Active Chemistry:
low cost classroom activities, small scale investigations, and active assessment

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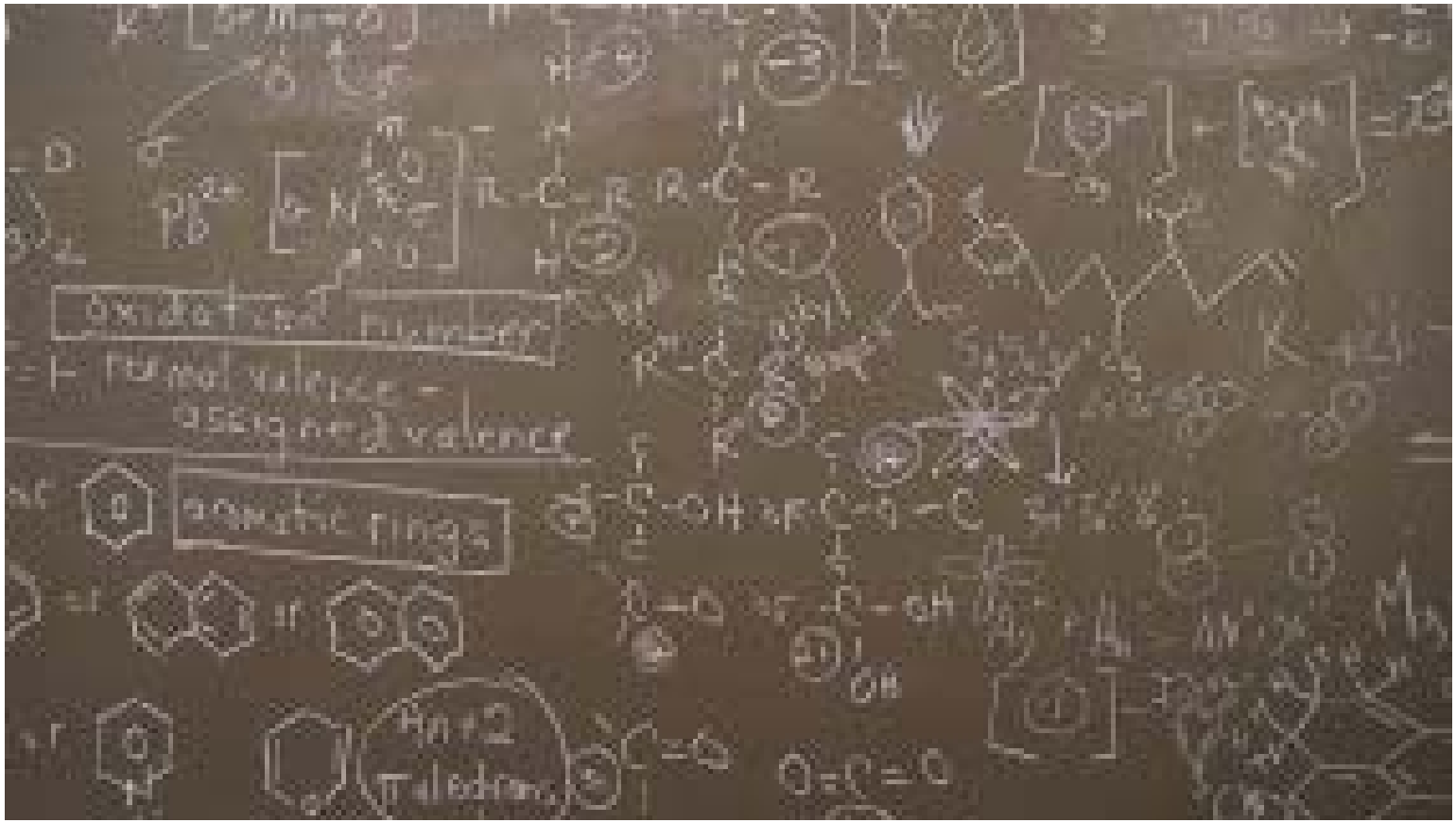
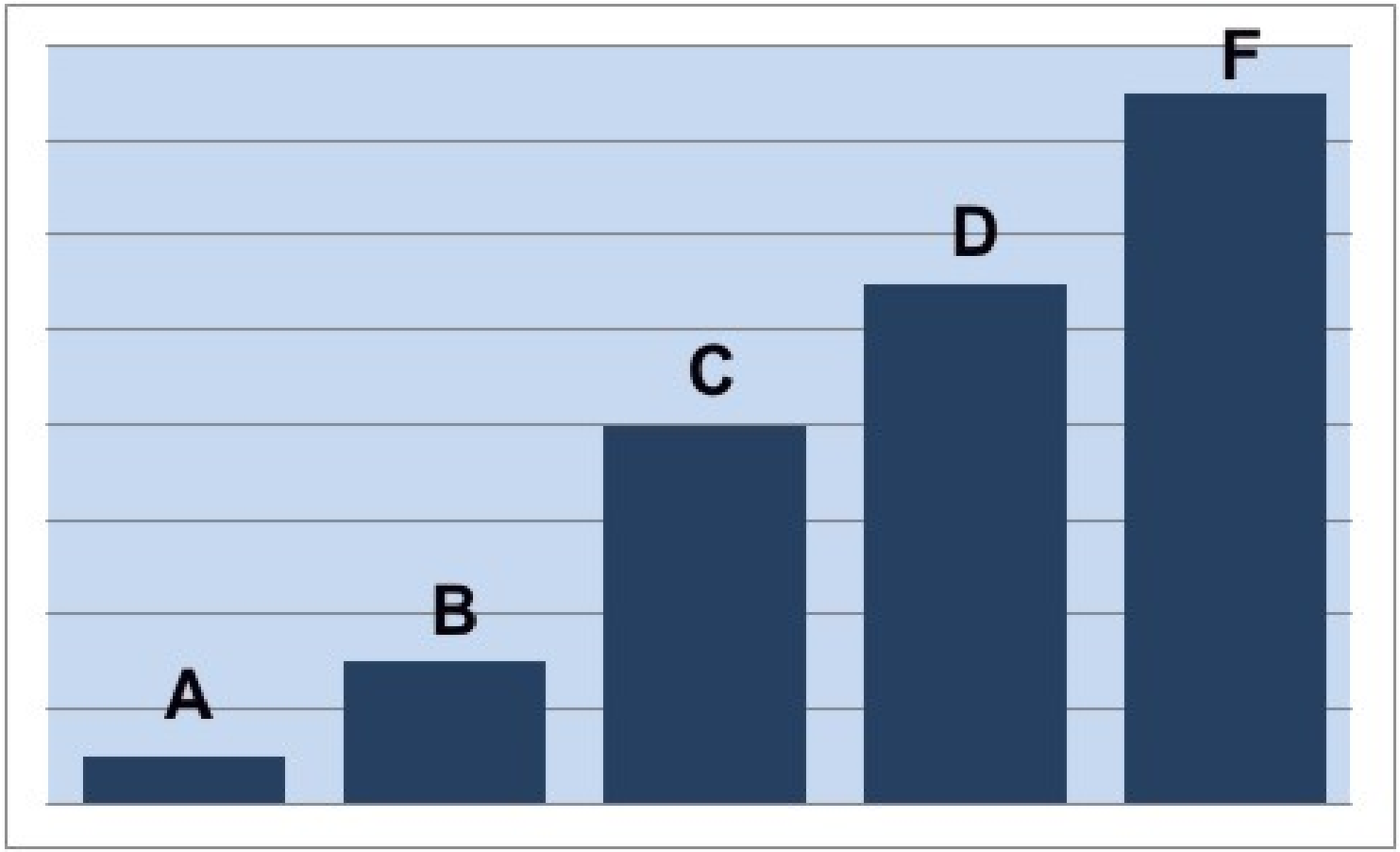
Do your class notes look like this



DO YOUR STUDENTS LOOK LIKE THIS?

DO YOUR CLASS GRADES LOOK LIKE THIS?

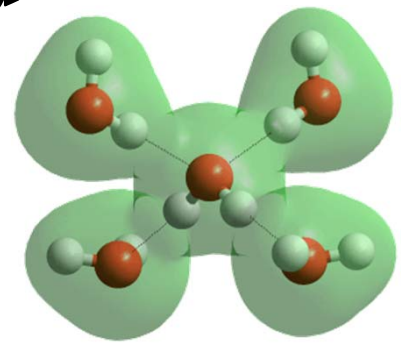


Why is chemistry “hard”?

- Technical vocabulary
- Concepts and abstractions – difficult to relate to everyday
- Difficult to visualize electrons, atoms, molecules, reactions, etc…
- Cannot memorize information – must have some degree of understanding
- Boring lectures (“chalk talks”) with a lot of information (information overload)
- