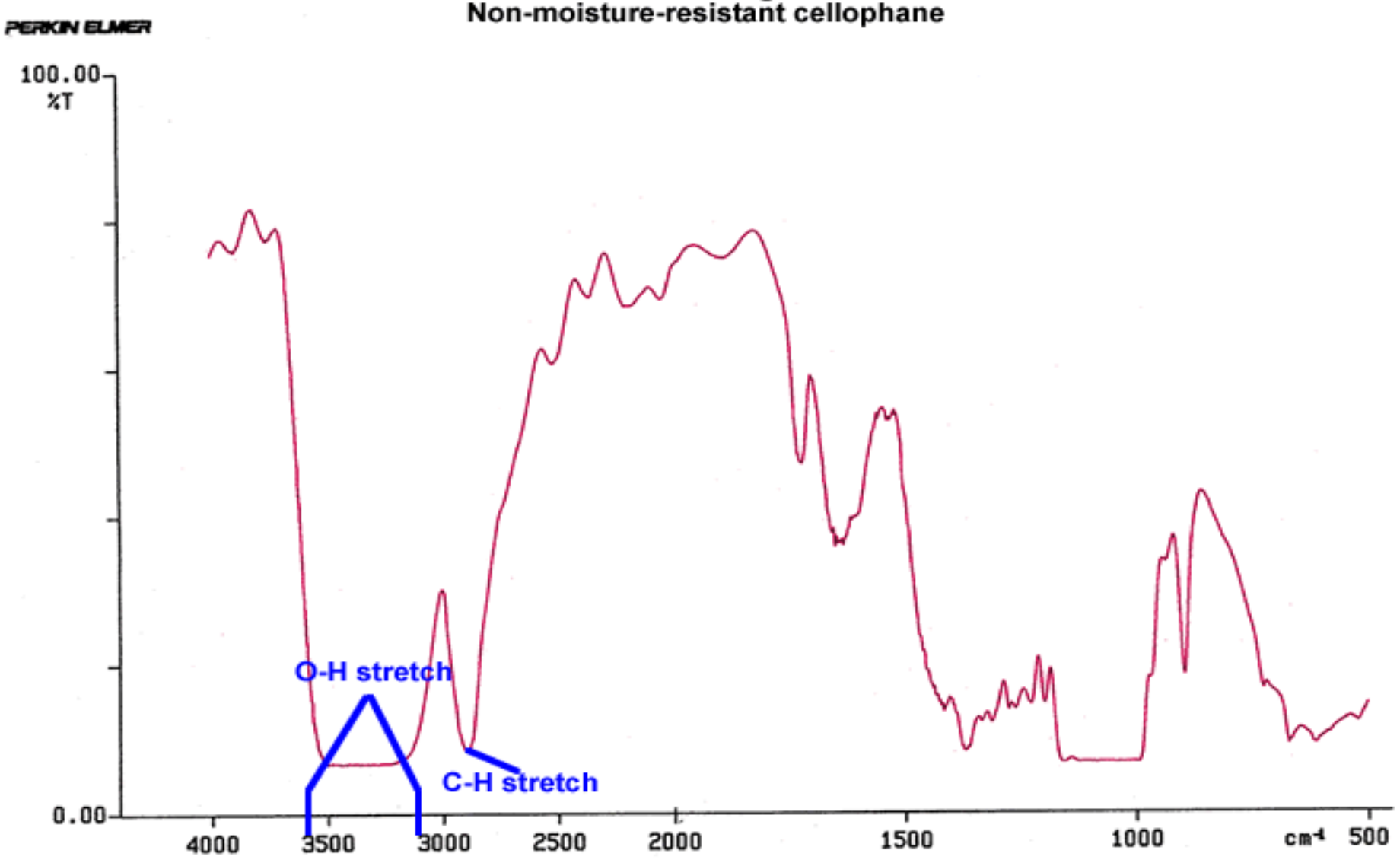
Additional research & literature reveals

Fortune Telling Fish
Non-moisture-resistant cellophane



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Fourier Transform Infra Red Spectrometer (FTIR)

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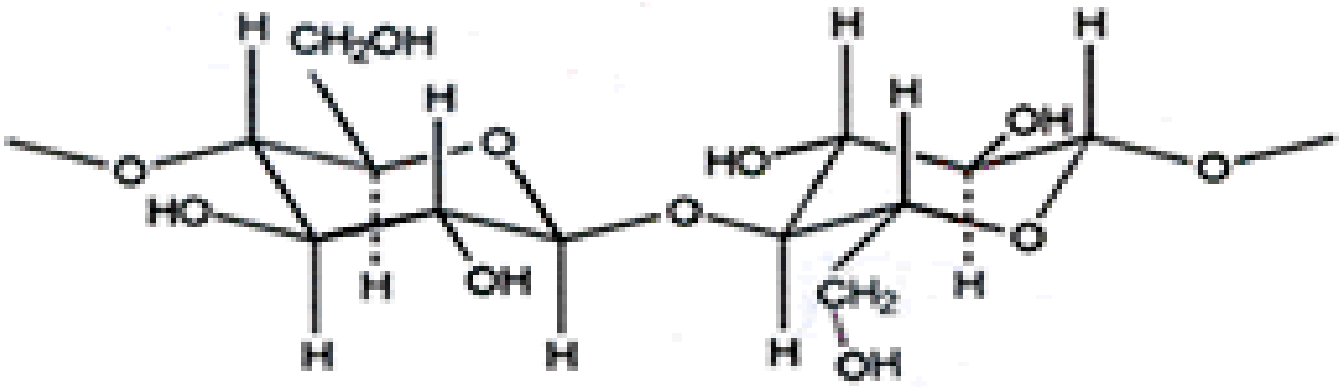
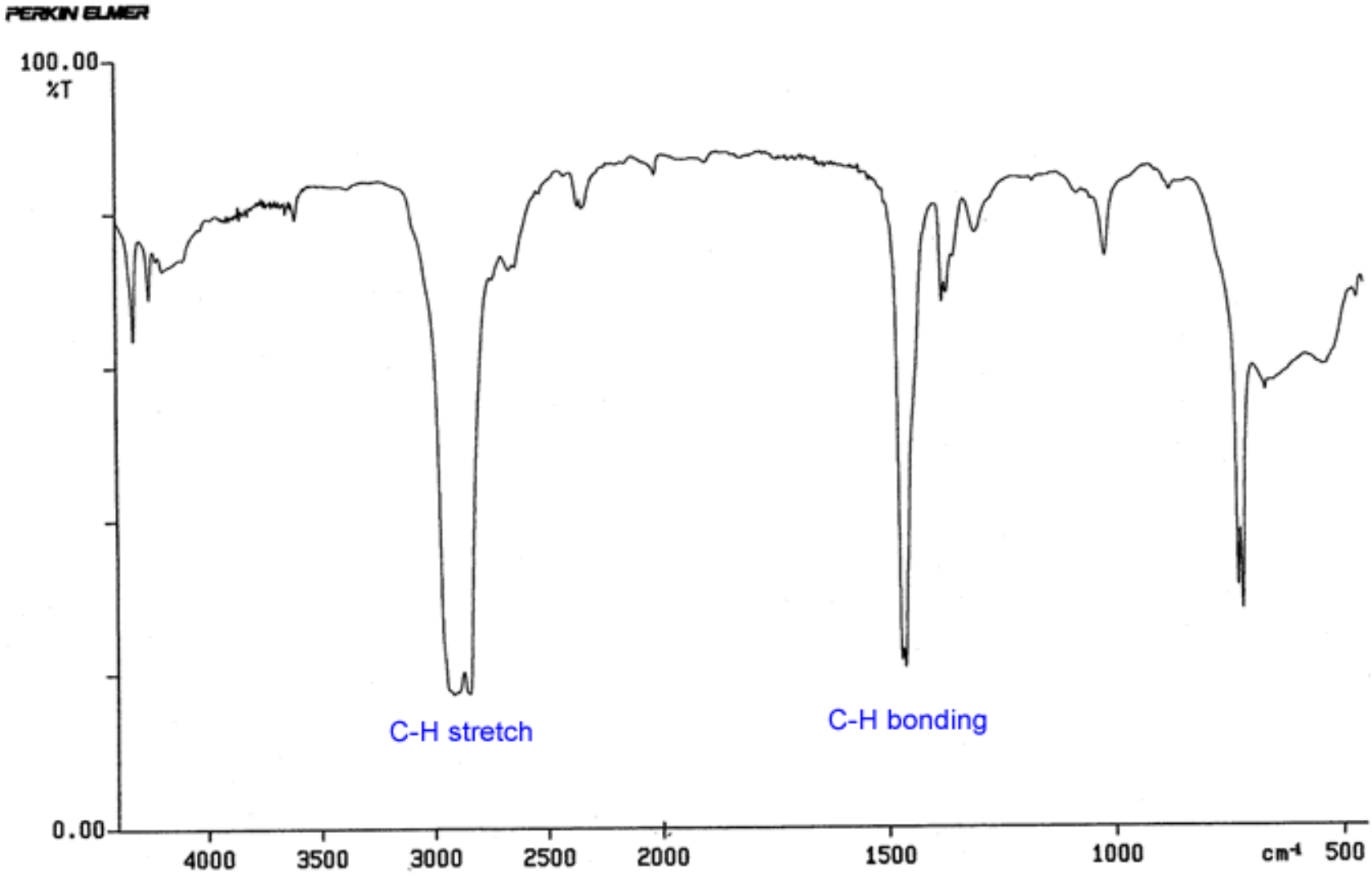
the fish is made of



Cellulose

Wrapper for Fortune Telling Fish



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Fourier Transform Infra Red Spectrometer (FTIR)

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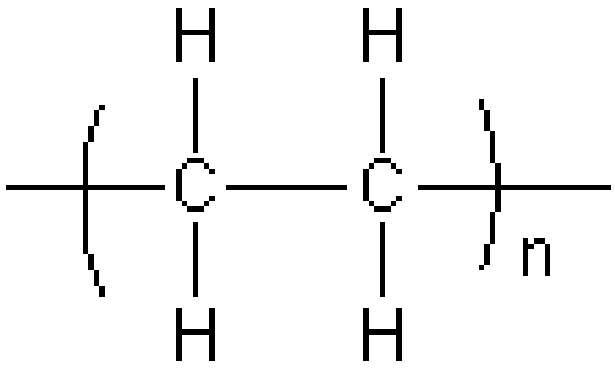
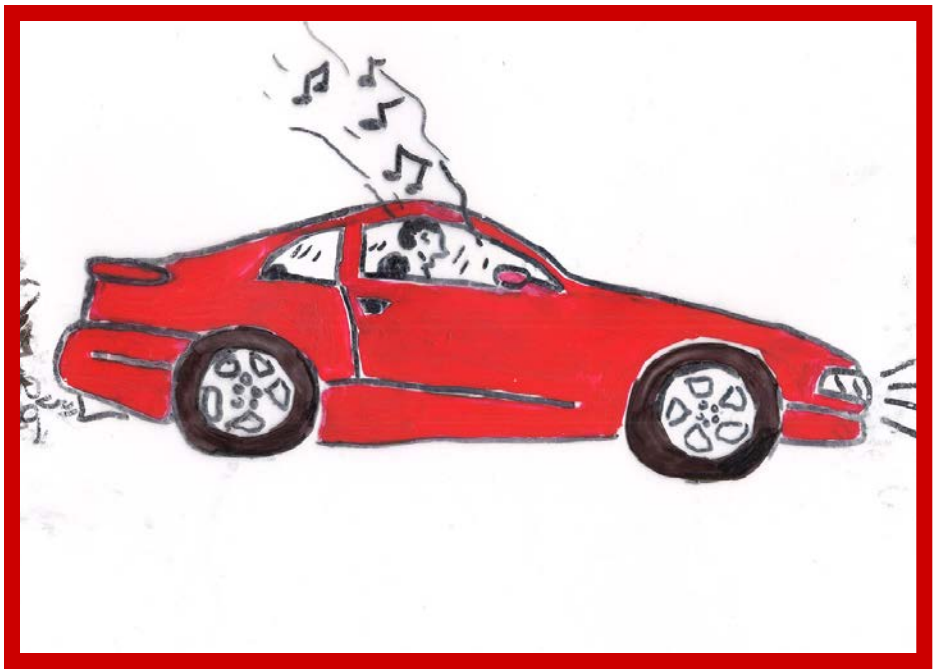
the wrapper is made of

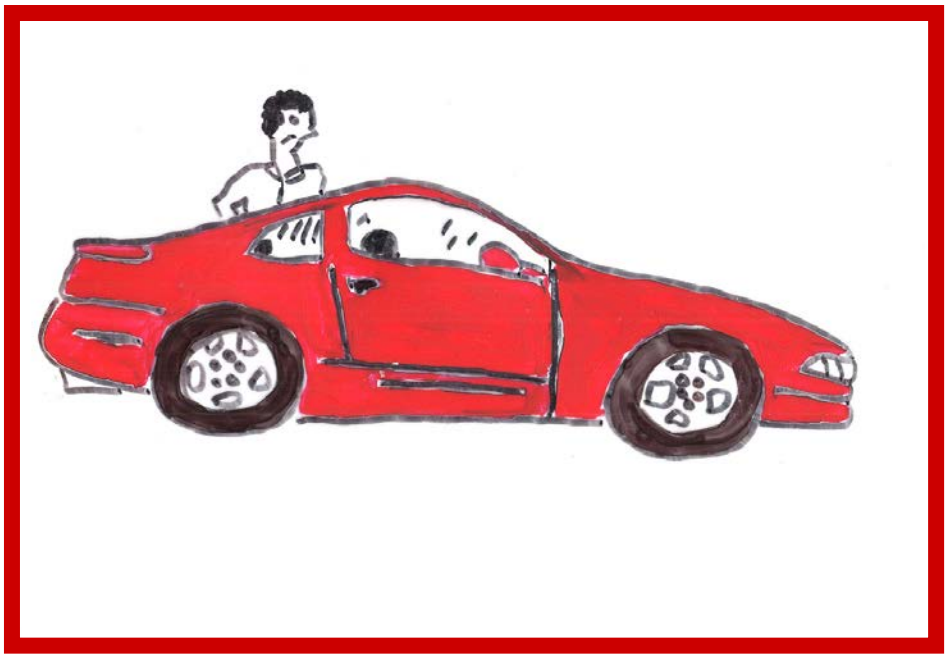


Polyethylene

Where Would We Be Without Chemistry?

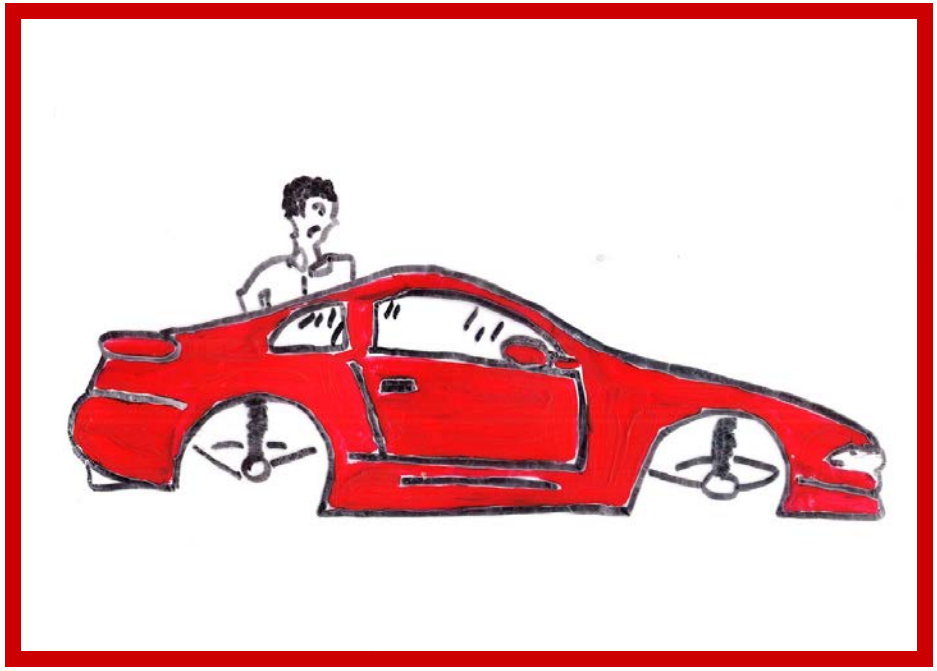


Where Would We Be Without Chemistry?



no chemical reactions

Where Would We Be Without Chemistry?

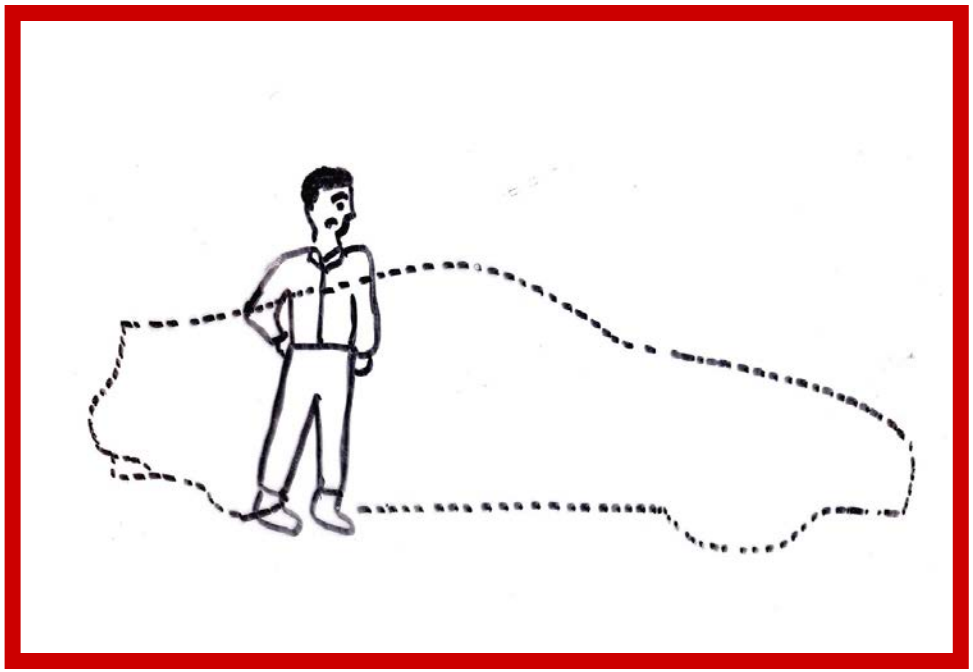


no leather or rubber

Where Would We Be Without Chemistry?

no paint or coatings

Where Would We Be Without Chemistry?



no metals or polymers

Where Would We Be Without Chemistry?

No fabrics

Where Would We Be Without Chemistry?

70 kg male

H_2O	50.1 kg
C	12.6 kg
N	1.8 kg
Ca	1.7 kg
P	.68 kg
K	.25 kg
Na, Mg, Fe, etc	.32 kg

Where Would We Be Without Chemistry?

No you!

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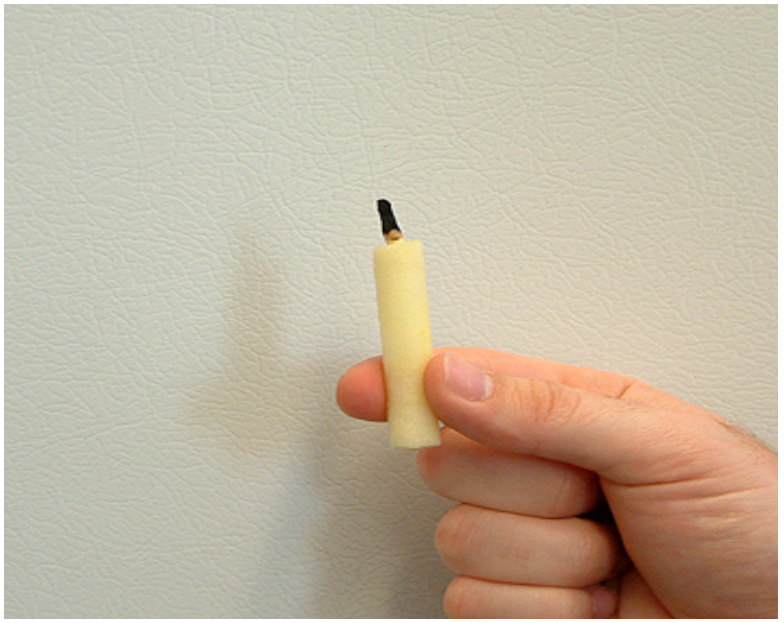
What types of observations?



Qualitative Observations

Quantitative Observations

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Discrepant events are only possible if ***prior experience*** *would tell you otherwise*

"Expect the unexpected"

Chinese proverb

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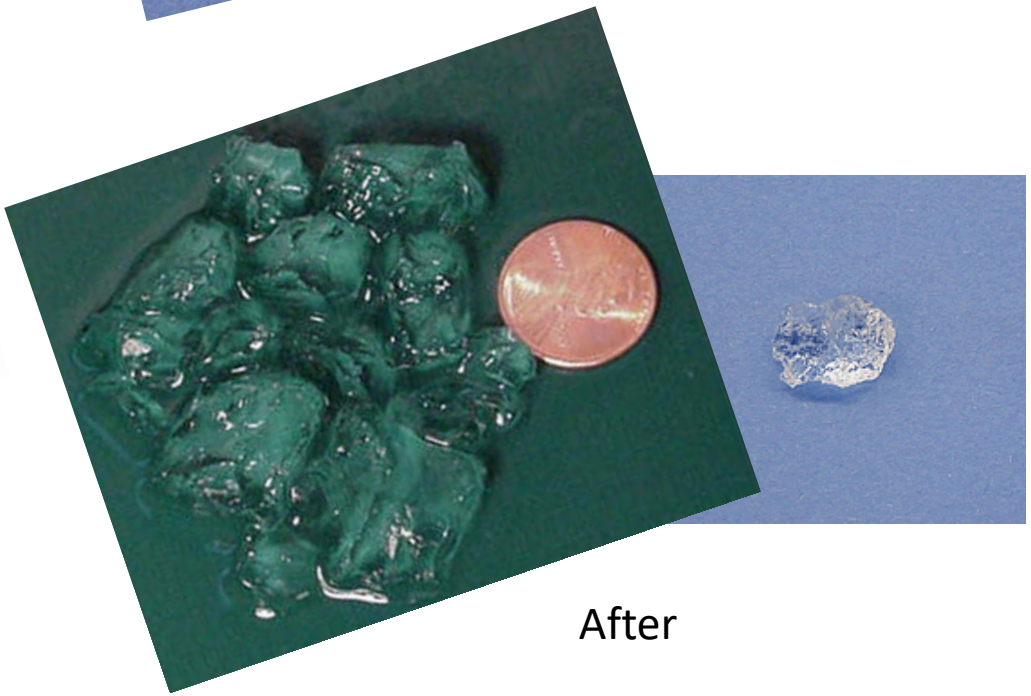
What's your testable question?

sodium polyacrylamide

Before



After

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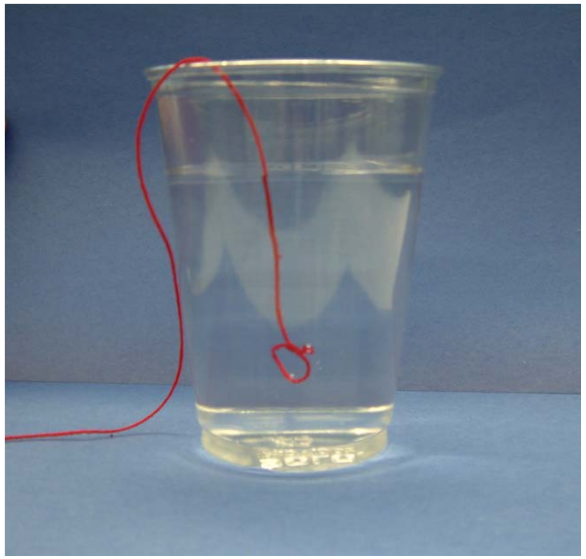
A little physics too

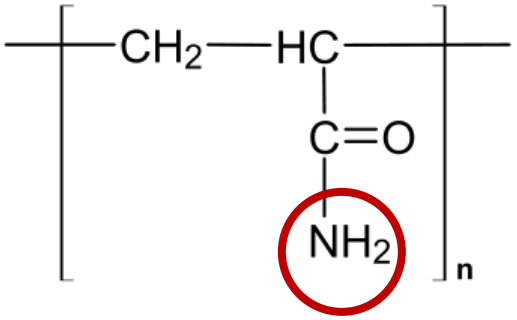


What makes this crystal seemingly invisible?

And this one isn't?

Water saturated polymer has the same index of refraction as water

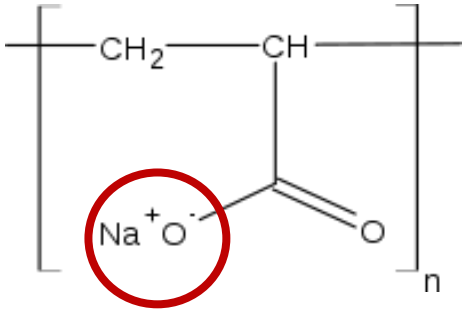
close relatives



polyacrylamide
Soil Moist

sodium polyacrylate

‘Where’d the water go?’ demo



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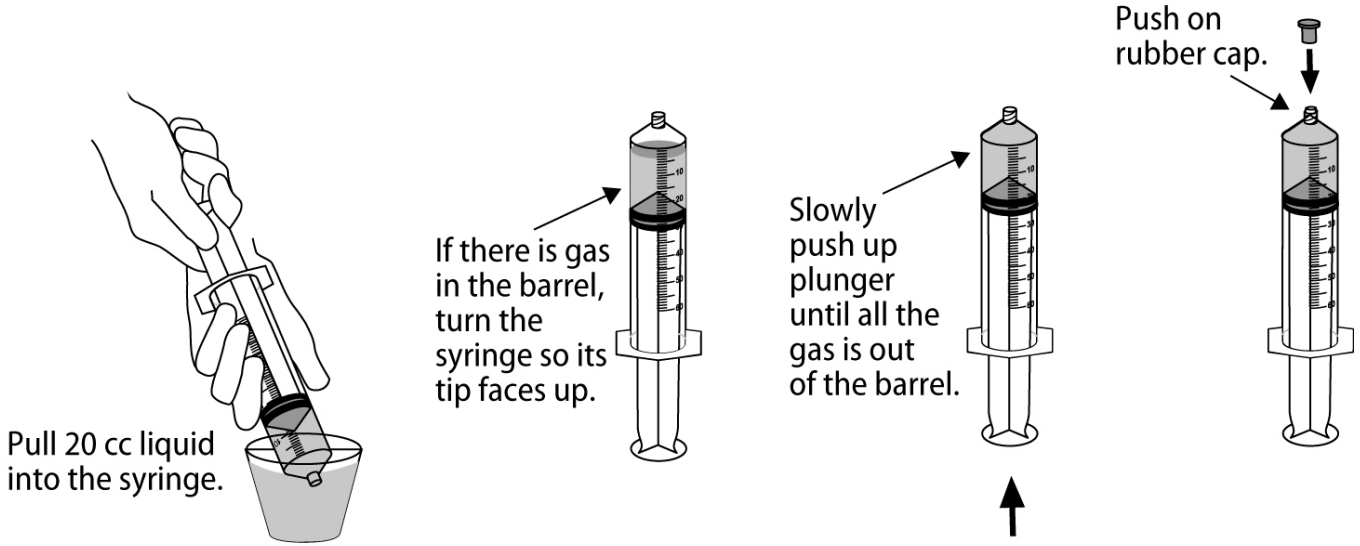
Reunite the FUN and MENTAL aspects of scientific play !

- By combining the fun/hands-on and mental/minds-on aspects of science teaching and learning, we have found that BOTH increased motivation and understanding result.

Exploring solids, liquids, & gases in a syringe



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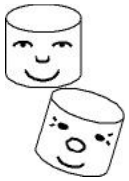
From phenomena to student generated models…

- Trap air inside a syringe. Observe as you increase and decrease the pressure.

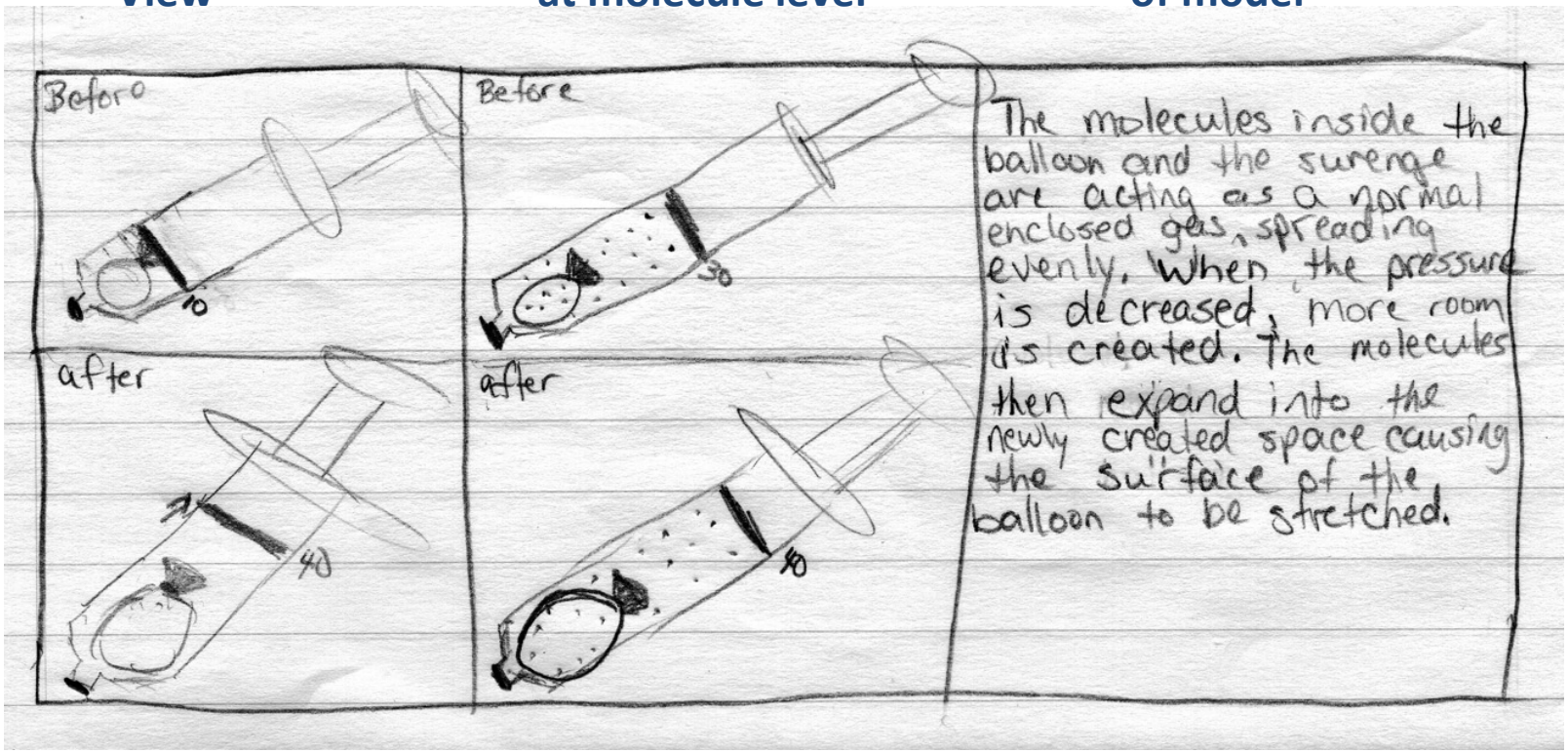
- Put a small, tied-off balloon into the syringe. Close the system. What happens if you decrease the pressure in the syringe?

- Repeat the experiment with a marshmallow. What happens?



HS Student's Visualization & Storyboarding

Macroscopic View | **Visualization at molecule level** | **Explanation of model**



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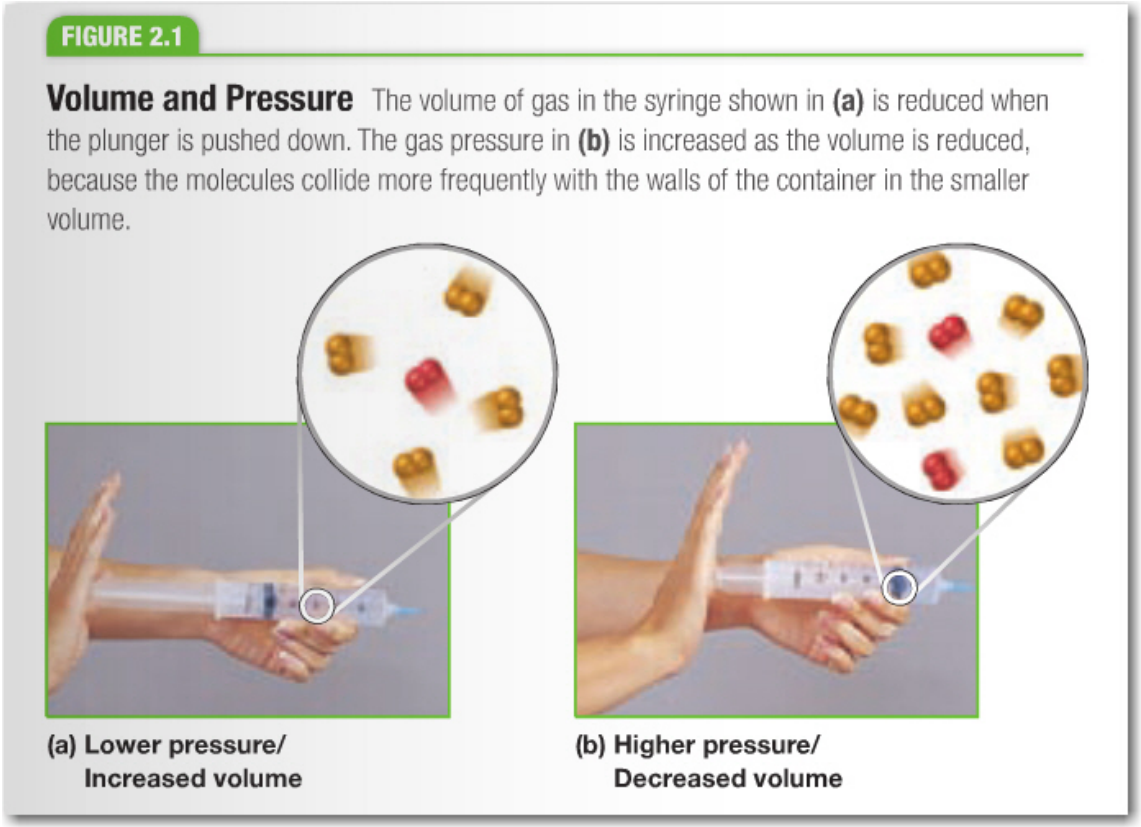
- Trap air inside a syringe. Observe as you increase and decrease the pressure.



What's the evidence that the pressure inside is increased?

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What do whoopee cushions, potato guns, and exploding straws have in common?

Straws: Science Tools

Work in pairs.
One partner hold a straw.
The other prepare to flick.
Then

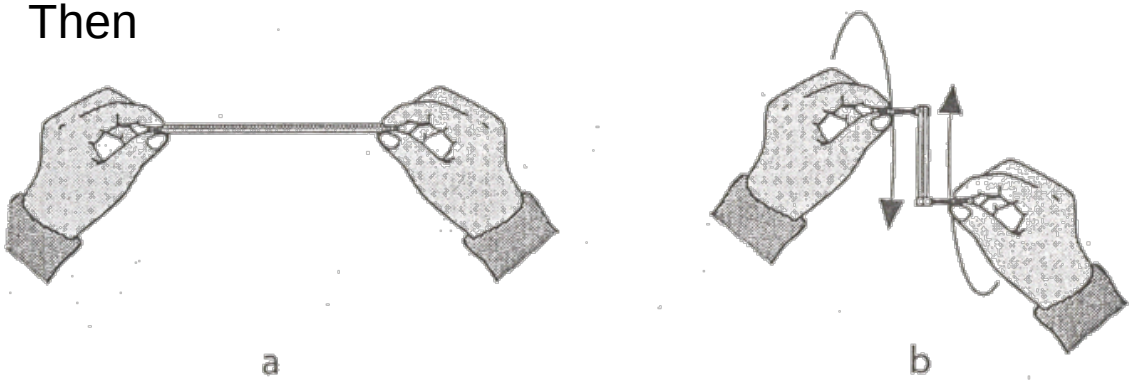
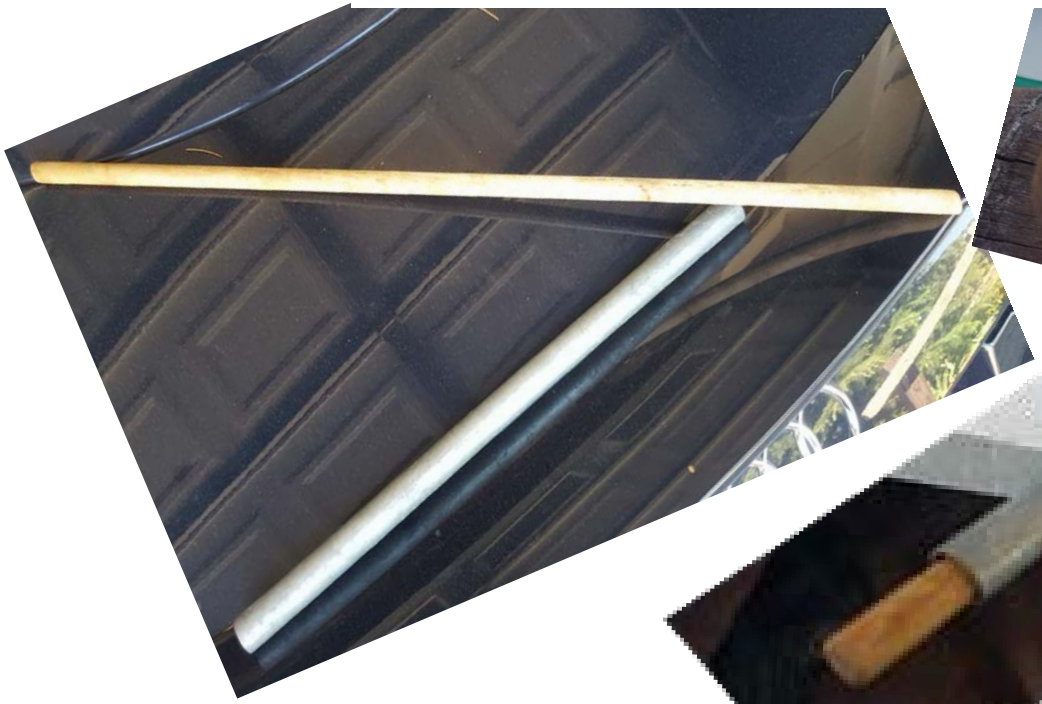


Figure 3: After (a) grasping the straw with both hands, (b) twist one hand over another until about two inches of unrolled straw are left in the middle.

Home-made potato shooter

wooden dowel rod (1cm diameter at least 60cm long)



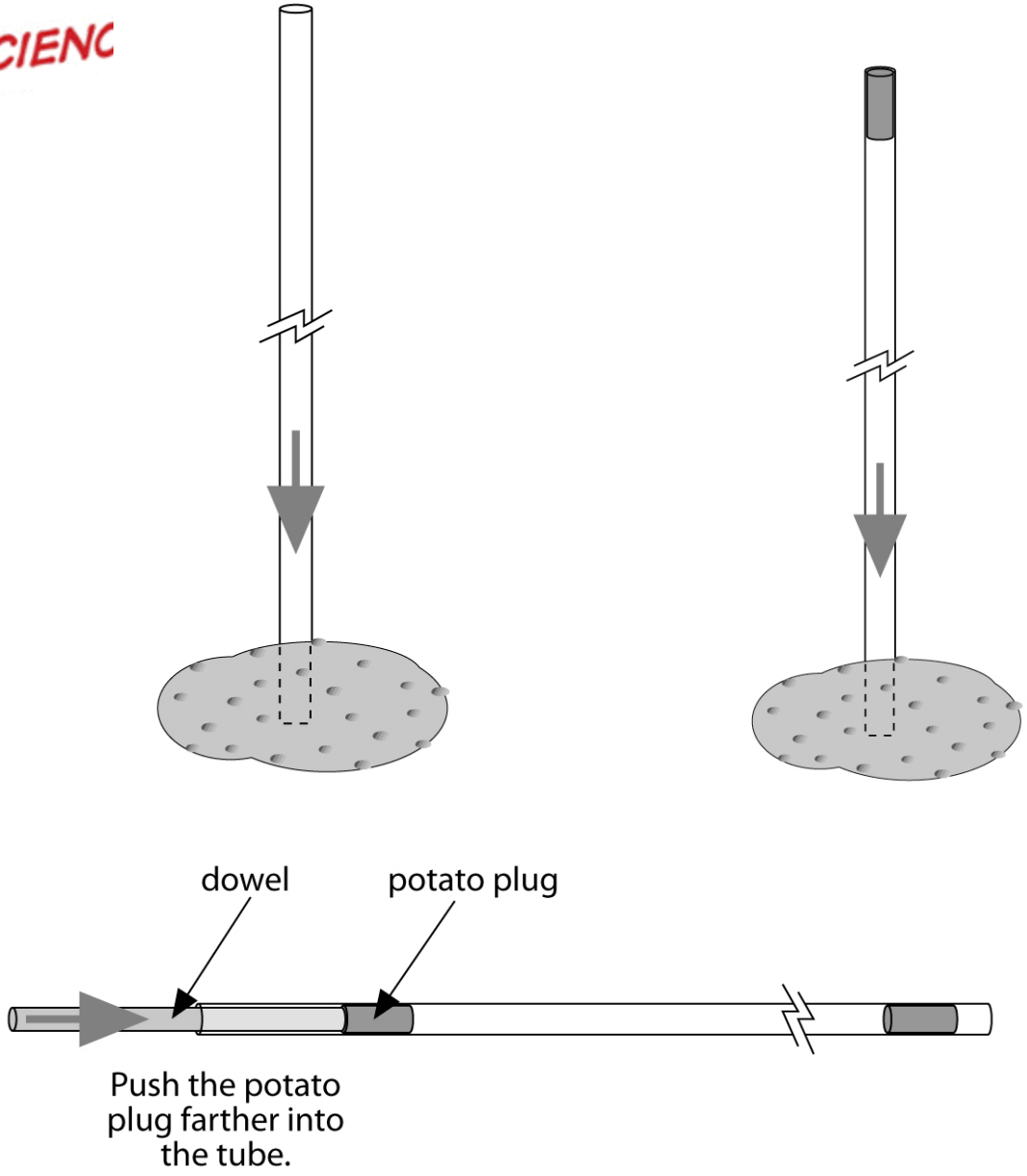


Figure 4: Push the plug 5–6 cm (about 2 inches) into the tube with the dowel.

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Charles Law meets the bubble film

Simple… yet surprising

&

they are doing it!

Placement in your curriculum

- gas laws ($V \alpha T$)

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fizz keeper

preform

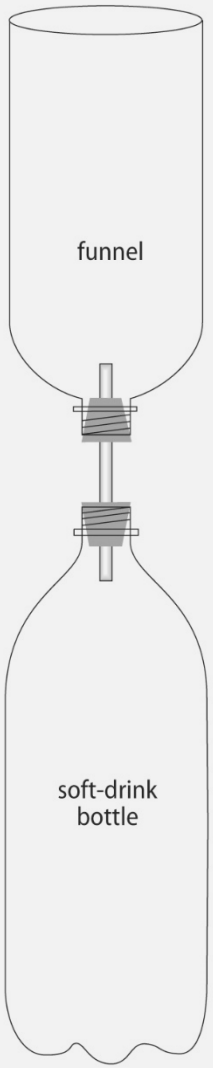

Figure 1: Assemble the setup.

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~~Hiccup~~ bottle

Burping bottle

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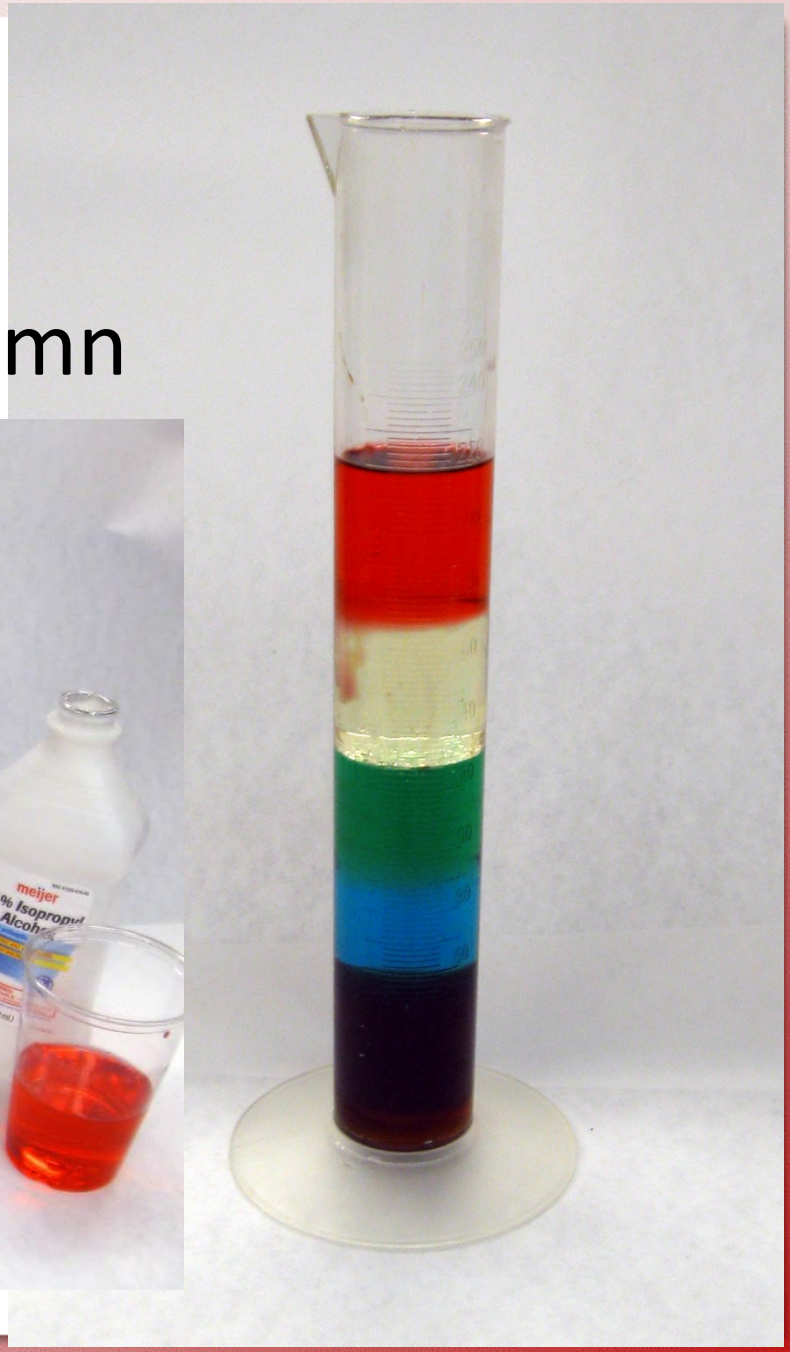
Household Density Column



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What's happening here?

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Can you pour a gas?

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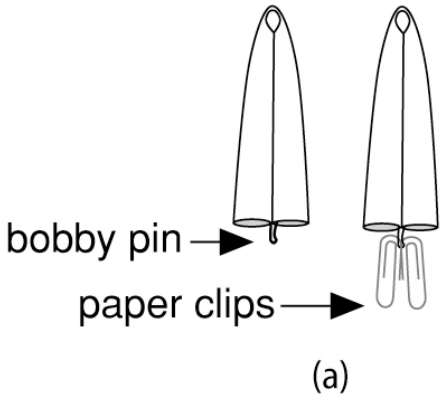
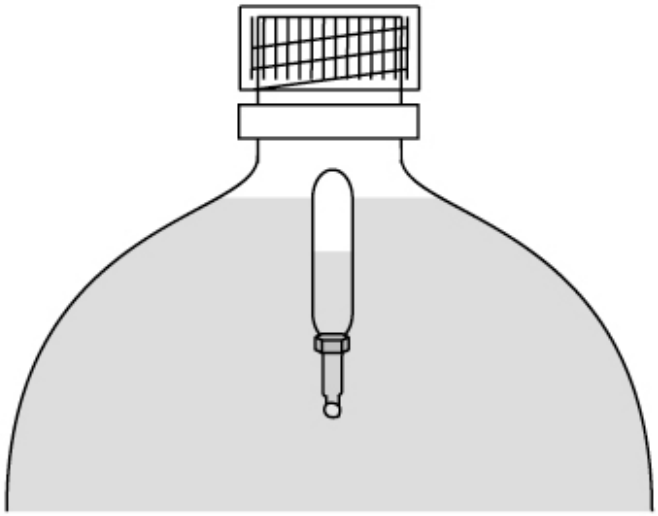
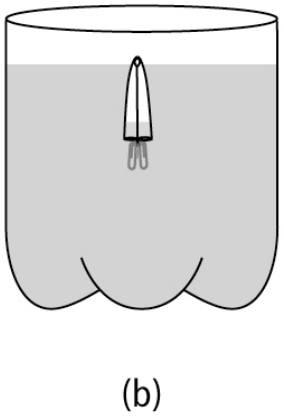
Cartesian Divers







Beral Pipet

Folded straw

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Ok.. Do it without pushing it with your hands!

What pushed the egg in?

atmospheric pressure

Can you use a raw egg in its shell?

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Collecting evidence to understand the system

The System

Procedure:

- Light the candle
- Invert jar or other container
- Quickly lower it over the candle & into the water

Students observe:

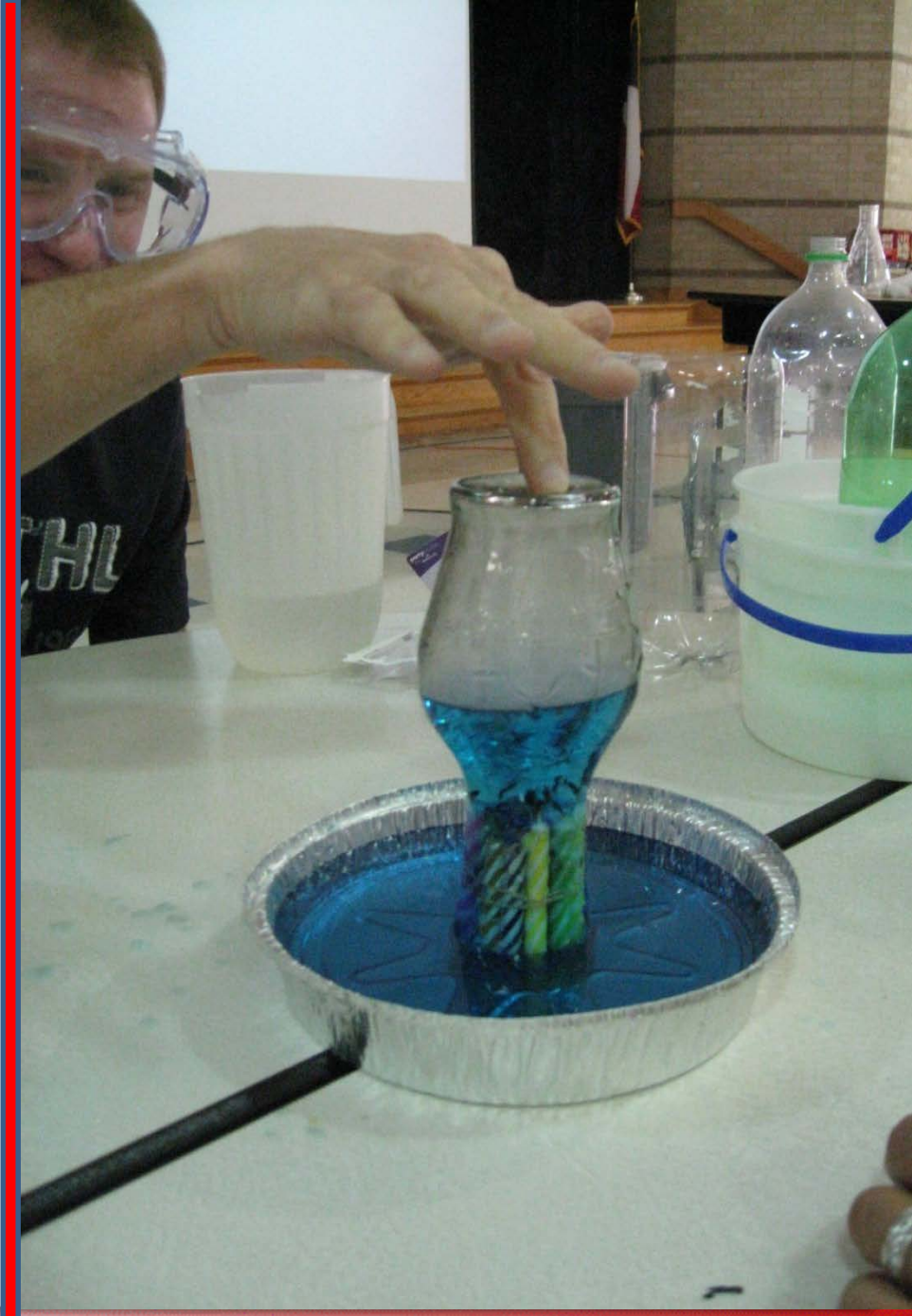
- A few bubbles at the very beginning (~40% of the time)
- Water rises into the jar
- The flame goes out
- Water continues to rise even after flame is out

What *testable* questions can you ask?

What variable would you change that could allow you to collect information to answer your question?

Group 1

Does increasing the amount of heat affect the results ?



Group 2: testable question

Does the height of the candle change the results?


TEXAS
2006
BLOOD DON

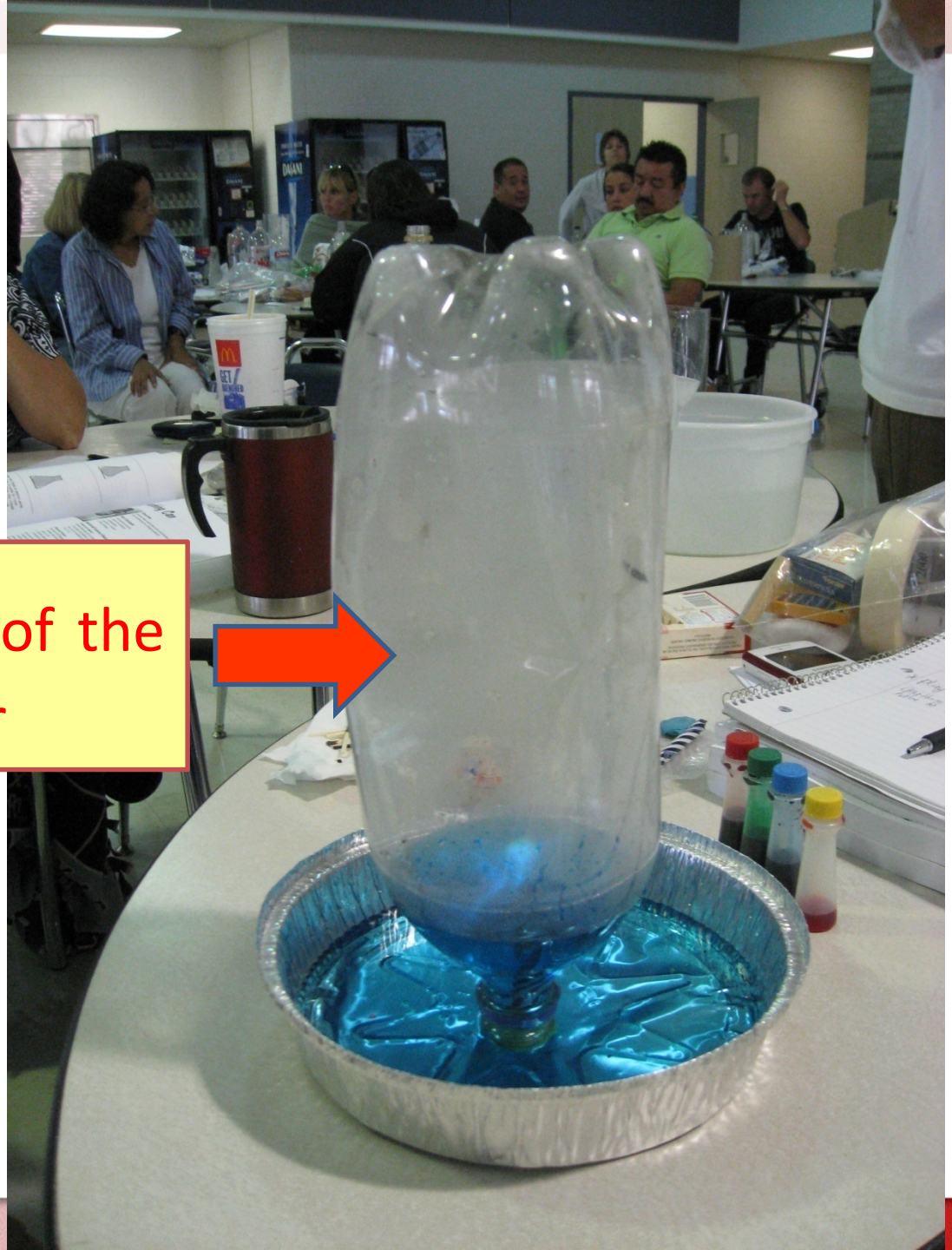
Group 3

Does a larger bottle affect the results ?


DAJANI

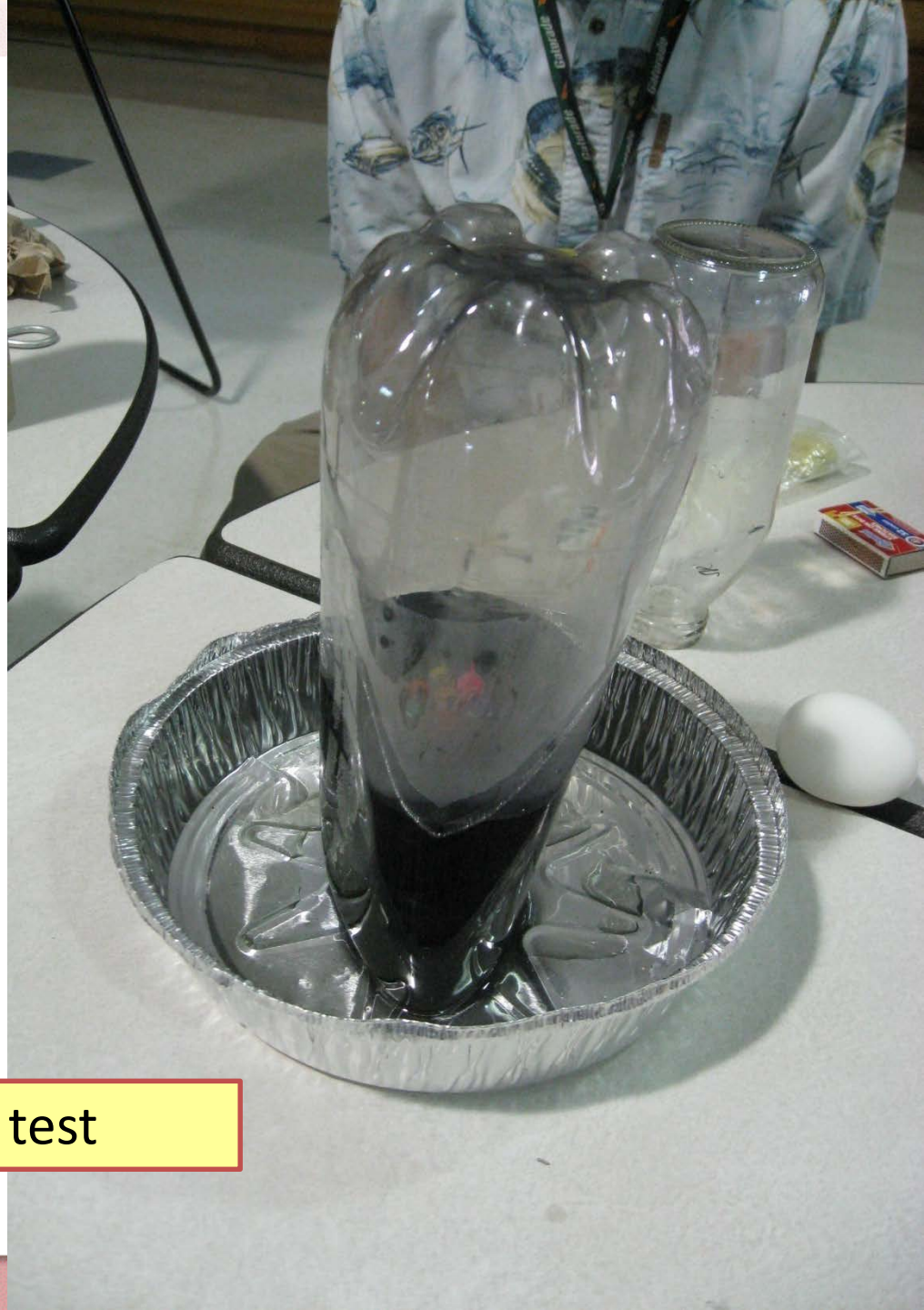
Group 4

Note the sides of the container



other views

Group 5



Another group tries a similar test

What happens when the warm jar is NOT placed over the candle?

What if the jar is held over the candle for a VERY long time?

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Pooling results…

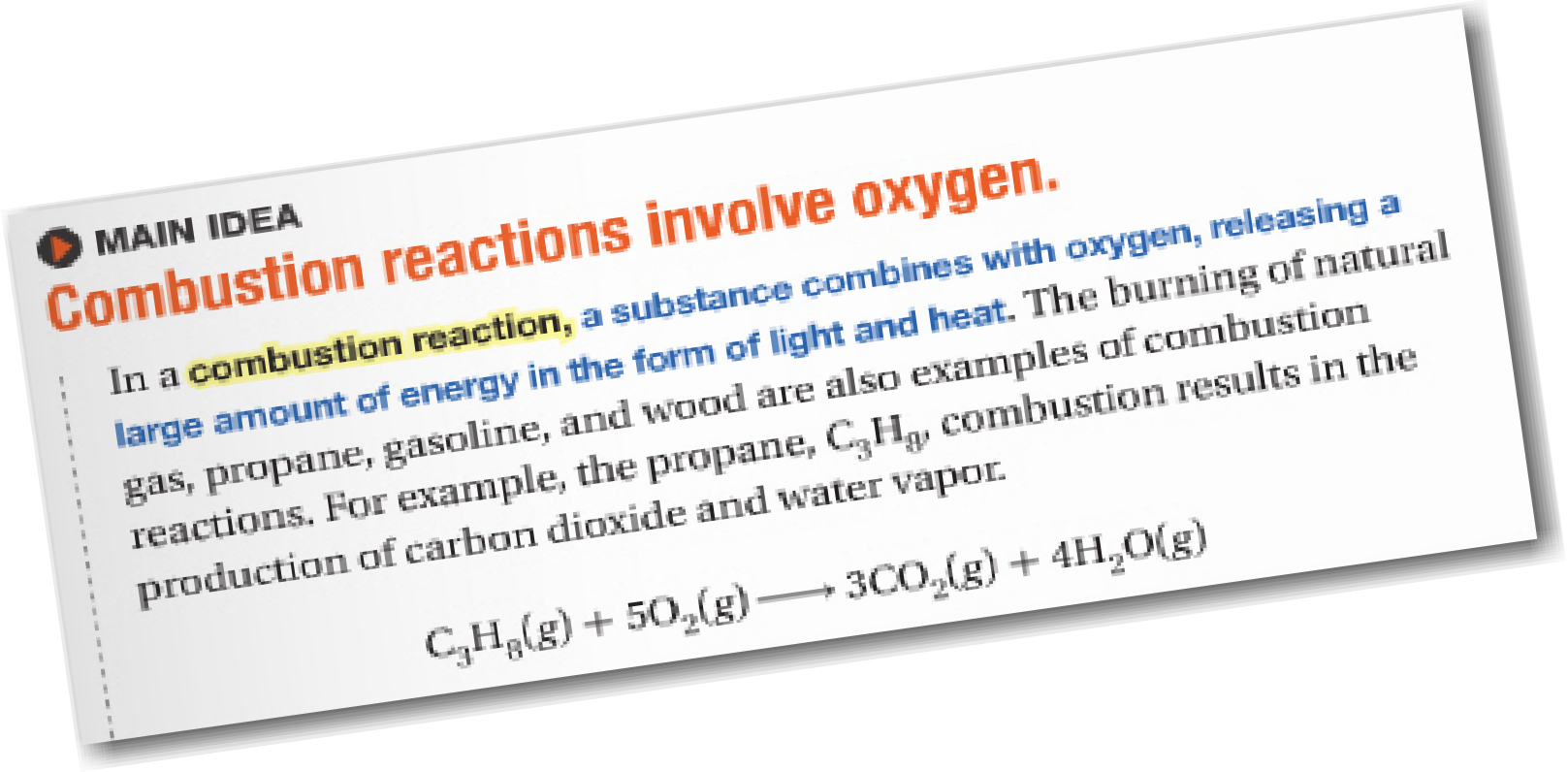
The Sum is Greater than the Parts

- As groups share their claims and evidence with the class, the knowledge base of the class increases.
- As a class, they negotiate meaning from the various studies that were undertaken.
- Formulate more advanced claims as the discussion progresses.

What would most kids say was responsible for the water rising into the container?

the Oxygen was used up…

… but is that the whole story?



MAIN IDEA

Combustion reactions involve oxygen.

In a **combustion reaction,** a substance combines with oxygen, releasing a large amount of energy in the form of light and heat. The burning of natural gas, propane, gasoline, and wood are also examples of combustion reactions. For example, the propane, C_3H_8, combustion results in the production of carbon dioxide and water vapor.

$$C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g)$$

Resource search reveals

Charles' Law: $V \propto T$

accounts in part for

- the bubbles observed initially $T\uparrow V\uparrow$
- water moves into jar $T\downarrow V\downarrow$

BUT wait.. There is MORE to search…

Yet more….

Gay-Lussac's Law: $P \propto T$

accounts in part for

- the bubbles observed initially $T\uparrow P\uparrow$
- water moves into jar $T\downarrow P\downarrow$

BUT wait.. There is MORE to search…

And more…

$n \propto P$

BUT wait.. There is MORE to search…

And more …

Avogadro's Law: $V \propto n$

But is “n” changing?

Combustion of wax

Candle wax is typically paraffin C_nH_{2n+2}

$$C_{17}H_{36}(g) + 26\ O_2(g) \rightarrow 17\ CO_2(g) + 18\ H_2O(g)$$

Moles of gas as reaction occurs:

1 (g) + 26(g) → 17(g) + 18(g)

27 moles (g) reactants 35 moles (g) products

n↑V↑

When the system cools: $18\ H_2O(g) \rightarrow 18H_2O(l)$

Moles of gas once cooled:

1 (g) + 26(g) → 17(g) + ~~18 (l)~~

27 moles (g) reactants 17 moles (g) products

n↓V↓

n↓P↓

Phases changes make a difference

1 gram of $H_2O(g)$ occupies about

1300 times

the volume of the same mass of $H_2O(l)$! ! ! !

Using chemistry to crush an Al can

A used soda can

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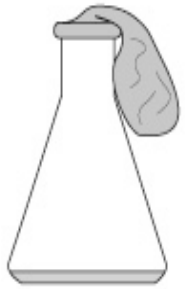
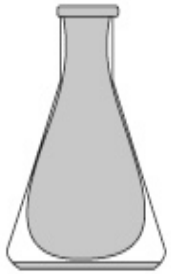
Safety mandates demos at times…

Balloon in a Flask

Boiling water →



Cap flask with balloon



Remove from heat and cool

…doesn't eliminate testable questions or experimental design

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Challenge the students to be mentally engaged…

- What should we try?
- You follow their suggestions within safety limits
- Students make observations & analysis results

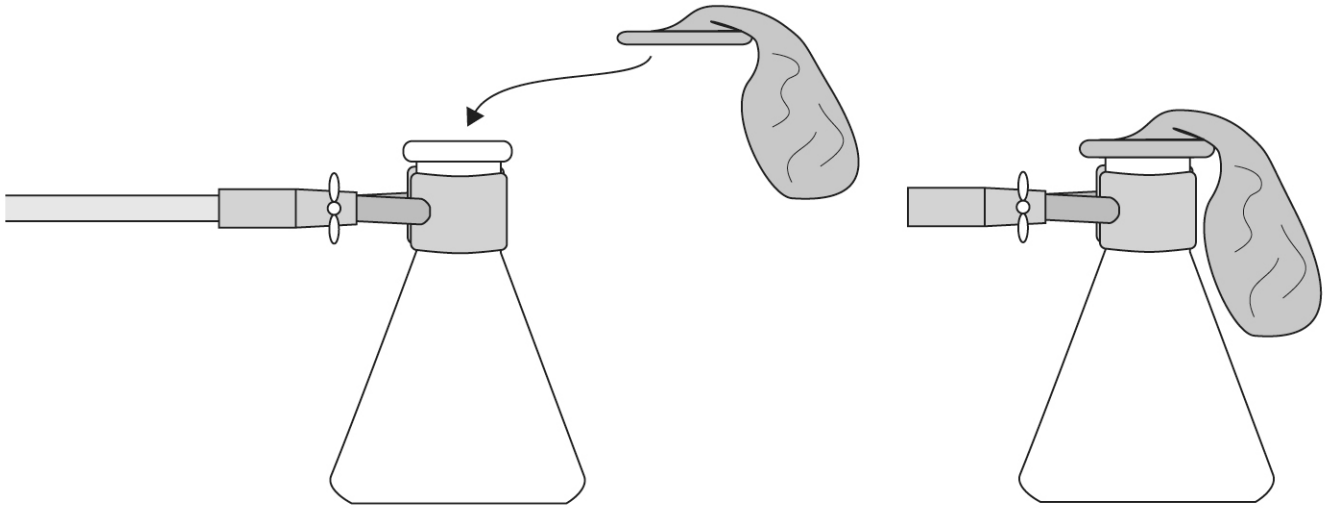

Figure 1: Have an assistant hold the flask with a laboratory clamp or tongs as you slip the balloon over the mouth of the flask.

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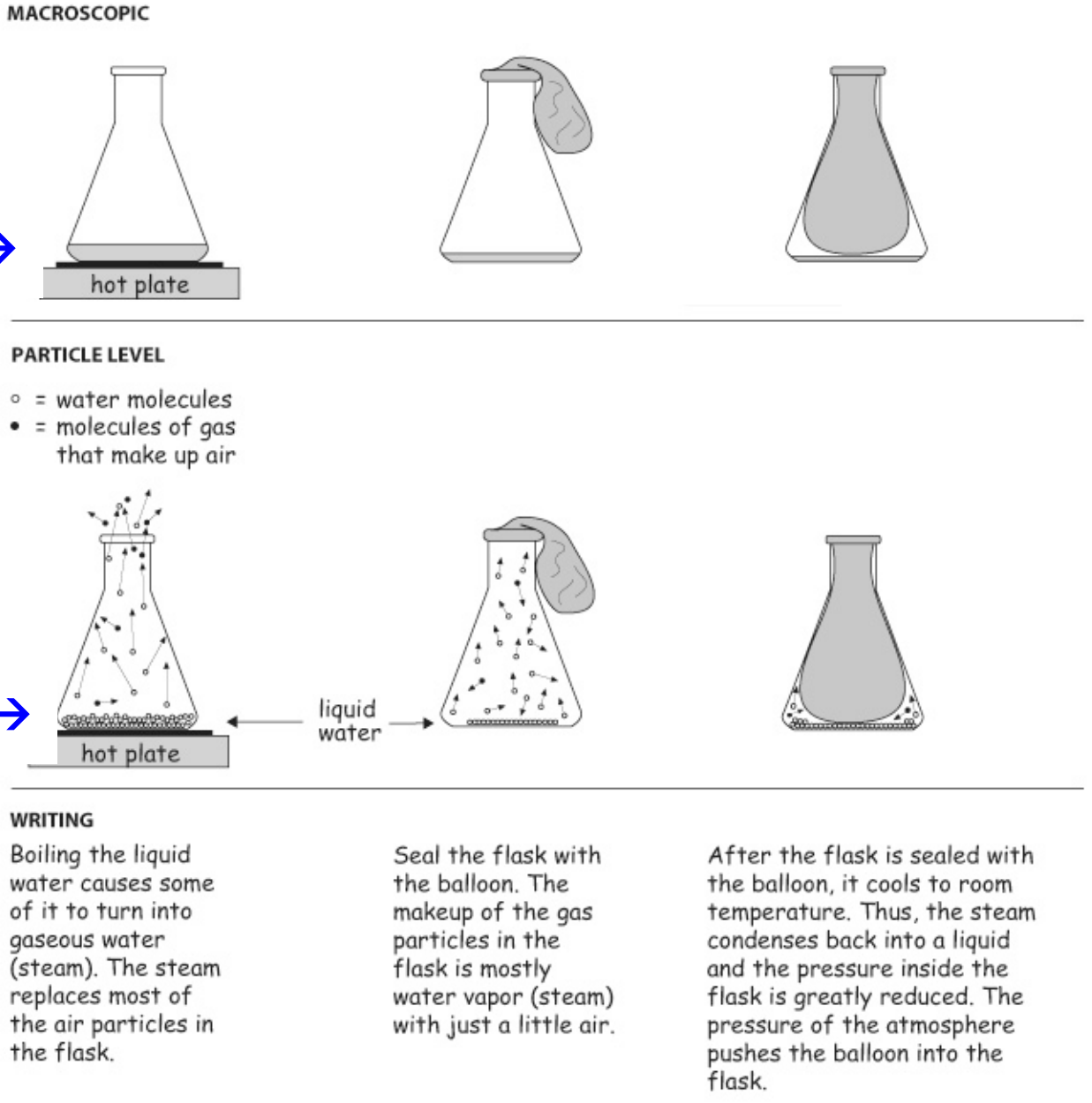
Storyboarding to build understanding

Boiling water →

Boiling water →



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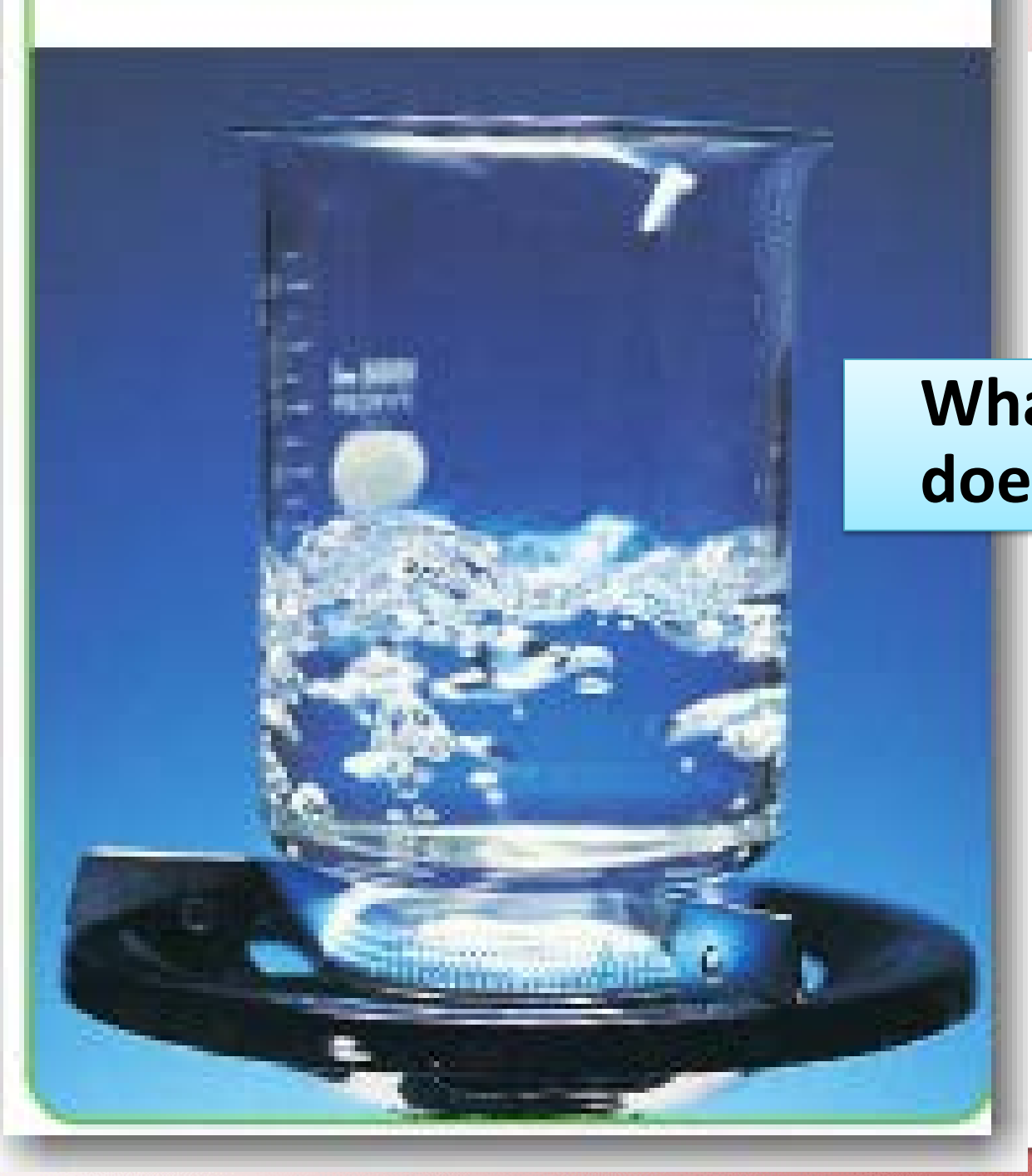
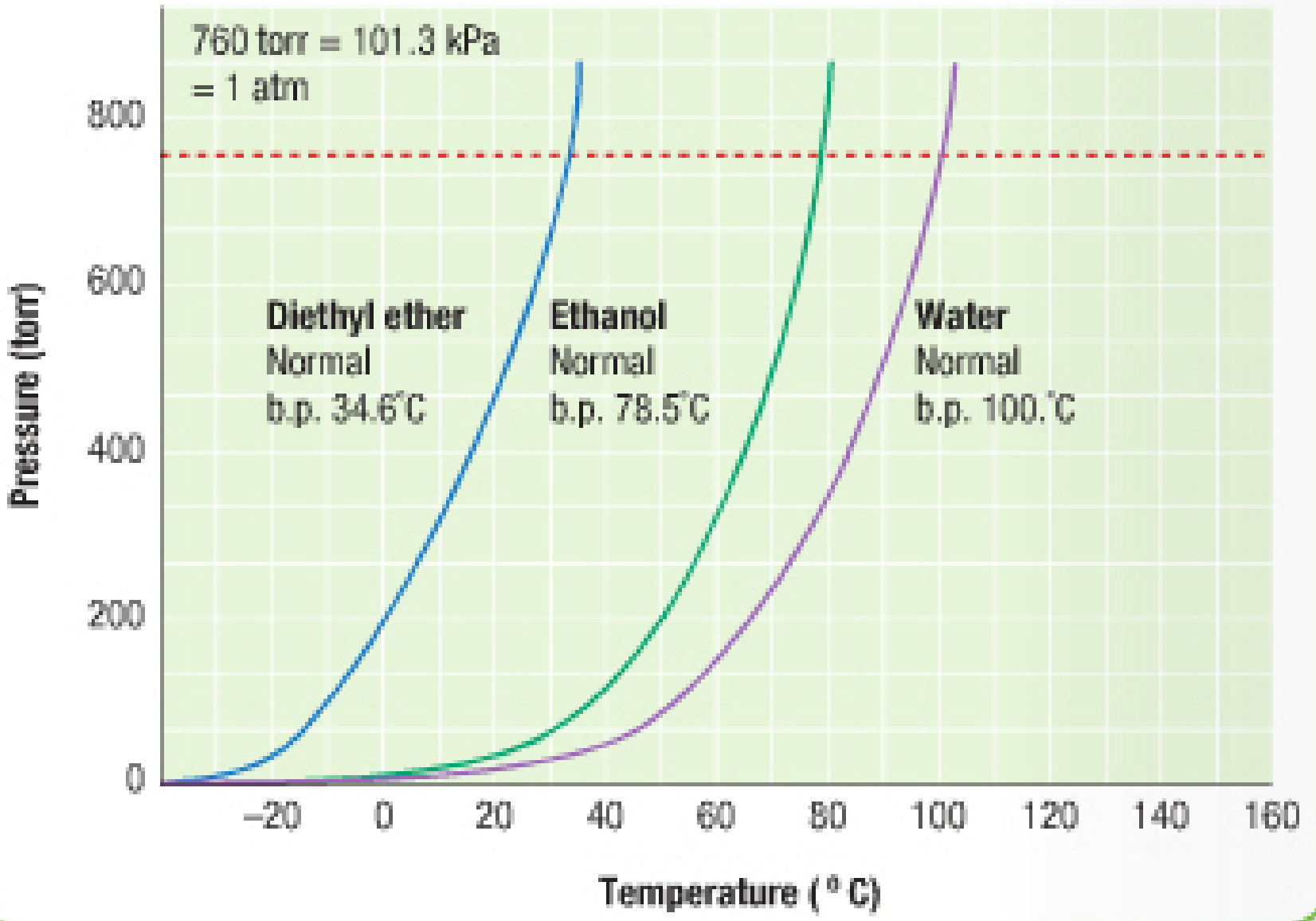
What's happening to the water?



What temperature does water boil at?

Vapor Pressures of Diethyl Ether, Ethanol, and Water at Various Temperatures



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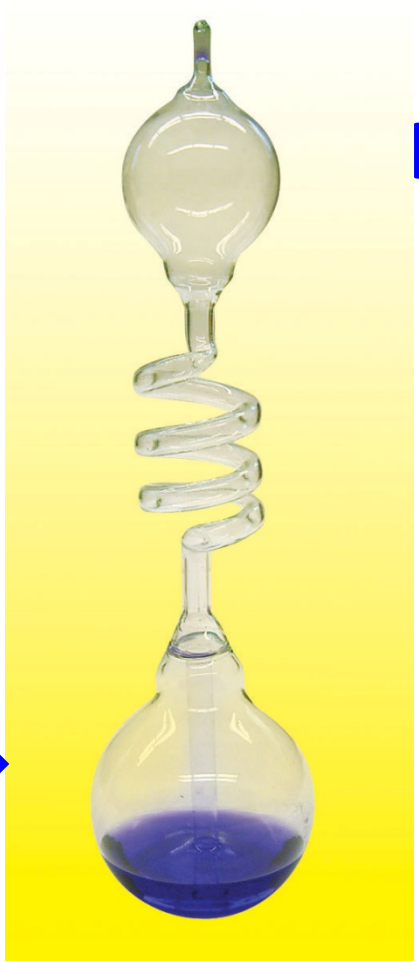
Hand boiler (love meter)



How does it work?

Is this boiling?

base chamber→

Useful, engaging, & fun chemistry tools!

Hand boiler (love meter)

Challenge students to figure out

- the engineering/design of the toy
- the science of the system

Placement in your curriculum

- how gases make pressure
- gas laws ($P \propto T$)
- what is boiling & what isn't

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carefully invert …

keeping ALL of the colored liquid in

the base chamber..

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What does the chamber feel like?

Ice-salt bath →

Distillation

Before

dye in solution

empty

After

← solid dye

colorless liquid

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Hats off to the Drinking Bird

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Fluorescence &Phosphorescence

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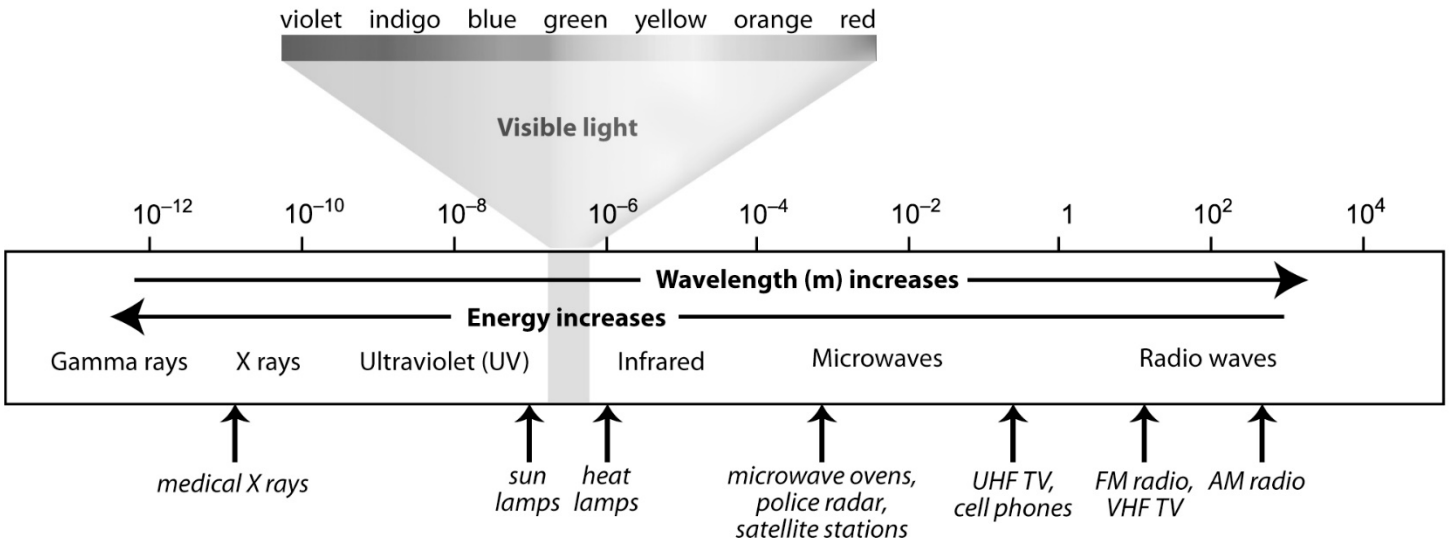

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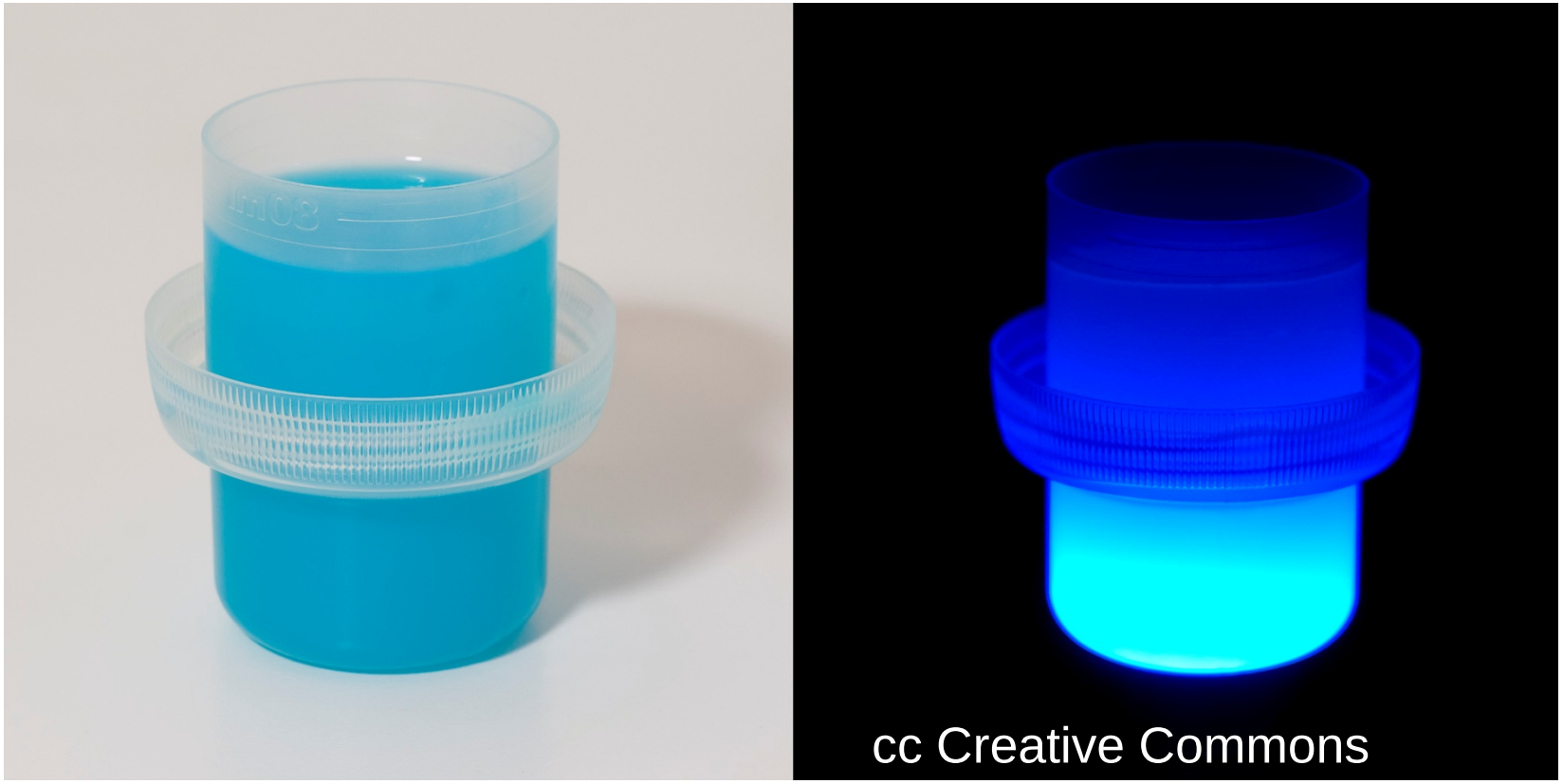
Whiter than white?

absorbs energy in the UV portion of the spectrum and re-emits it in the blue portion of the visible spectrum



Fluorescence

Models that involve role-playing




UV light provides energy to “kick” electrons up to an excited state. When they return to ground state, energy is given off as light.

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Phosphorescence




An intermediate level is available for excited electrons to land before returning to the ground state. Light continues to be given off even after energy source is removed.

phosphorescent vinyl another use

ZnS doped with Cu:
emission occurs at 520 nm

Wavelengths of the LED light:

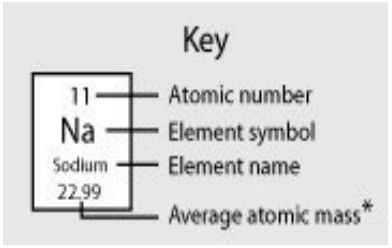
- **RED** $\lambda = 630$ nm
- **GREEN** $\lambda = 525$ nm
- **BLUE** $\lambda = 470$ nm

a common craft toy

Make observations

Generate testable questions

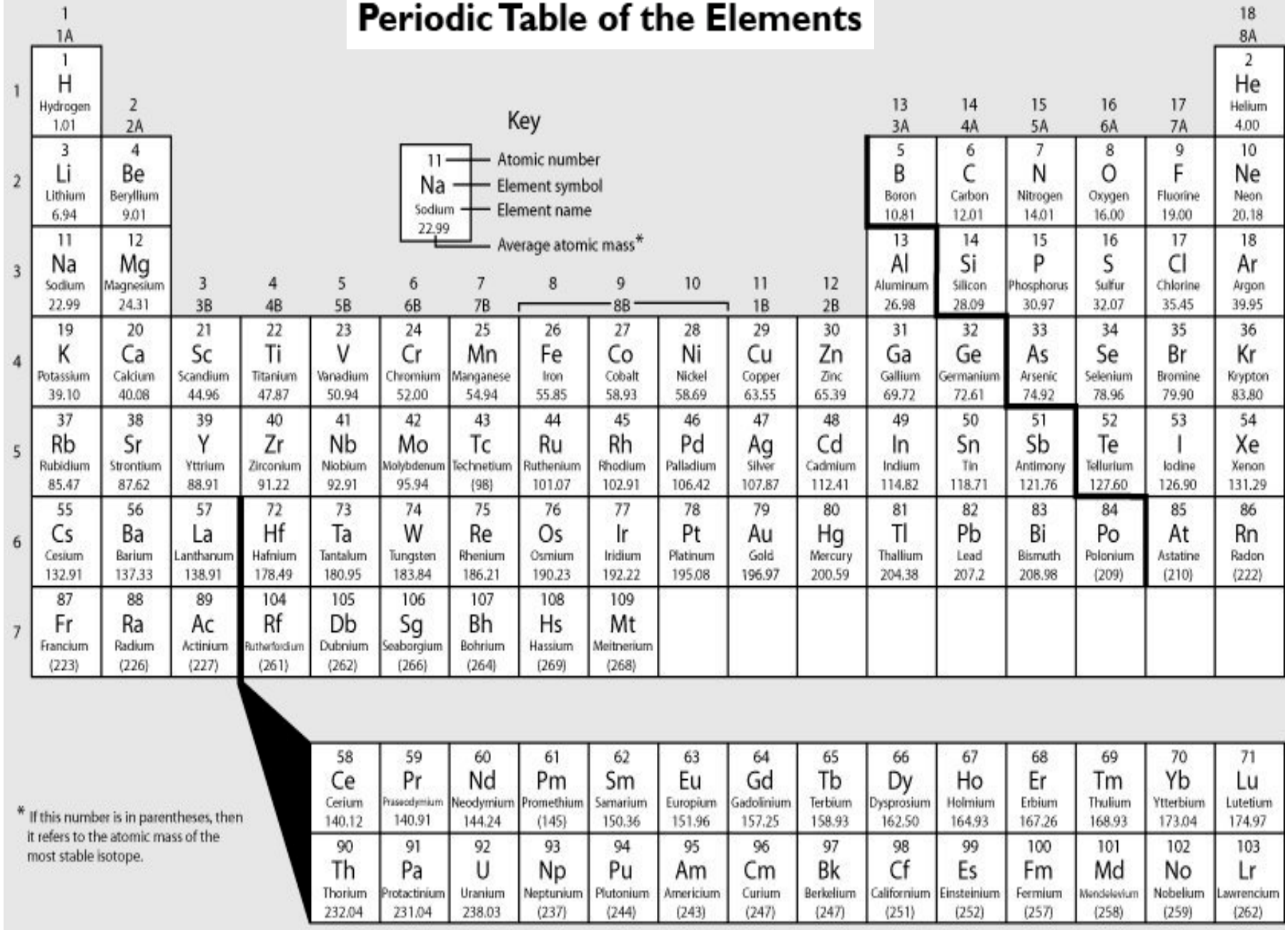
Periodic Table of the Elements



1																	18
1 H Hydrogen 1.008	2											13	14	15	16	17	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3	4	5	6	7	8	9	10	11	12	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molibdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.249
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinides	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

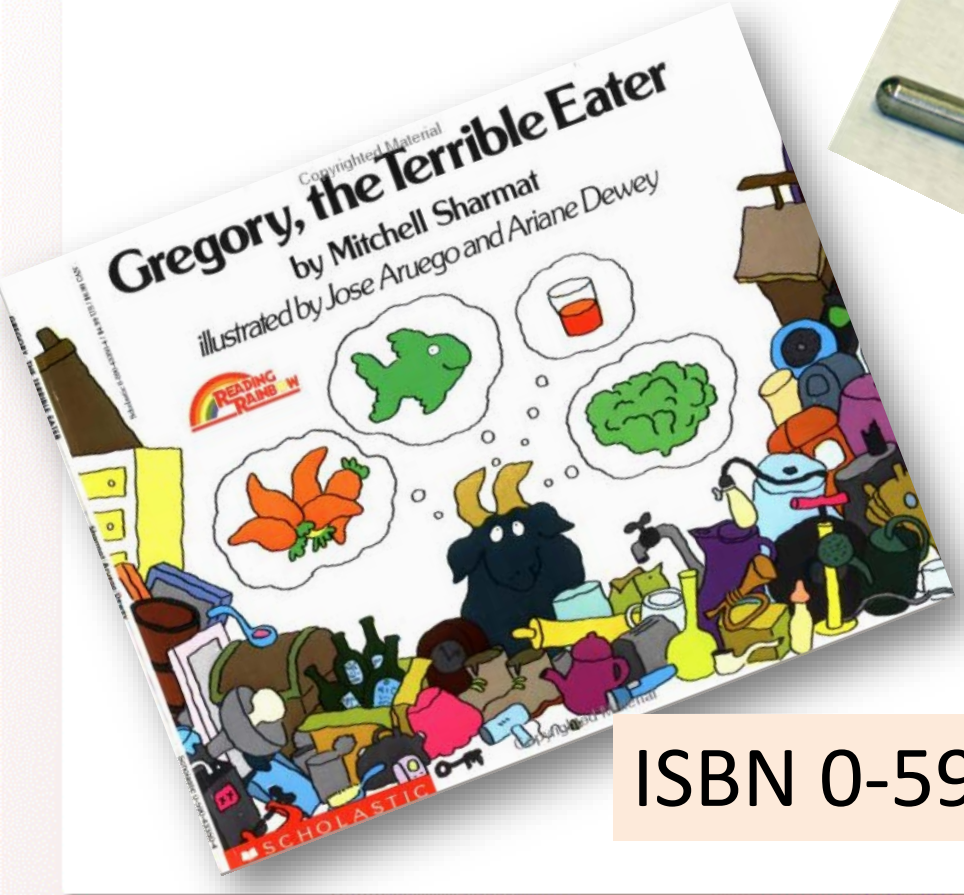
57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Periodic Table of the Elements



* If this number is in parentheses, then it refers to the atomic mass of the most stable isotope.

Iron
for breakfast



ISBN 0-590-43350-4

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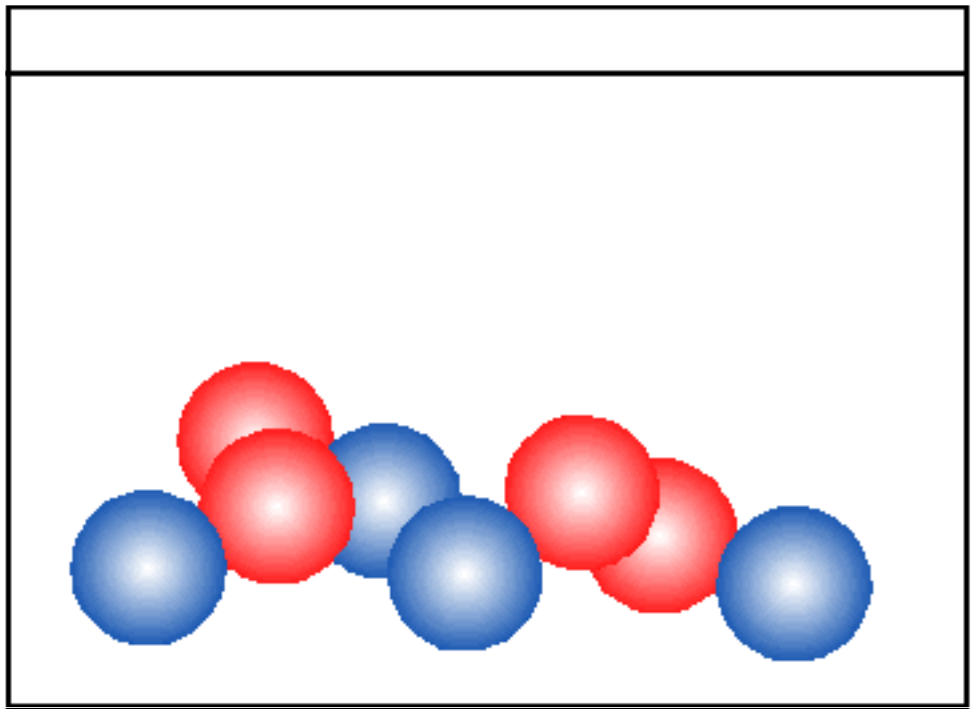
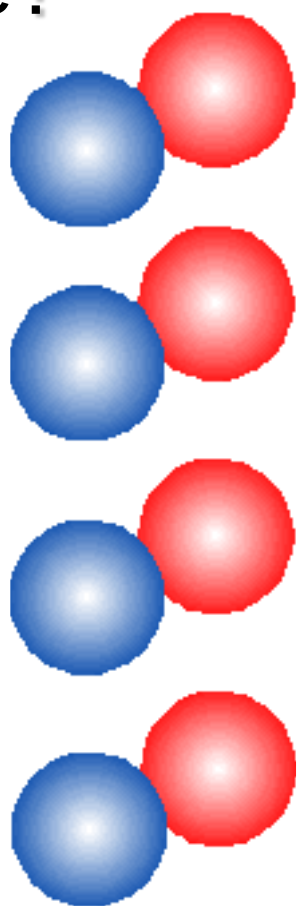
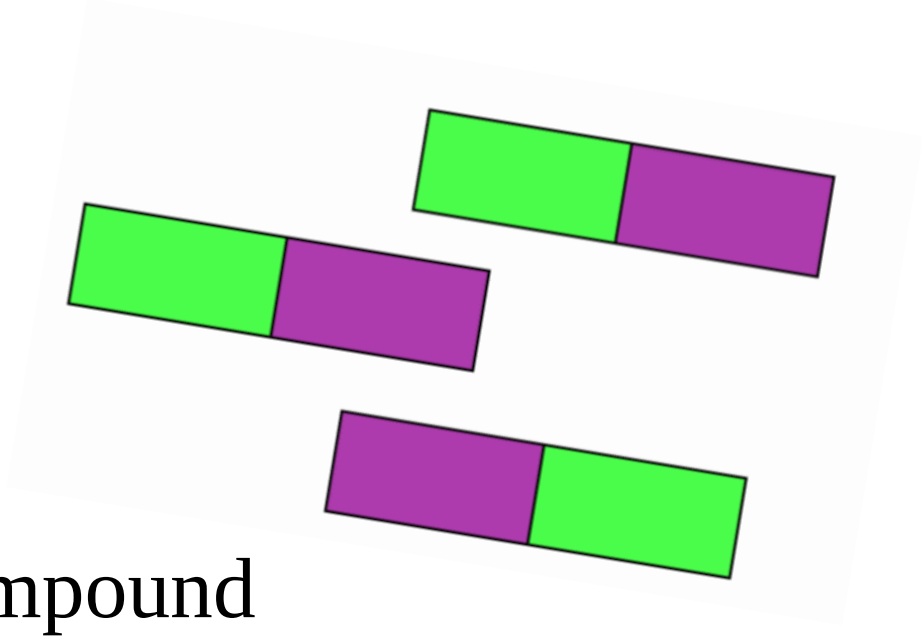
Mixture or Pure Substance?





Pop beads or Legos: Science Tools

?? Element, Compound, or Mixture ??

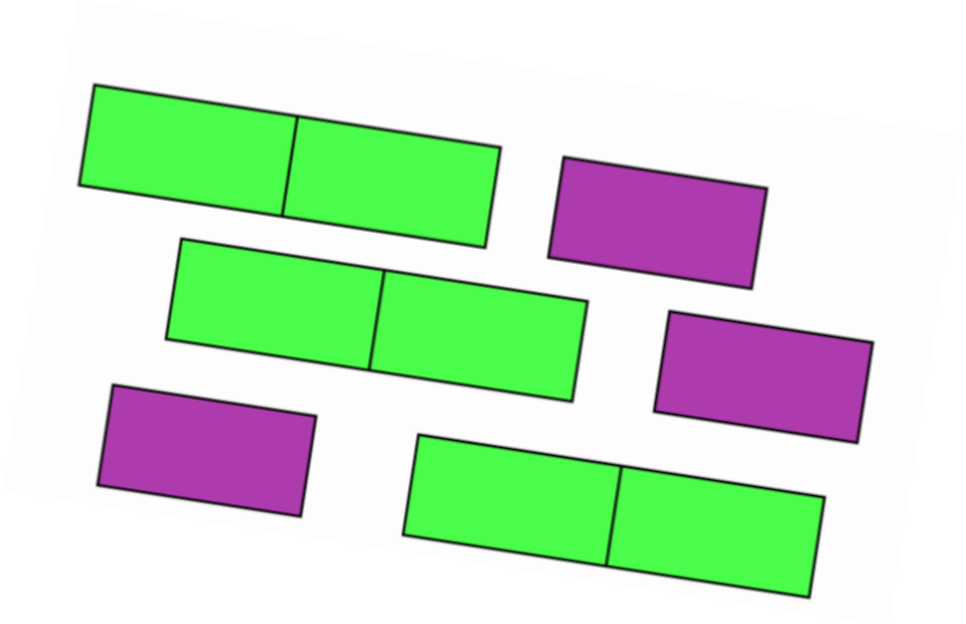


compound

XY or A-B

pure substance

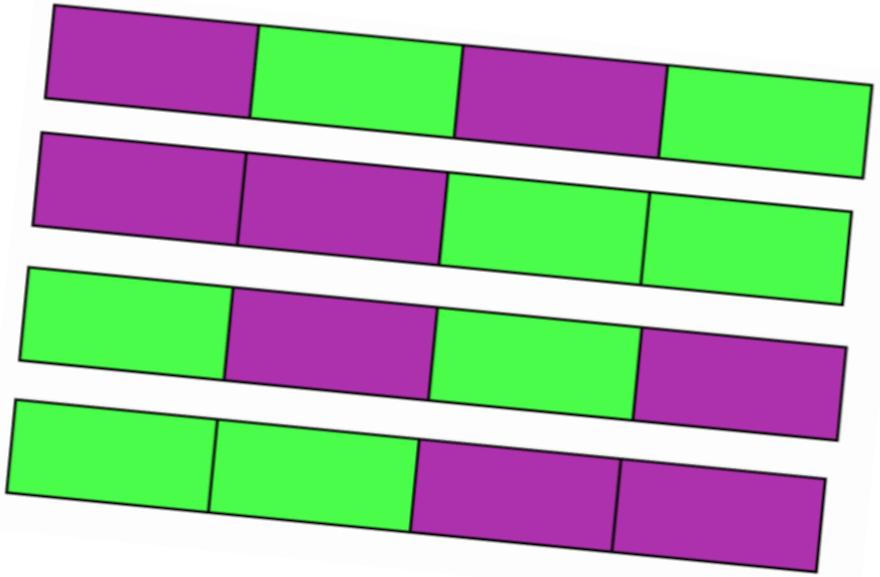
Sample B



mixture
of two different elements

Y [monoatomic element]
(X-X) [diatomic molecule]

Sample E



Mixture of 2 compounds

compound (X-Y-X-Y)
and
compound (X-X-Y-Y)

isomers

Share and Share Alike?

- While I was traveling to this meeting, I found a large bag containing $1,000,000, so I decided to **share** the money with everyone here.

I give each person $5 and keep the rest.

Yes, just not equally!

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University students demonstrate a pure covalent bond.

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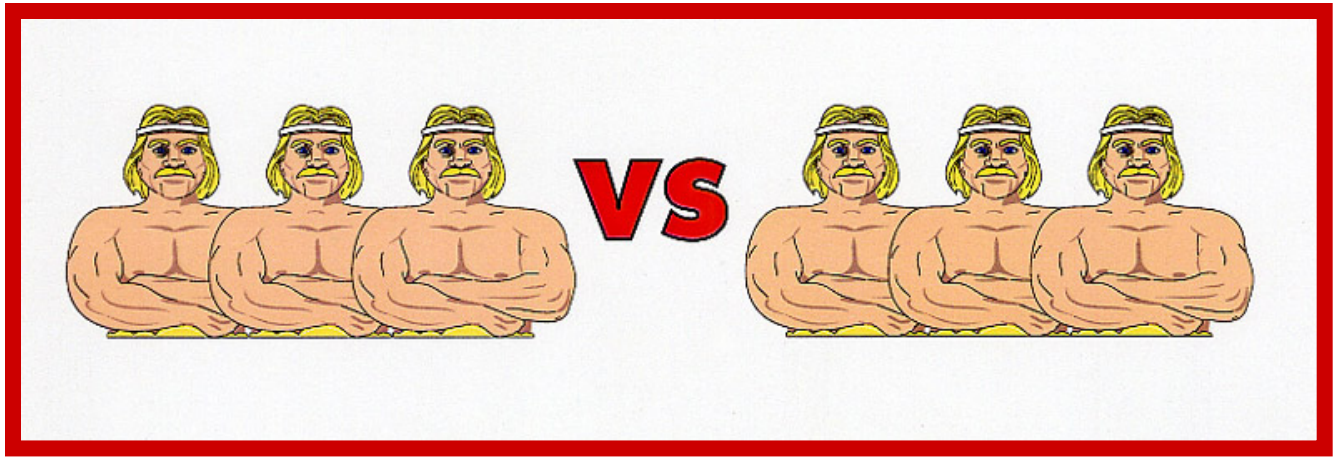
Tug of War



pure covalent

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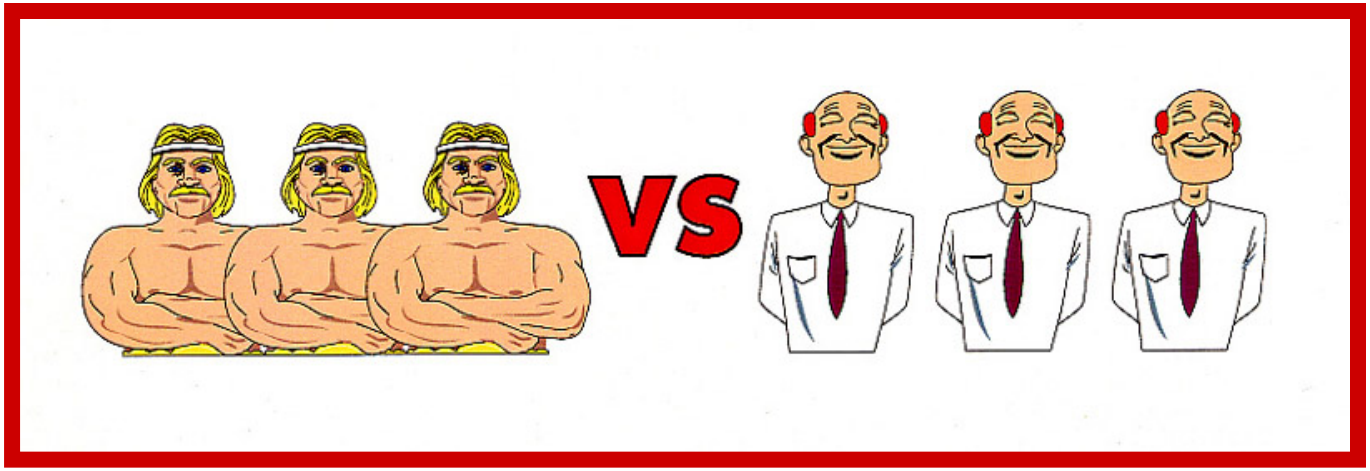
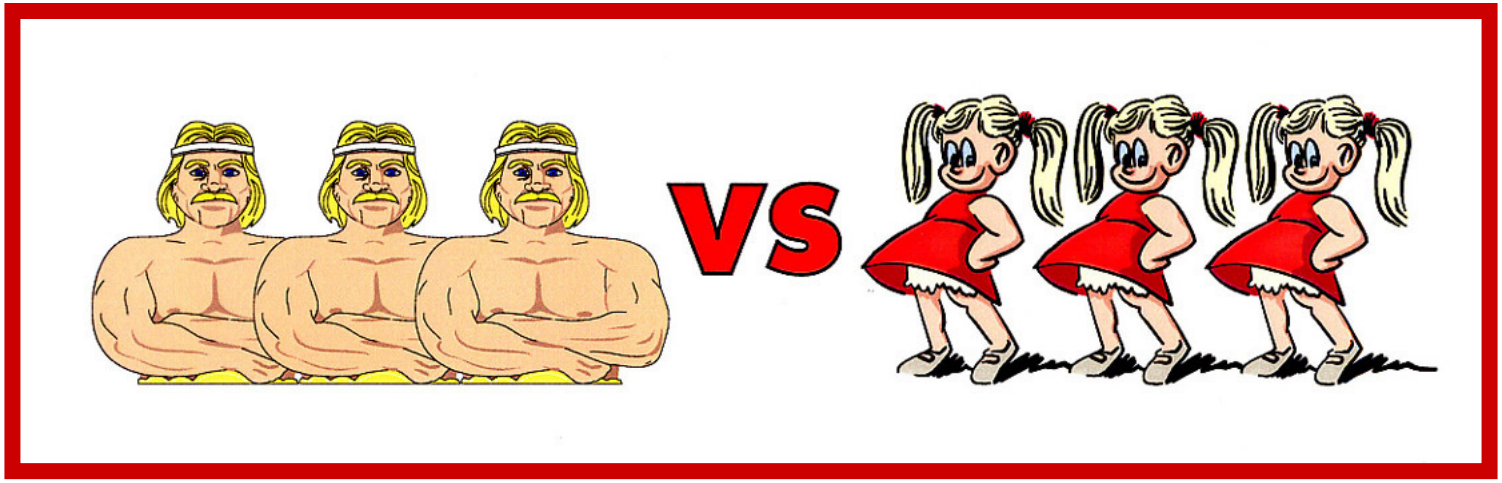
Tug of War



polar covalent

TERRIFIC SCIENCE

Tug of War

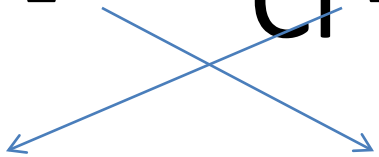


ionic

Formula writing

sodium chloride

Na^{+1} Cl^{-1} NaCl



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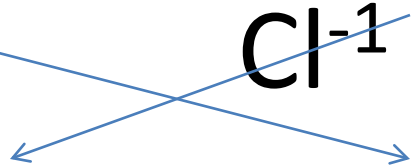
magnesium chloride

Mg^{+2} Cl^{-1} $MgCl_2$



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aluminum oxide

Al^{+3} O^{-2} Al_2O_3

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Radicals

hydroxide	OH^{-1}
sulfate	SO_4^{-2}
nitrate	NO_3^{-1}

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calcium hydroxide

Ca^{+2} OH^{-1}

$Ca(OH)_2$

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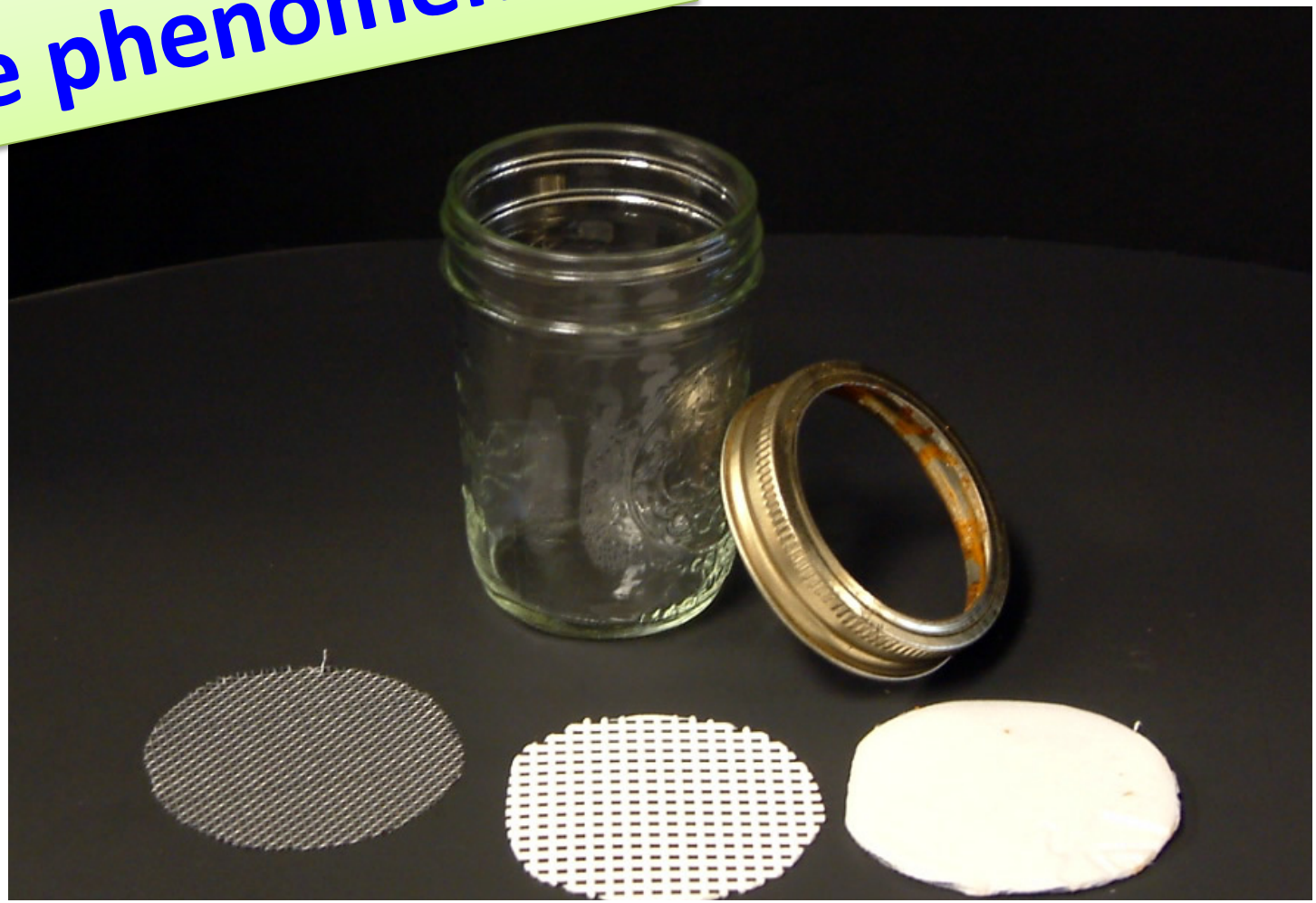
aluminum sulfate

Al^{+3} $SO4^{-2}$

$Al_2(SO4)_3$

demo to introduce the phenomena



Anti-gravity bottle

Testable questions ?

Other materials?

How big can the hole be?

~1.3 cm in diameter

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Models as teaching tools…

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Modeling the behavior of water

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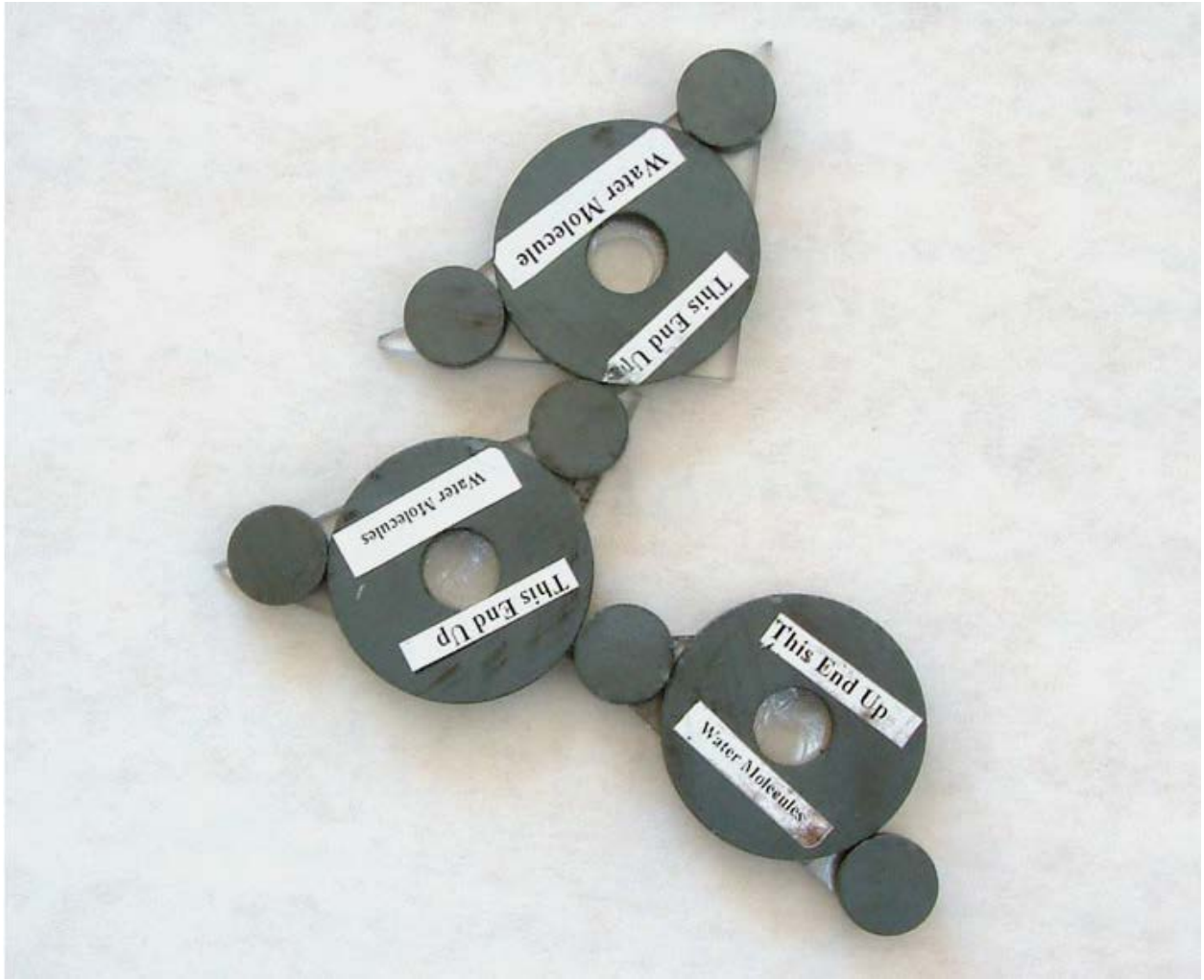
Modeling the behavior of water



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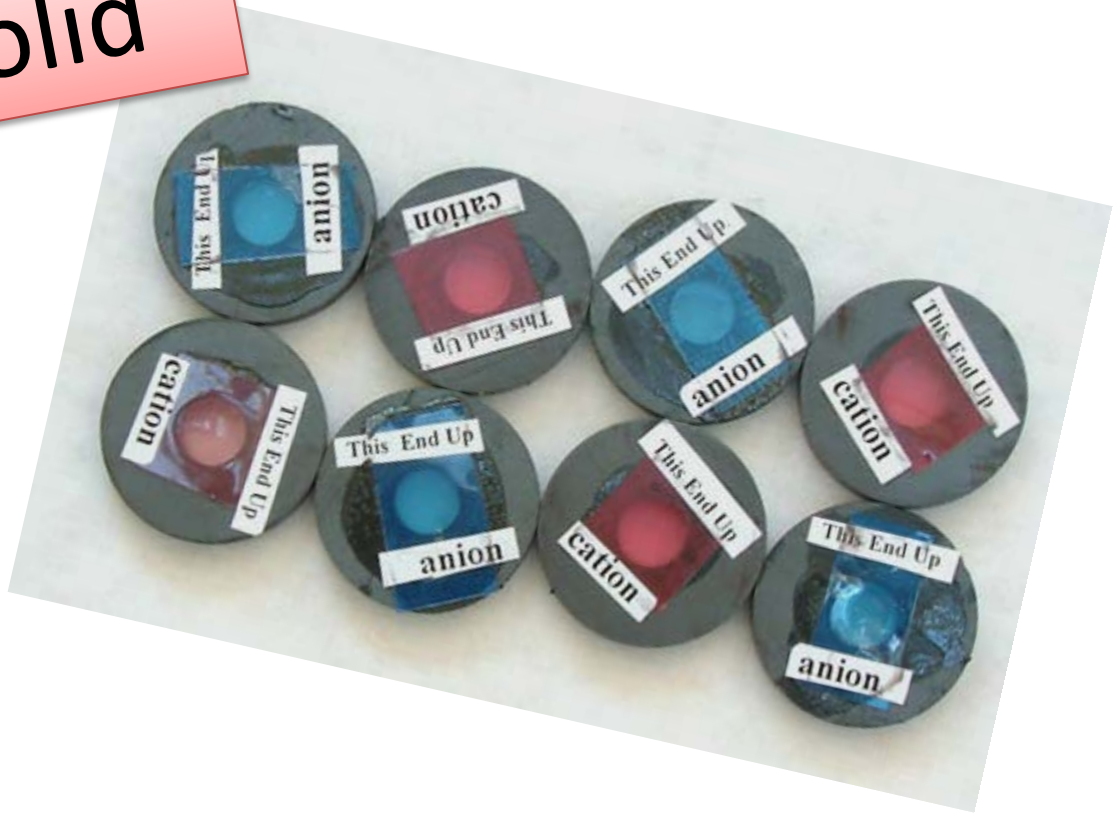
Modeling

an ionic solid



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Dissolving in water

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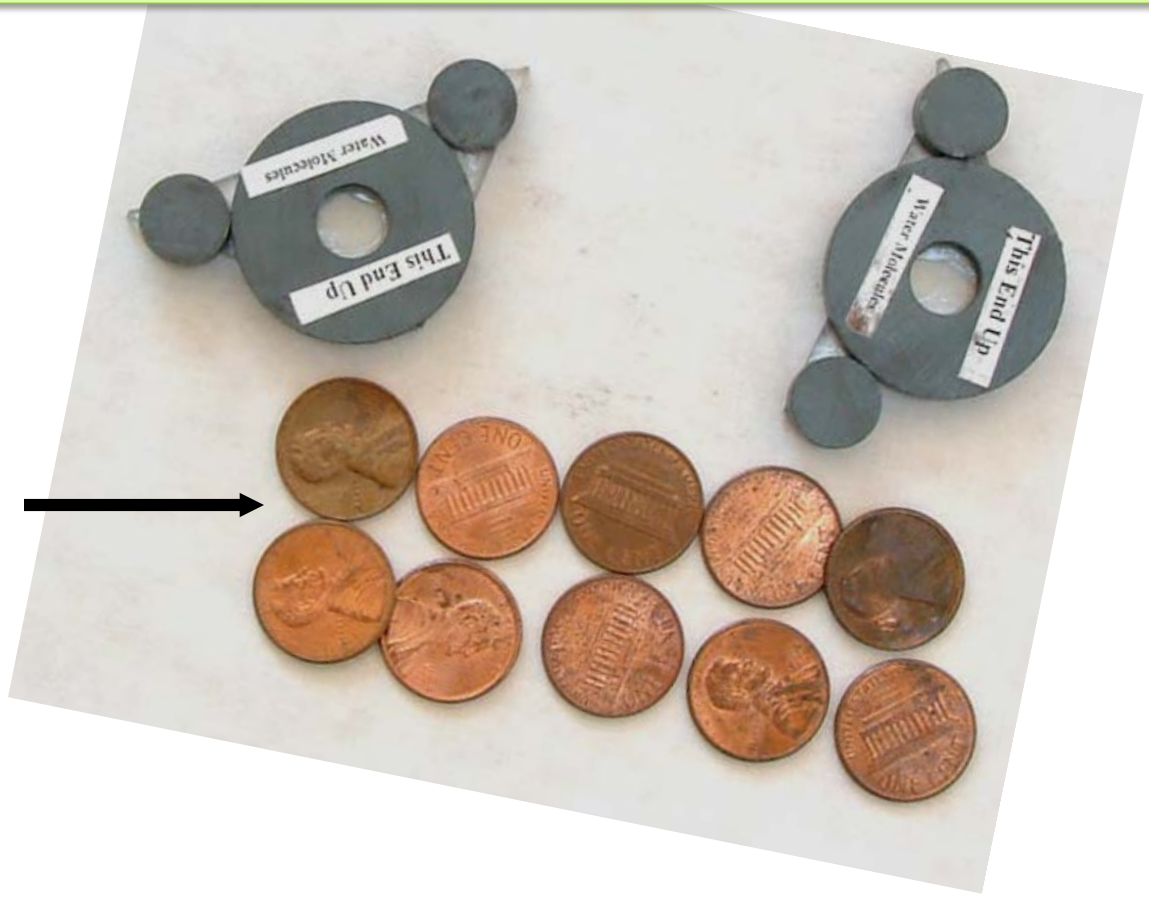
Hydration of the anion

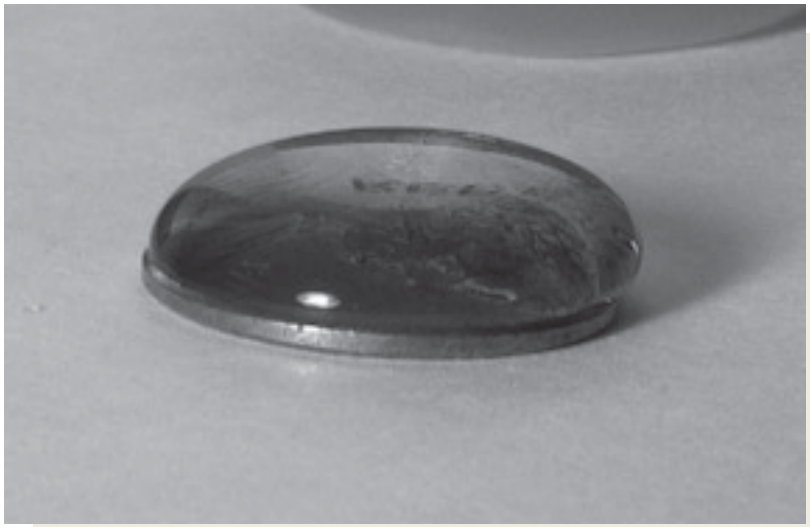
So what about a non-polar solid?

Pennies are used as the nonpolar substance

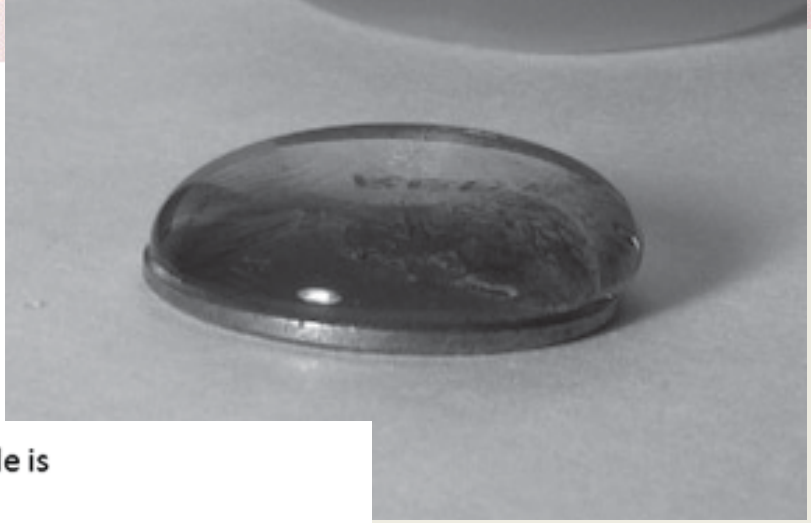


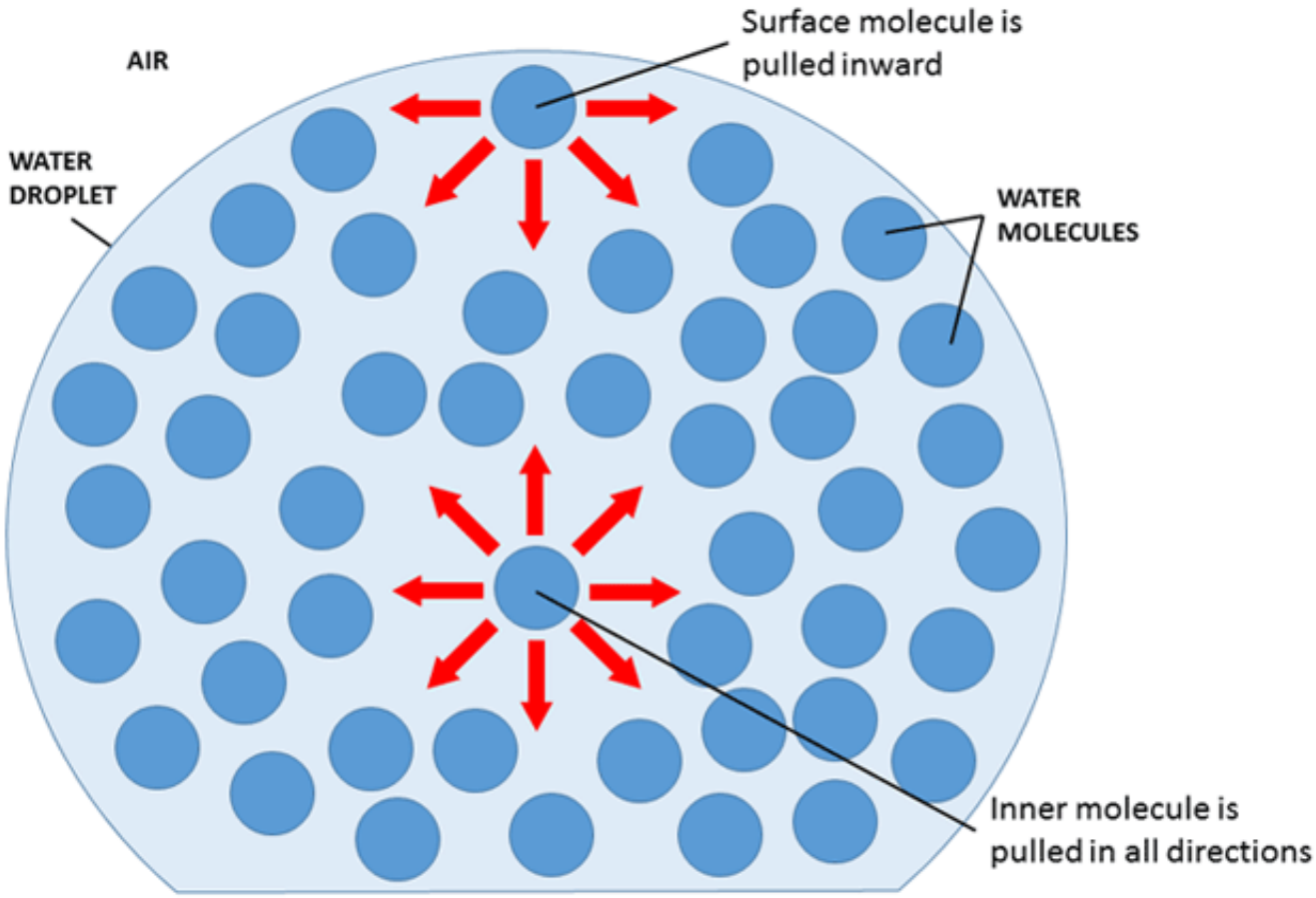
Drops on a coin

How many drops of water can you place on a coin before the water spills off?



Drops on a coin





Red drop---Green drop

Materials:

- Waxed paper
- Toothpick
- Red liquid
- **Green** liquid

- Examine a drop of each on waxed paper.
- Try drops on a penny with each.

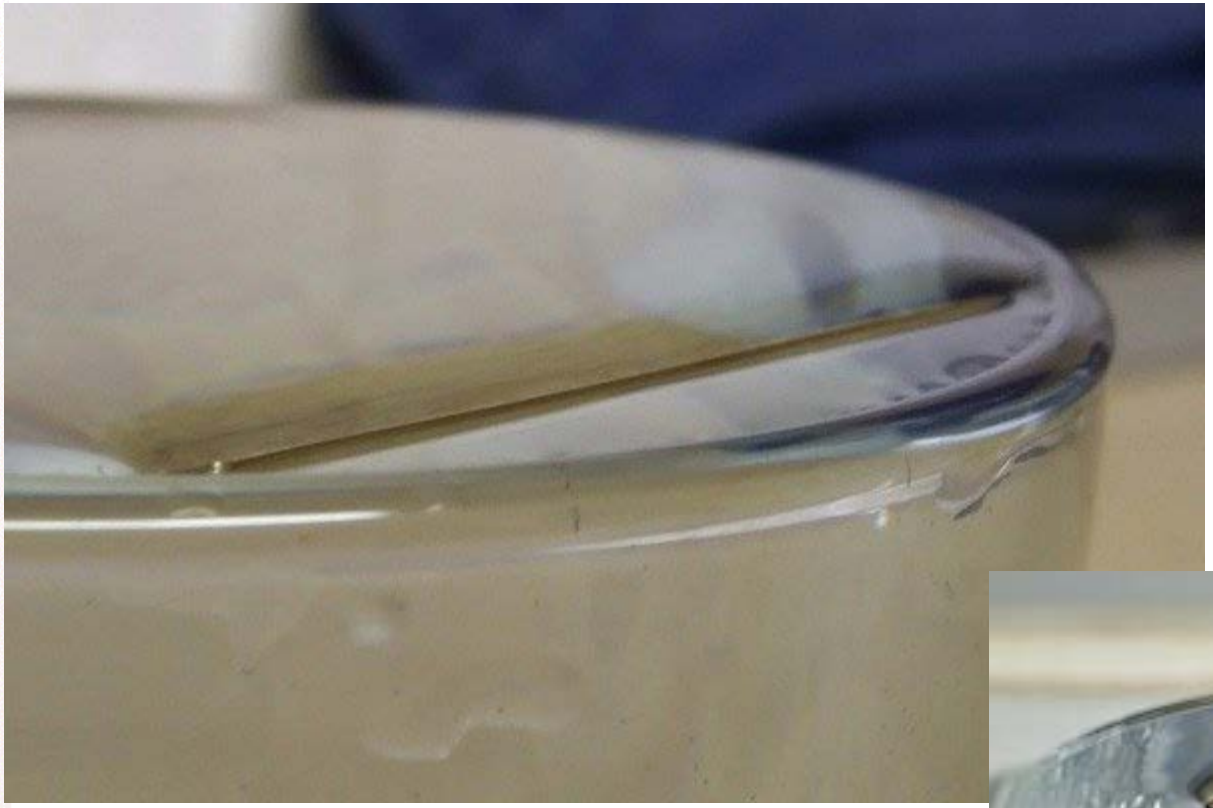
Which liquid is *colored* water?

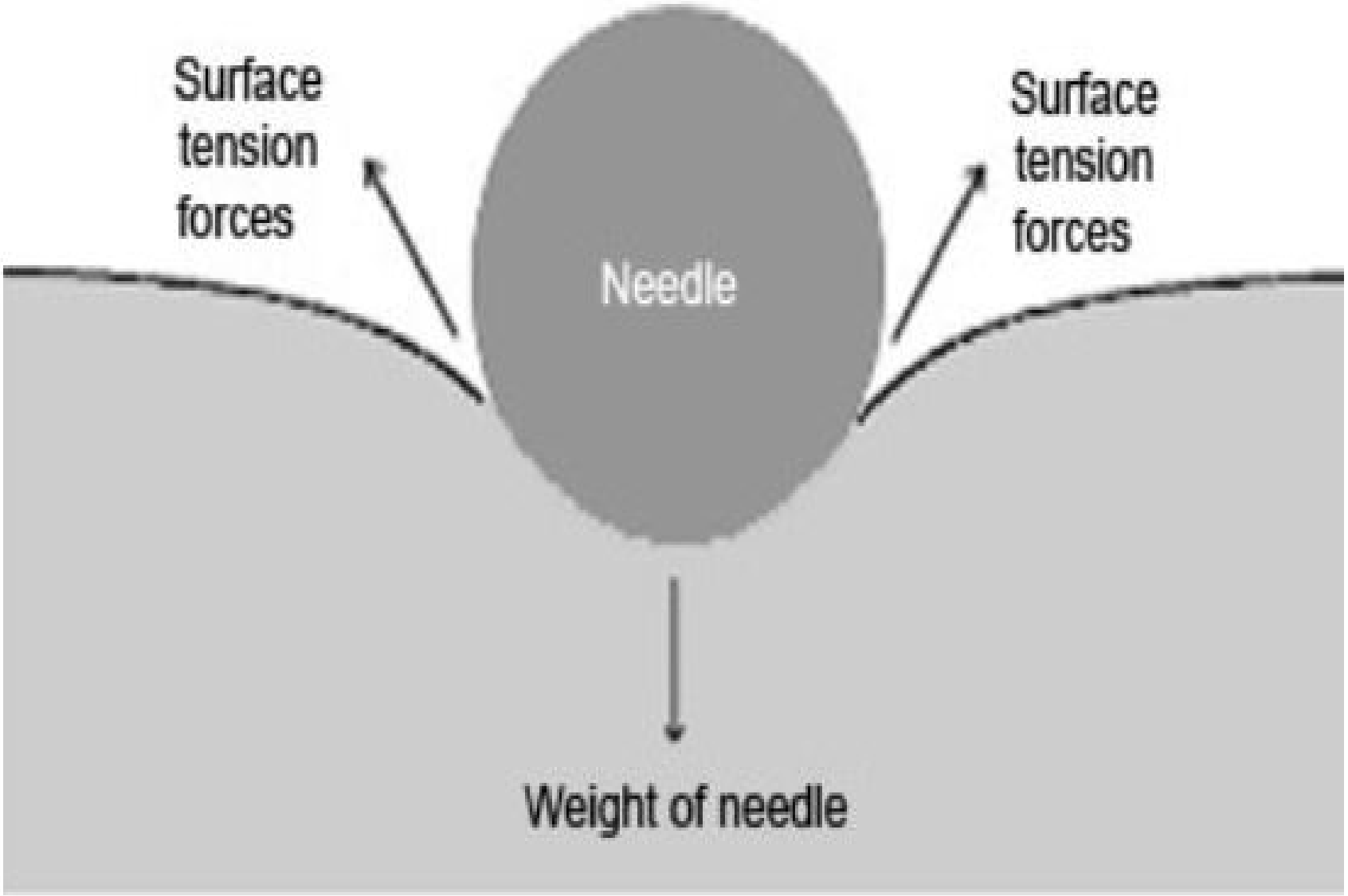
What type of chemical was added to the other liquid?

We used a surfactant.

How do they do this?

Can you do this?




Surface tension forces
Surface tension forces
Needle
Weight of needle

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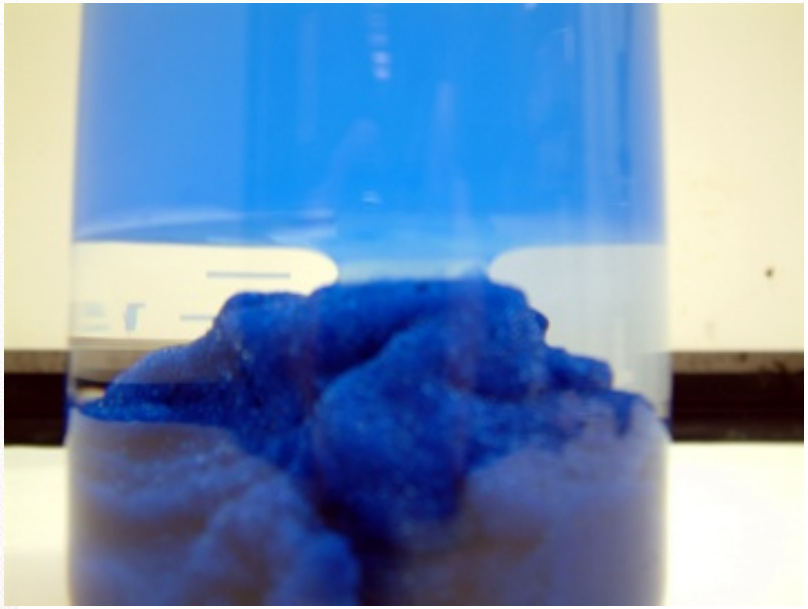
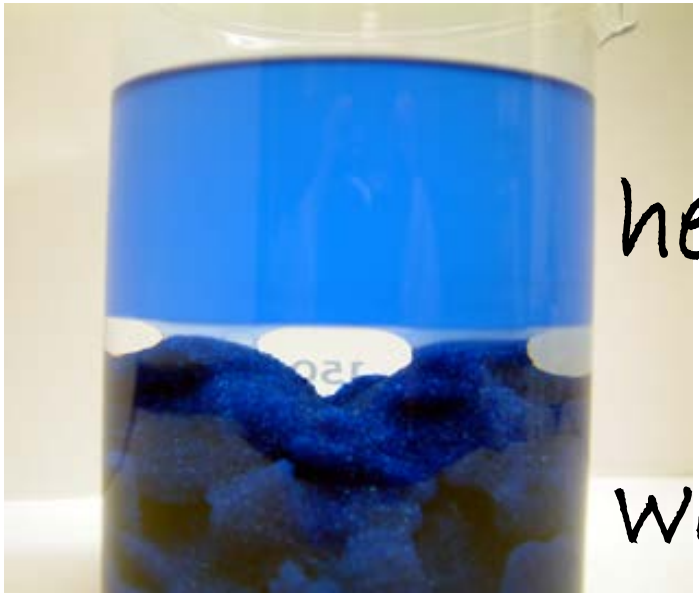
Magic sand


100 200
100ml
KIMAX
80
60
40
20





hexane

water

water

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WATER

- The “universal non-solvent”
- Hydrophobic effect

“ Human beings were invented by *water* as a device for transporting itself from one place to another.”

Tom Robbins
Even Cowgirls Get the Blues

Magic Sand: Modeling the Hydrophobic Effect and Reversed-Phase Liquid Chromatography

Ed Vitz, Kutztown University
Journal of Chemical Education
Volume 67, Number 6, June 1990


Adding water

"Holeyness of matter"

$H_2O + H_2O = ?$

- ½ fill tube with colored water
- add colorless water to COMPLETELY fill

(so the water "domes" at the top) **IMMEDIATELY** cover with your thumb & do **NOT** remove it until I tell you to!!!

- Invert 4 times while observing *(feel sides & look carefully)*

Quiet EVERYONE & listen carefully

"Holeyness of matter"

H_2O + alcohol= ?

- ½ fill tube with colored water
- COMPLETELY fill with alcohol **& IMMEDIATELY** cover with your thumb… **do NOT remove your thumb**

! ! ! ! ! ! ! ! ! ! ! !

- Invert 4 times while observing *(**feel** & **look** carefully)*

Quiet EVERYONE & listen carefully

50 mL H_2O + 50 mL H_2O = 100 mL H_2O

BUT

50 mL H_2O + 50 mL *alcohol* ≠

100 mL solution

Modeling to explain

= ?

Modeling to explain

“Holeyness of matter”

$H_2O + H_2O = ?$

- ½ fill tube with colored water
- COMPLETELY fill with colorless water **IMMEDIATELY** cover with your thumb… **do NOT remove your thumb**

! ! ! ! ! ! ! ! ! ! ! !

- SLOWLY Invert 4 times while observing *(**feel** & **look**)*
- Move close to ear and remove thumb

Quiet EVERYONE & listen carefully !!!

"Holeyness of matter"

H_2O + alcohol= ?

- ½ fill tube with colored water
- COMPLETELY fill with alcohol **& IMMEDIATELY** cover with your thumb… **do NOT remove your thumb**

! ! ! ! ! ! ! ! ! ! !

- SLOWLY Invert 4 times while observing *(**feel** & **look**)*
- Move close to ear and remove thumb

Quiet EVERYONE & listen carefully !!!

Distillation

Before

dye in solution

empty

After

← solid dye

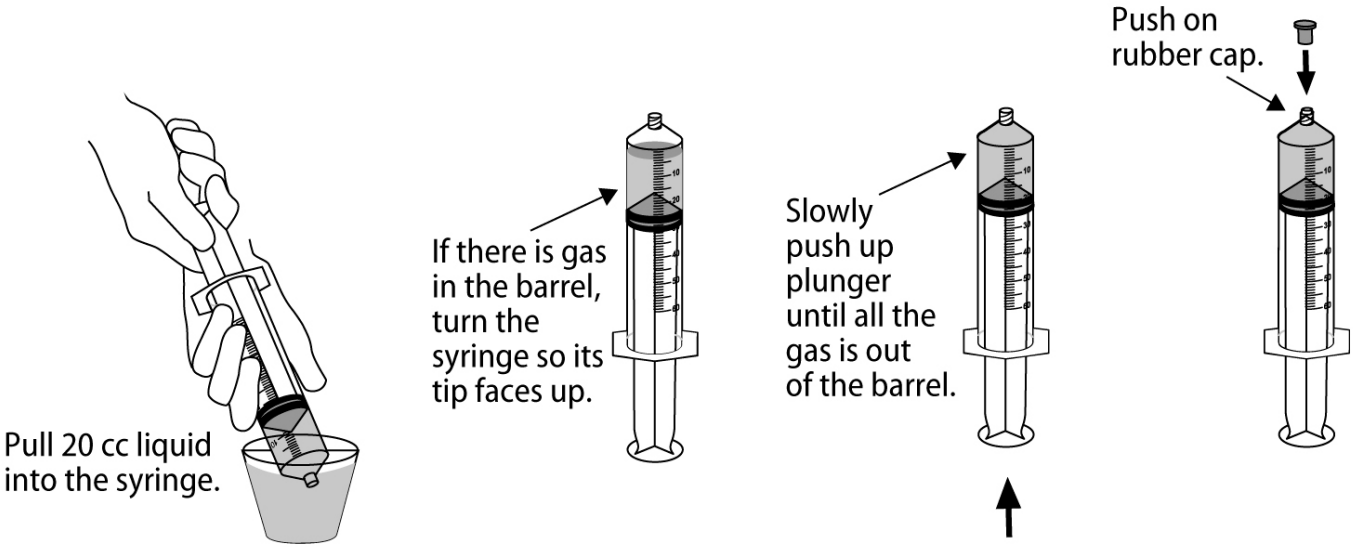
colorless liquid

Separating a mixture

shake

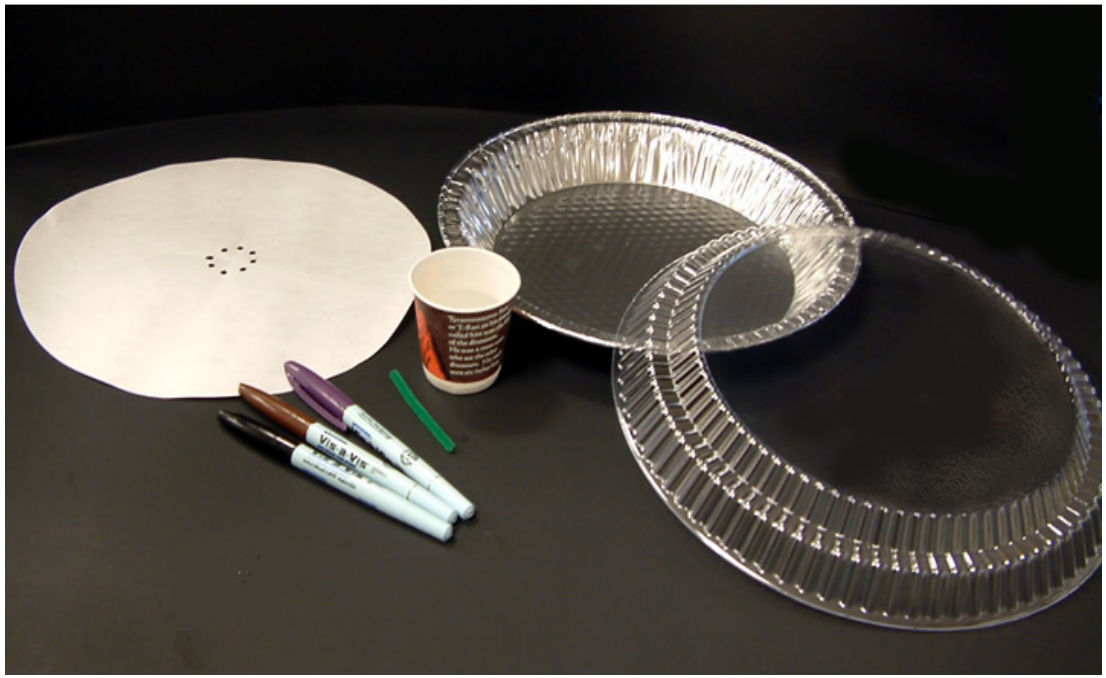
Volume estimate

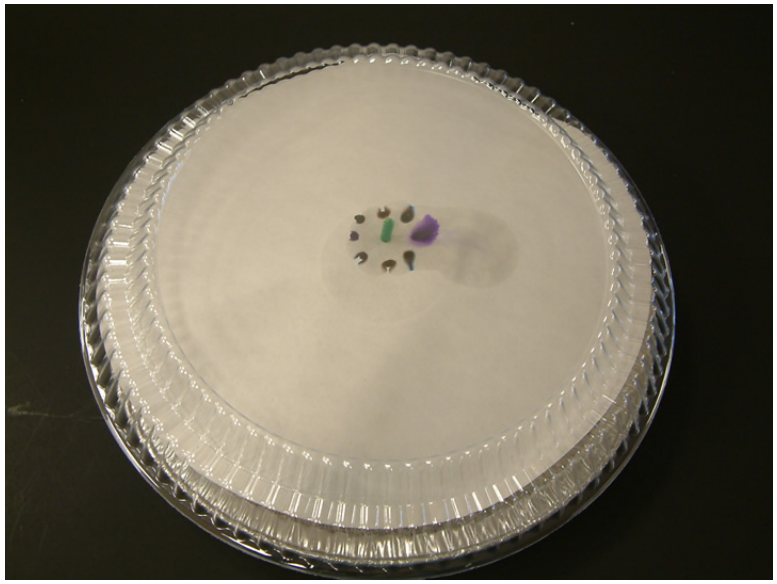
Student explorations



- pressure changes
- temperature changes
- methyl red indicator (if colorless soda)

Radial Chromatography





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Colorful Gala

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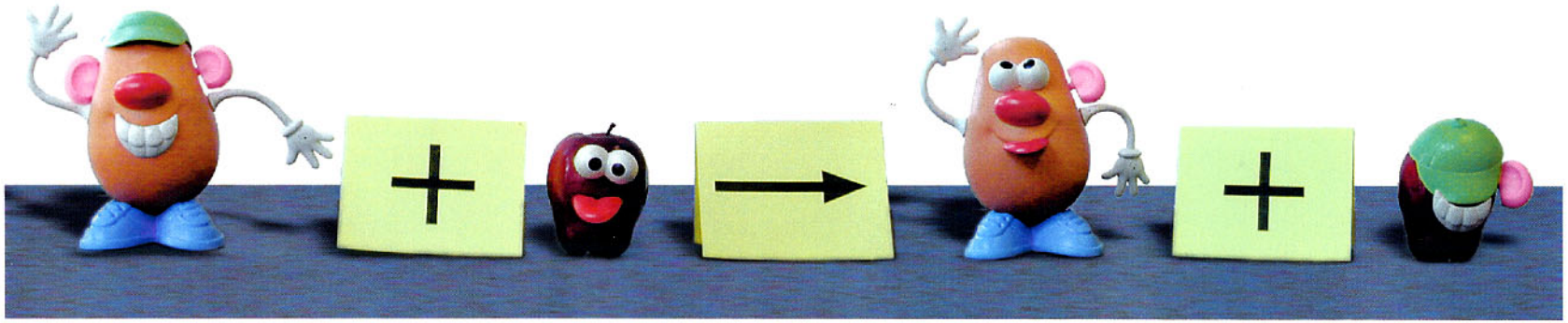
Visualizing a Chemical Reaction



reactants **products**

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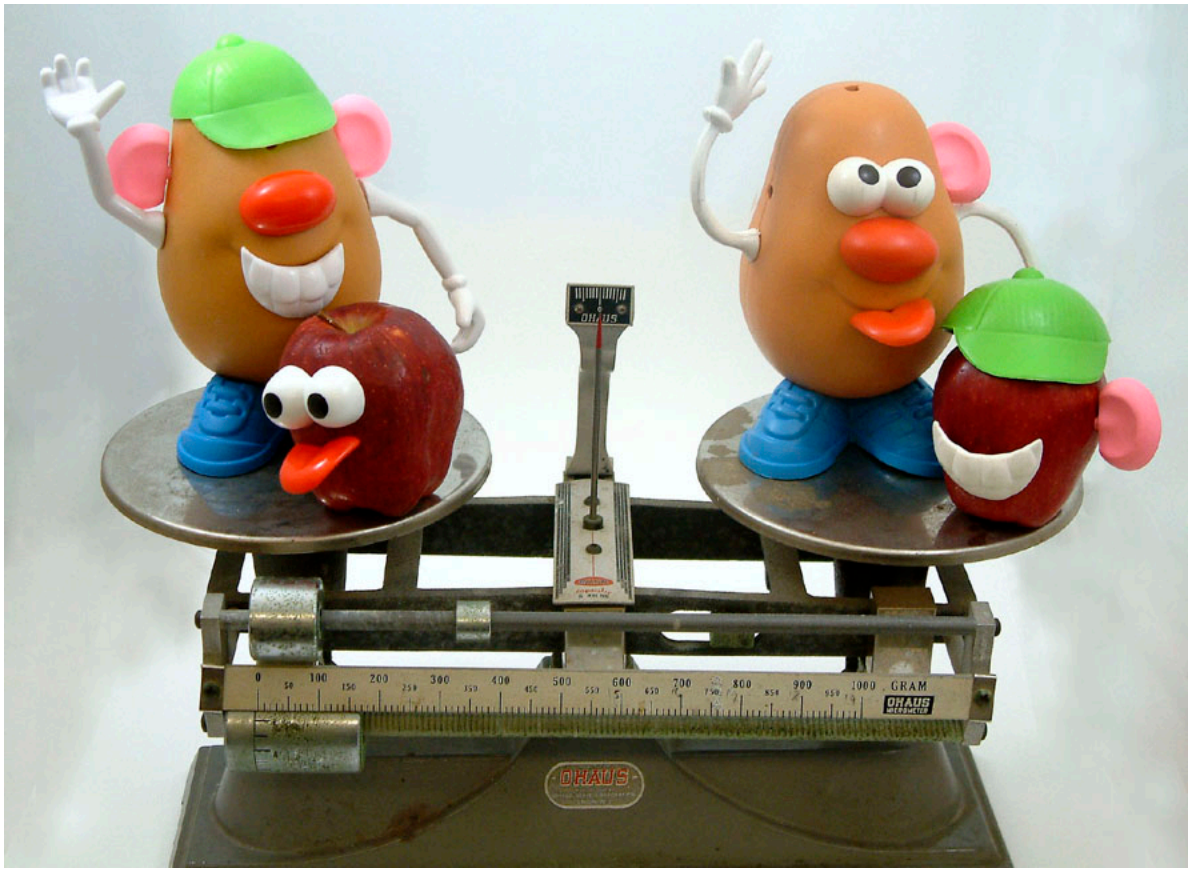
Conservation of Mass



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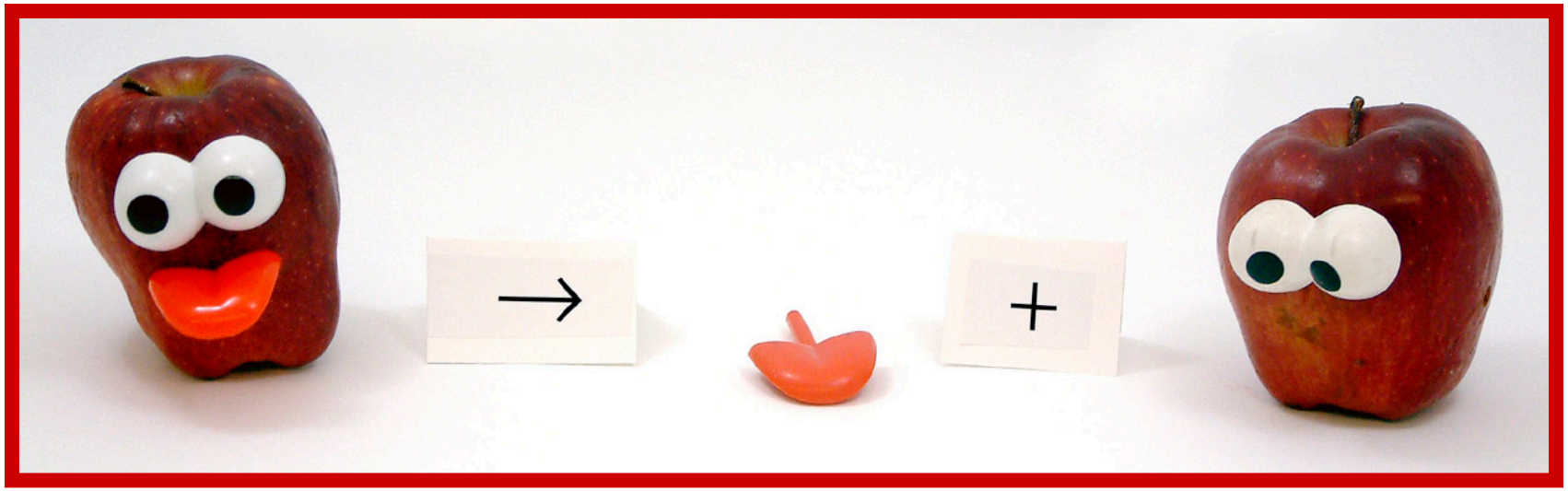
Visualizing a Chemical Reaction



decomposition reaction

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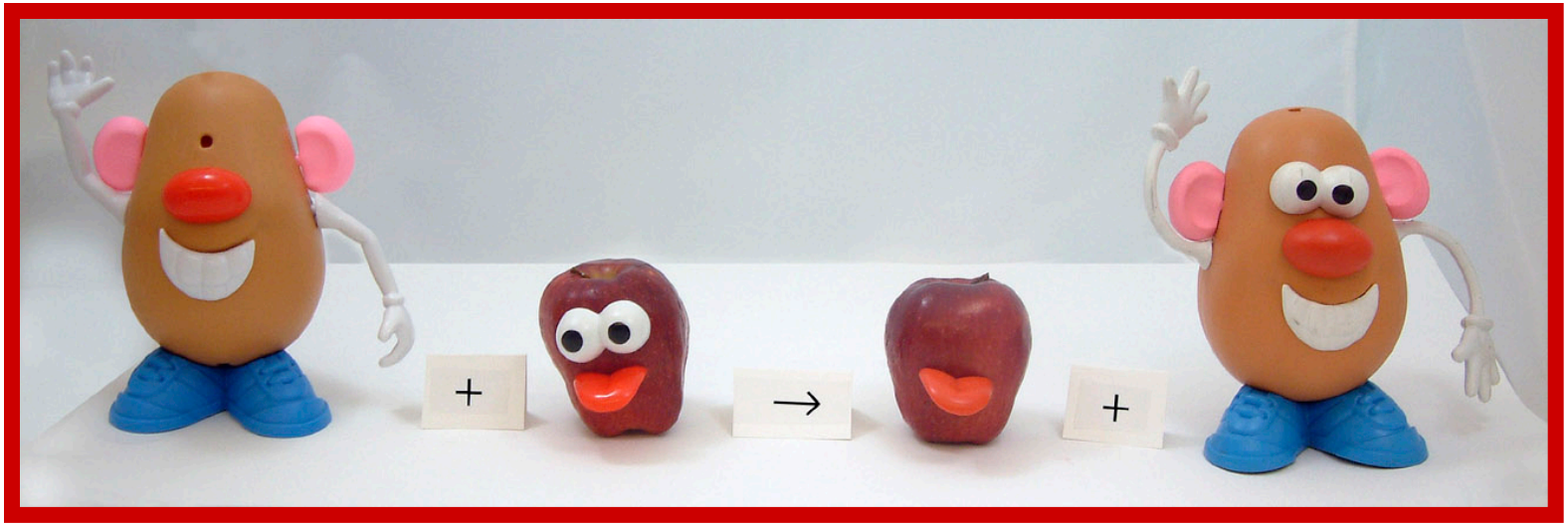
Visualizing a Chemical Reaction



single replacement reaction

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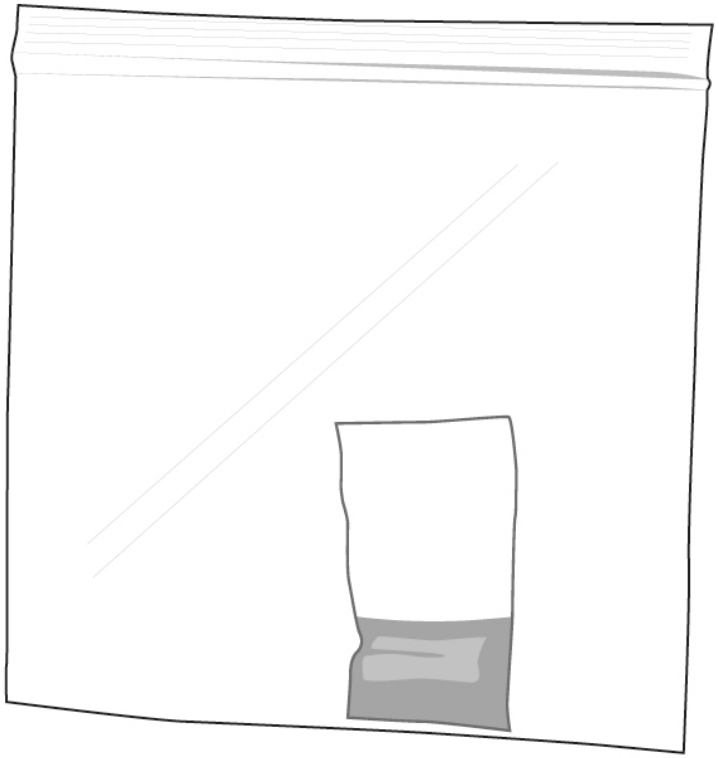
bag full of chemistry



Small open bag of phenol red soln inside the larger bag

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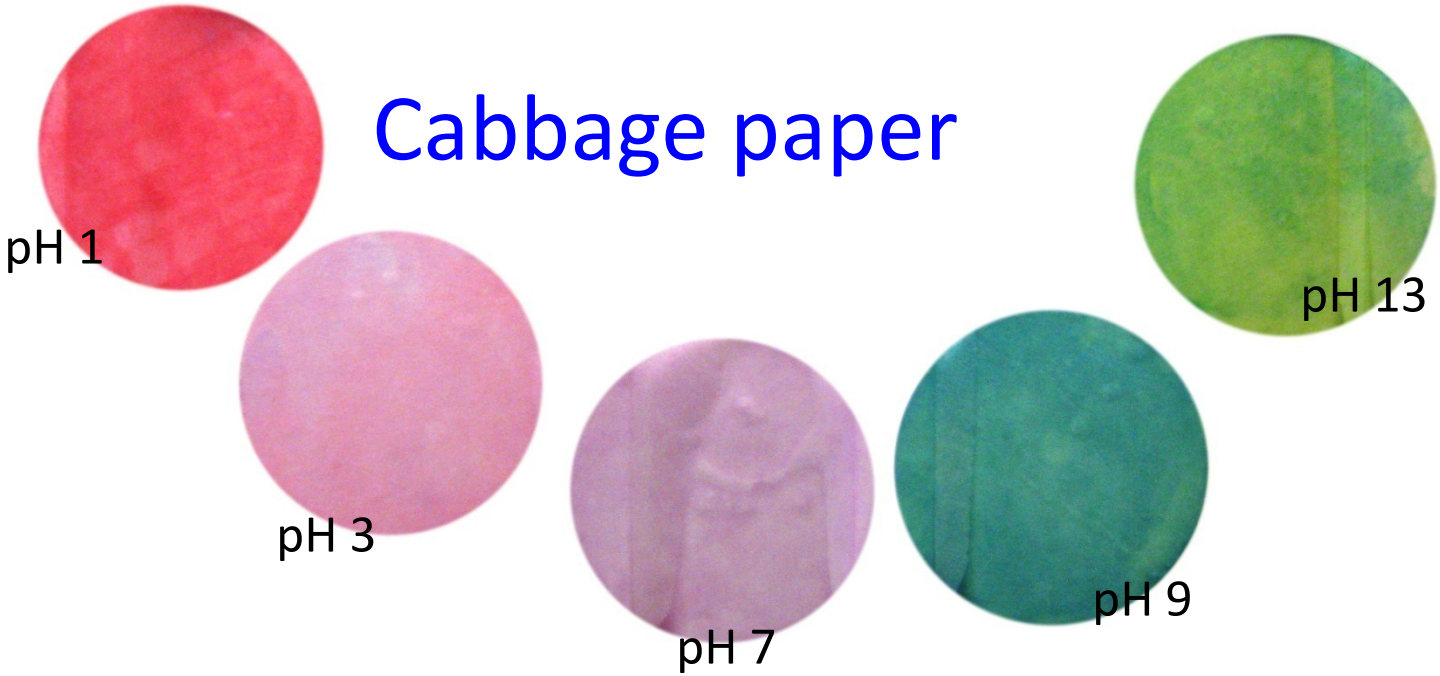
2 TBS calcium chloride $CaCl_2$

1 TBS baking soda $NaHCO_3$

10 mL phenol red in aqueous solution

Acid/Base Indicators

--------acidic---------neutral--------basic--------



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Acid/Base Indicators


WATER
10% EPSOM SALT SOLUTION
UNIVERSAL INDICATOR SOLUTION

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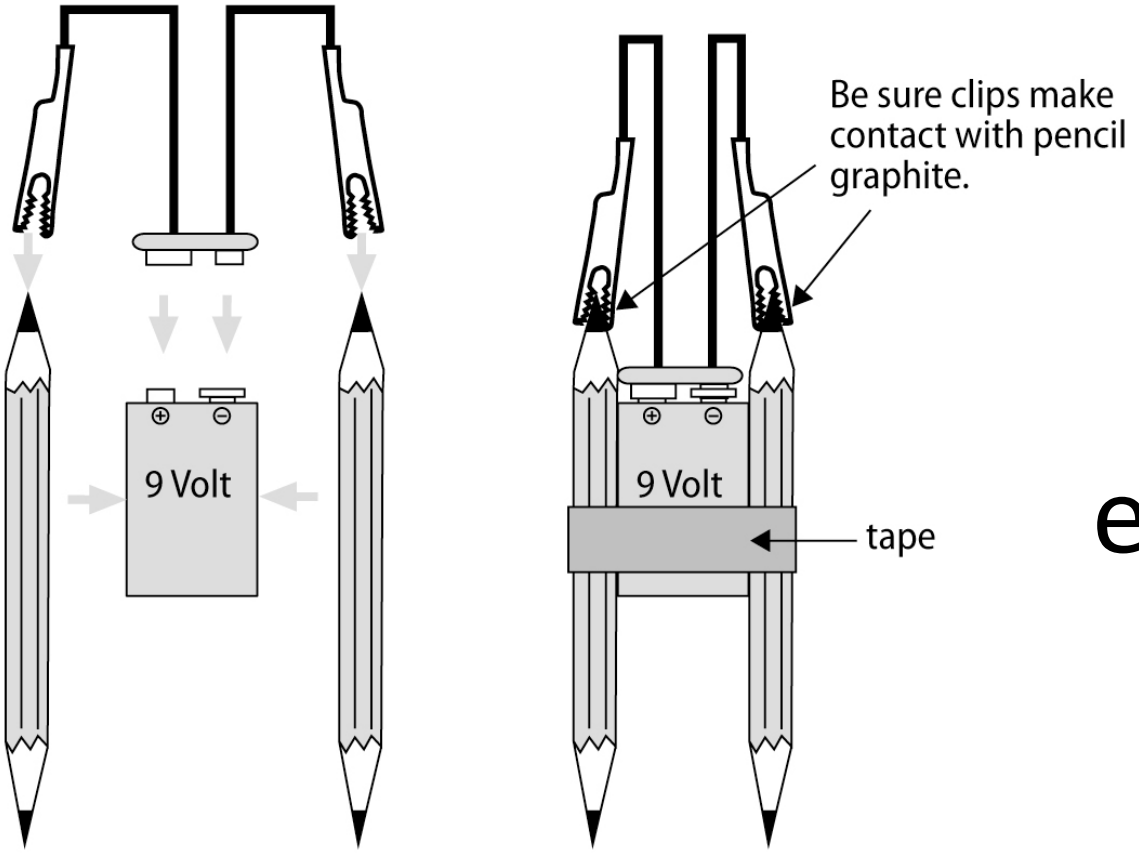

Figure 1: Assemble the pencil electrolysis apparatus.

Pencil electrolysis assembly

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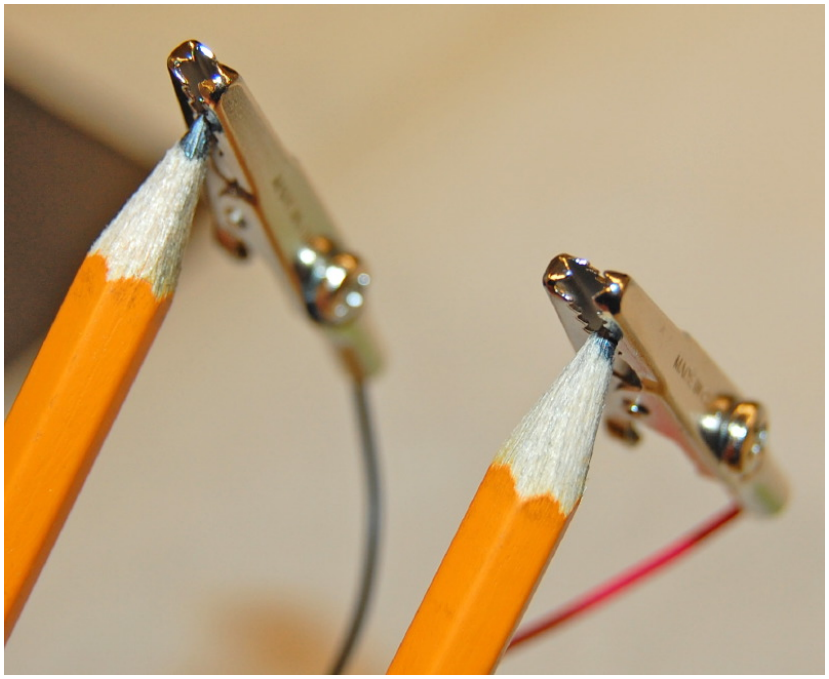

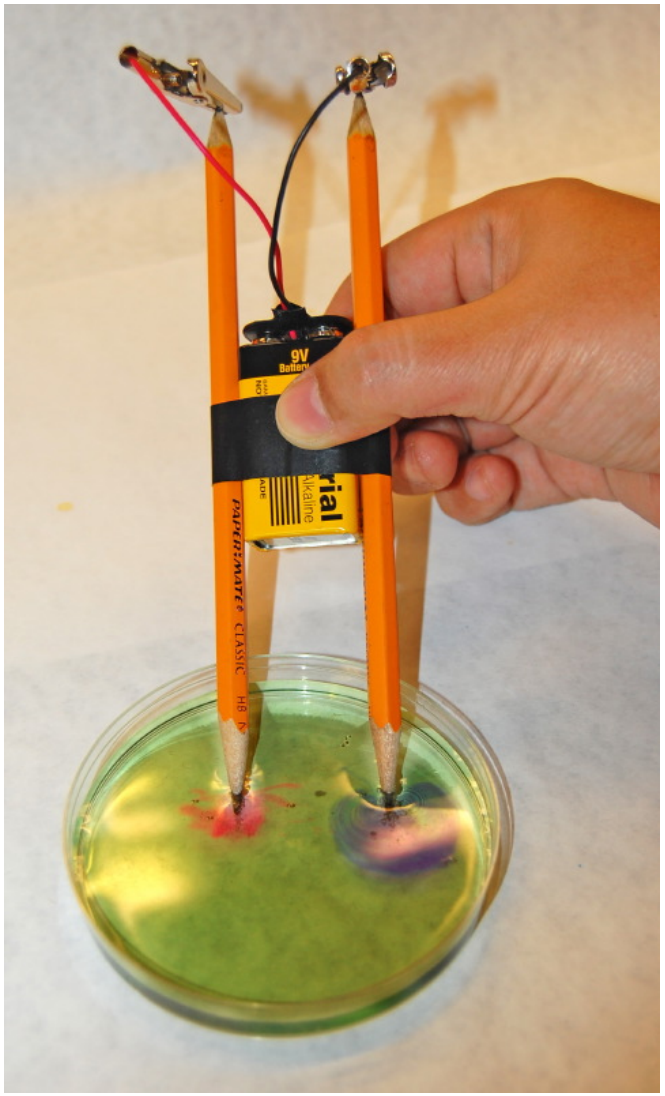

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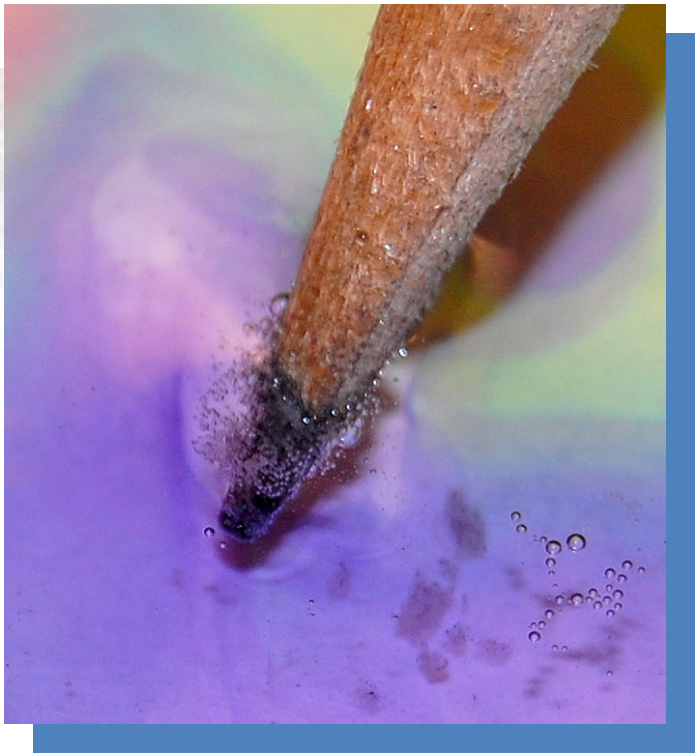

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$$4H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4OH^-(aq)$$

$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$$

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) + 4H_2O(l)$$

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When possible, student explorations are best

Micro-rocket challenge

Mix different ratios of

H_2 and O_2

to determine which makes the loudest pop.

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Micro-rocket challenge

Mix different ratios of H_2 and O_2 to determine which makes the loudest pop

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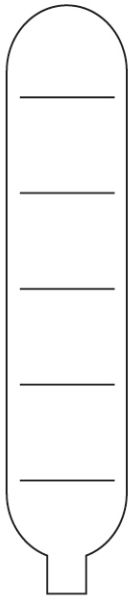
Micro-rocket challenge

Equipment used:

- Oxygen generator
  - 3% H_2O_2 with MnO_2catalyst
- Hydrogen generator
  - 3M HCl with mossy zinc
- pipet bulb with calibration
- contain of water
- Piezo electric igniter

Micro-rocket challenge



Use water displacement to collect gases into the calibrated pipet bulb

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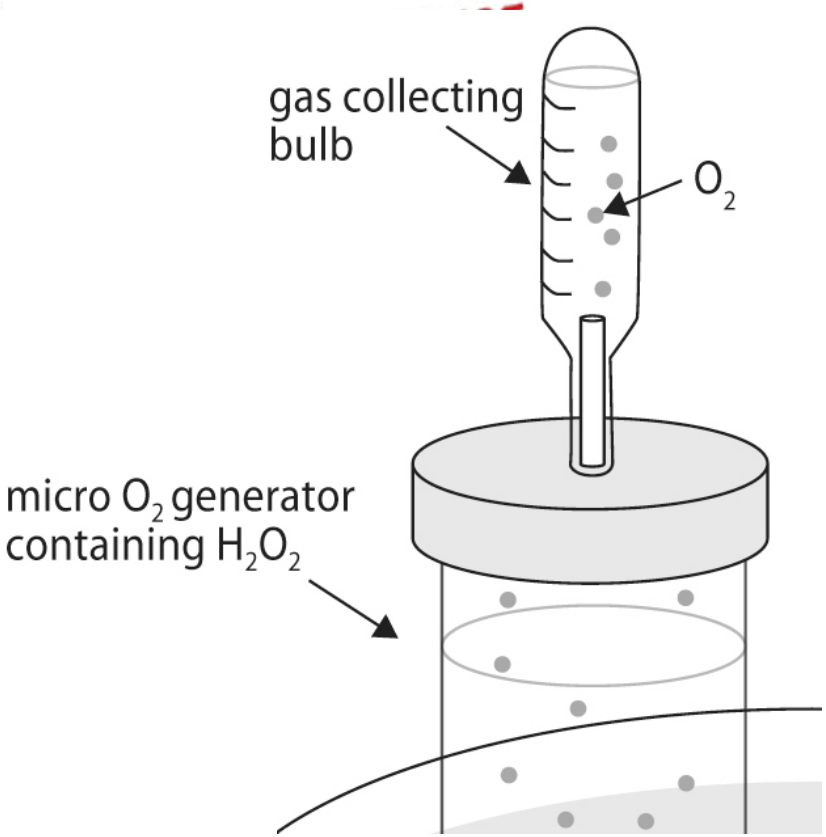
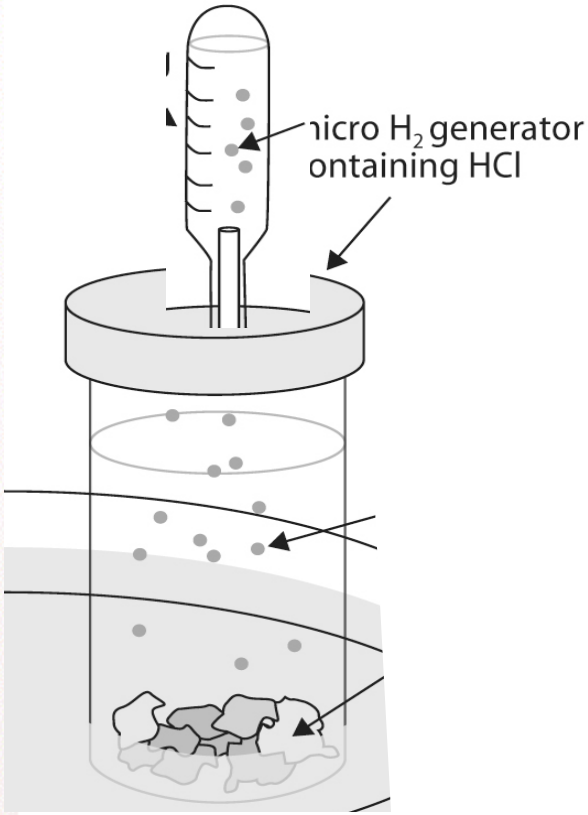


Place the water-filled bulb over the nozzle of appropriate generator.

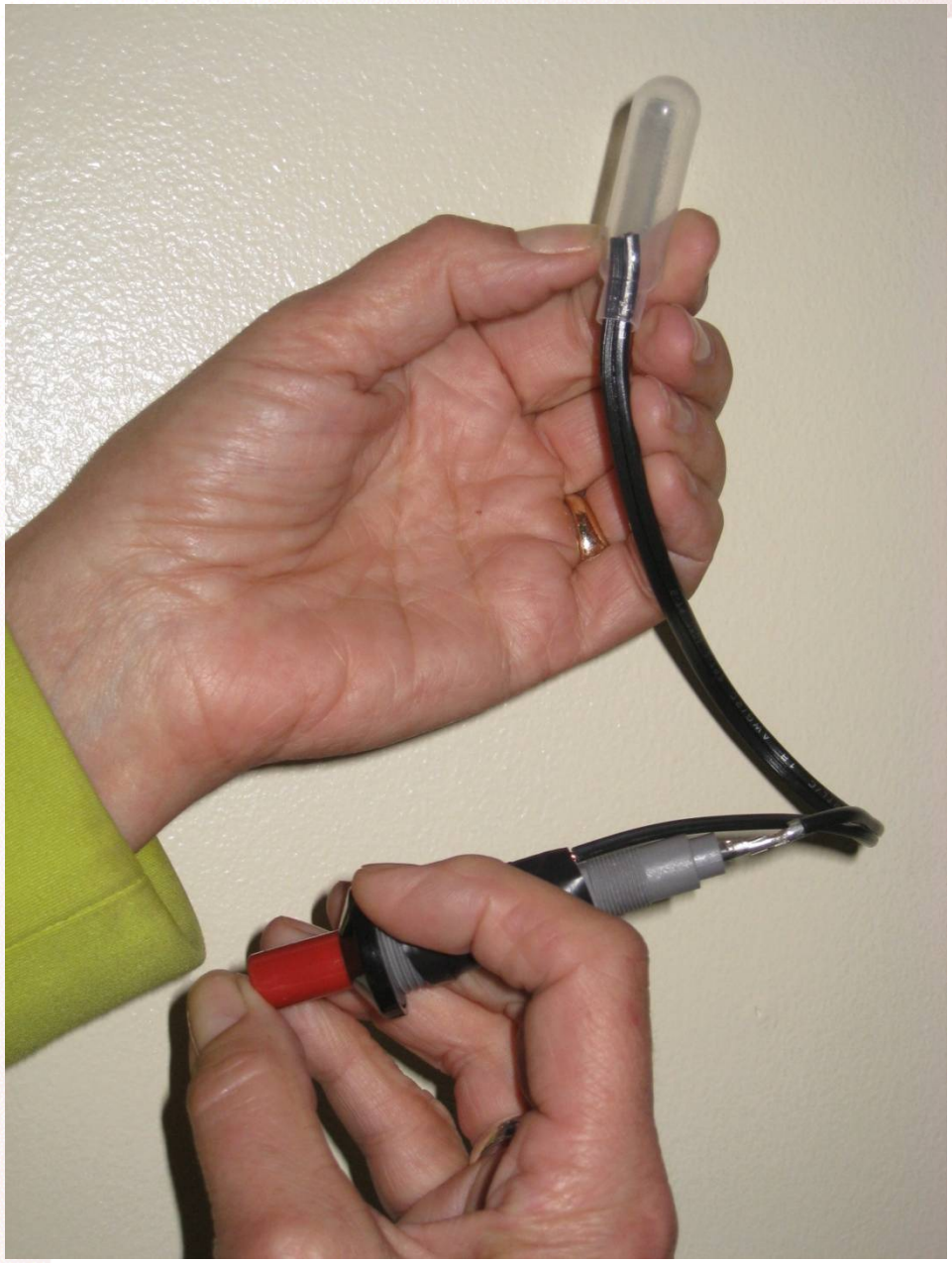
Fill with the amount of gas you want to try.

$$2H_2O_2(l) \xrightarrow{MnO_2} 2H_2O(l) + O_2(g)$$



once the bulb is over second generator fill it completely with second gas

$$2HCl(aq) + Zn(s) \rightarrow H_2(g) + ZnCl_2(aq)$$



- Place bulb over the ignition wires of the Piezo popper
- Hold bulb and press the trigger
- Rate the sound of pop on scale of 0 to 10

  (10 loadest)
- Change the variable and repeat as necessary to collect sufficient data

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$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

2 : 1 ratio gives

#10 pop

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Chemiluminescence

Using Simulations…

$2A \leftrightarrow A_2$

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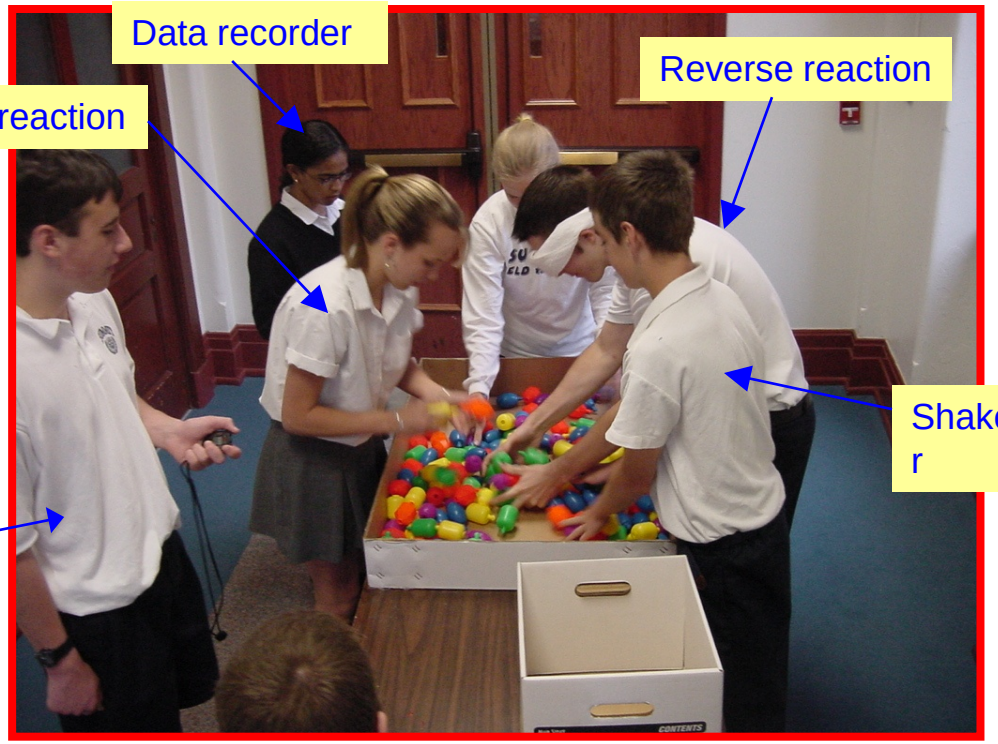
Equilibrium Simulation

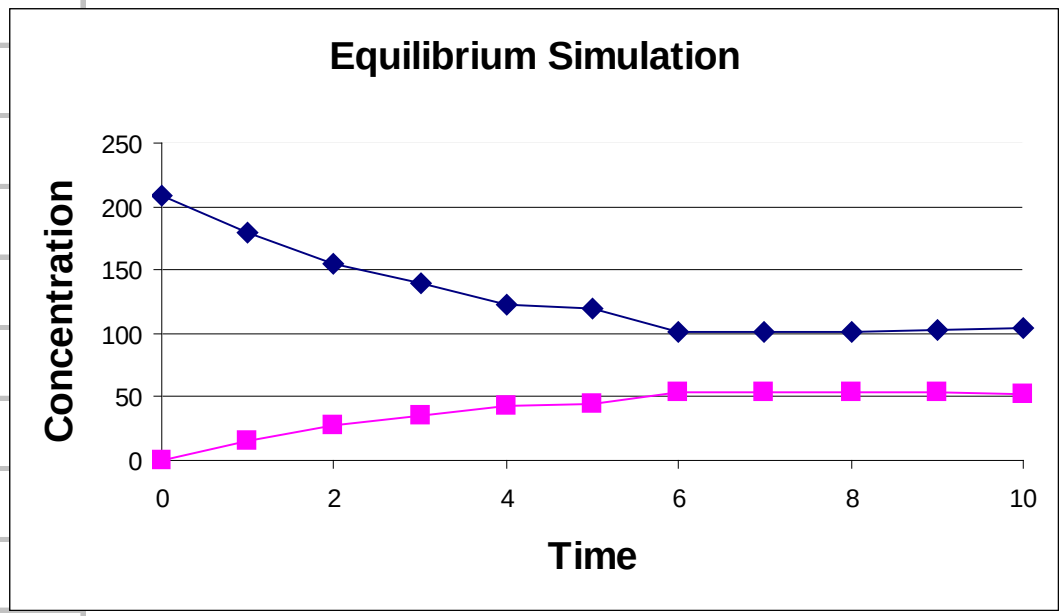


Equilibrium Simulations

- Students play the roles of:
  - forward reaction (1)
  - reverse reaction (1)
  - timer (1)
  - recorder (1)
  - shakers (4)
    (the number of shakers varies depending on the size of the container)
  - counters (2)
- This set-up allows 10 students to be involved in each experiment.

Student Data: $2A \leftrightarrow A_2$

Time	Reactant A	Product A_2
0	209	0
1	179	15
2	155	27
3	139	35
4	123	43
5	119	45
6	101	54
7	101	54
8	101	54
9	103	53
10	105	52



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Your challenge:

- make observations
- formulate testable questions
- design an experiment
- collect evidence
- formulate a claim
- share with your neighbors
- negotiate for understanding

- Authentic writing assignment

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A scientist is someone whose curiosity survives education's assault on it.

— *Sir Herman Bondi*

TERRIFIC SCIENCE

A scientist is someone whose curiosity is nurtured by education's impact on it.

Someone once said…

- A good teacher is…
  - 1/3 heart
  - 1/3 head
  - 1/3 ham

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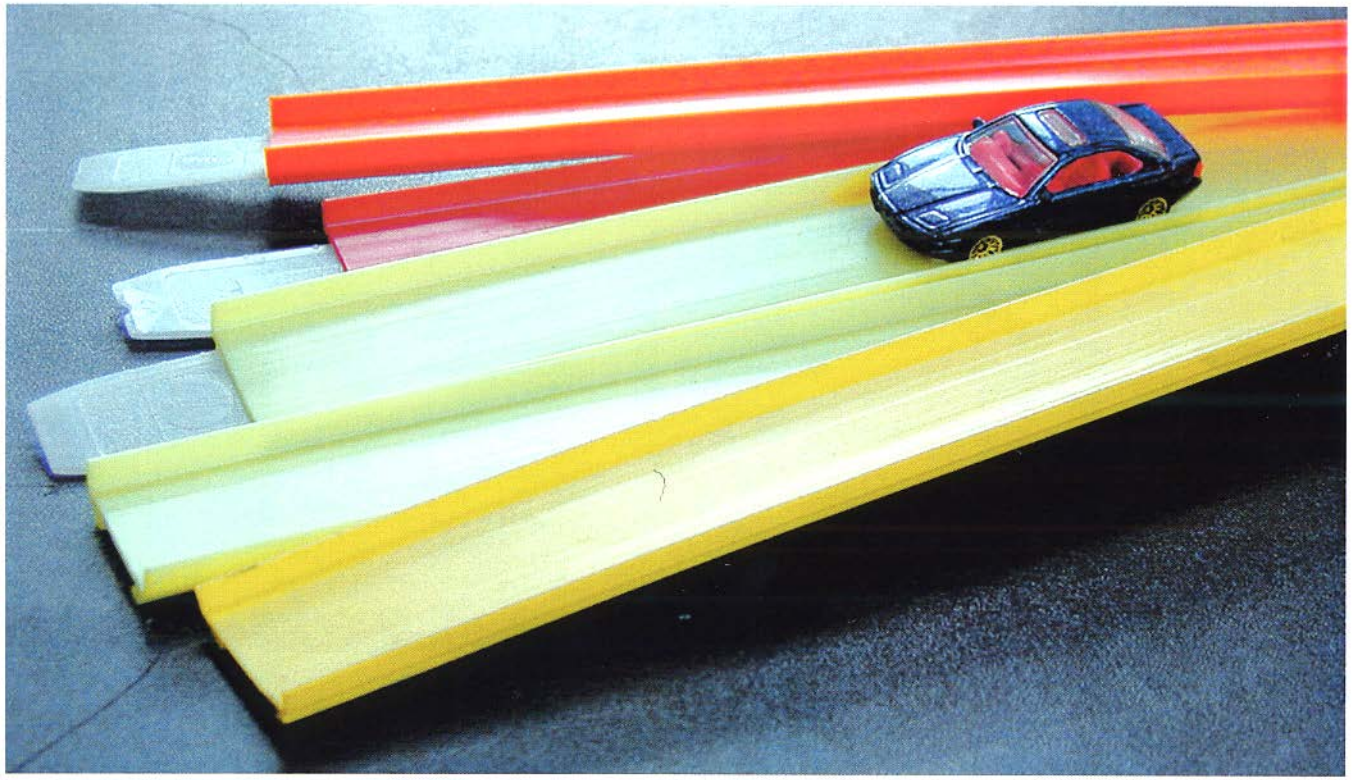
Models that use toys

The Fast Track to ΔH



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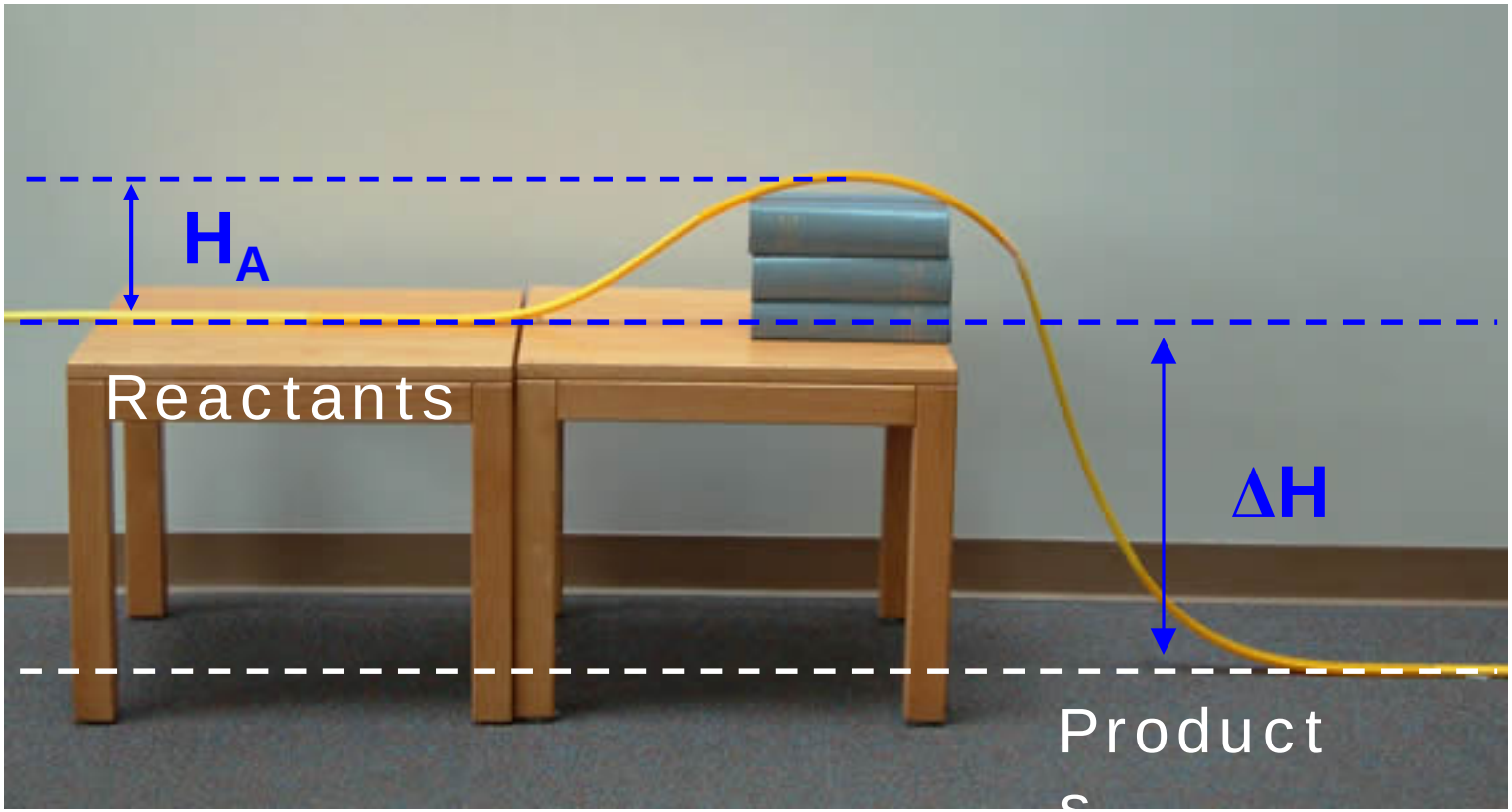
The Fast Track to ΔH



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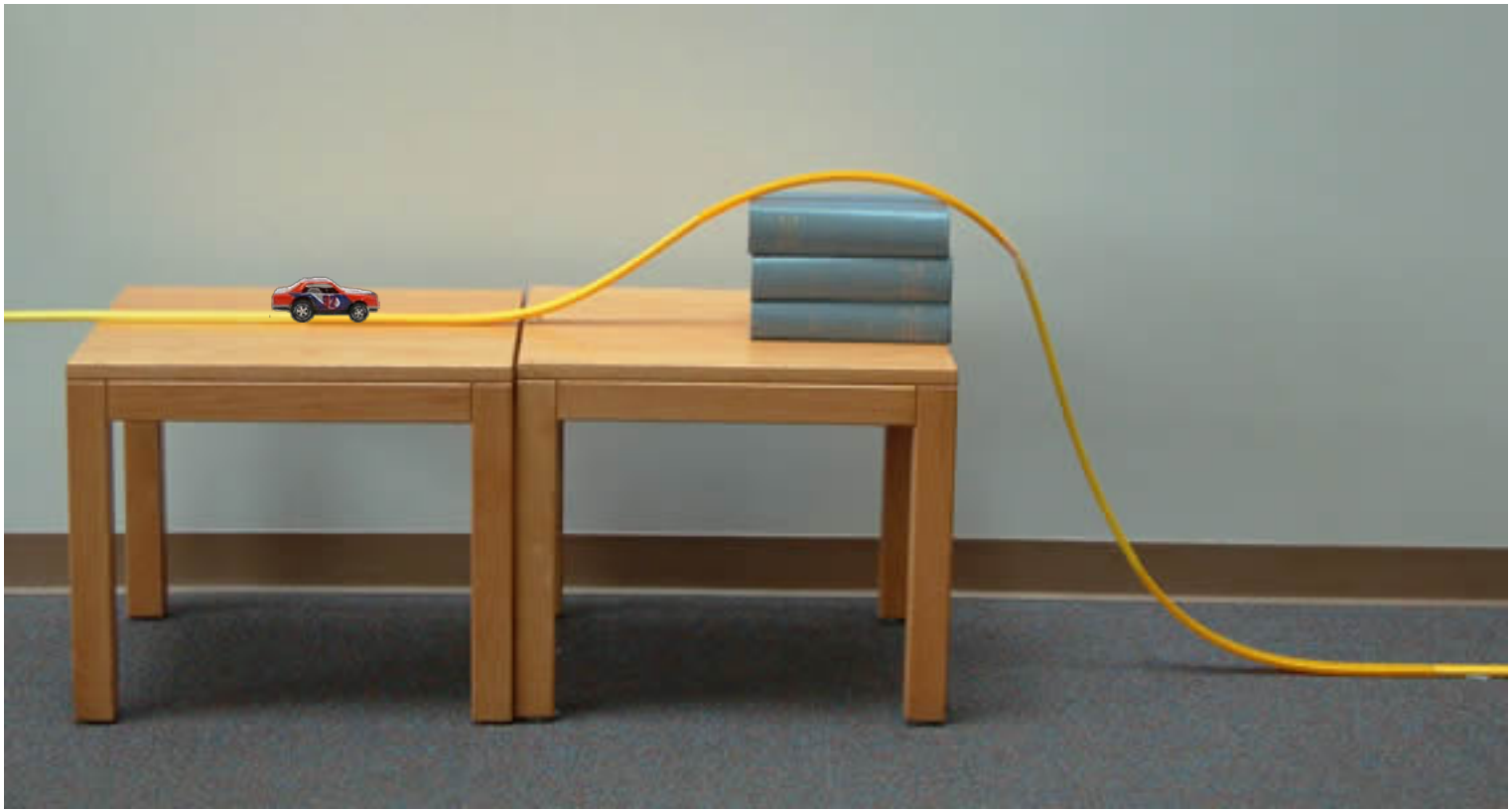
The Fast Track to ΔH



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The Fast Track to ΔH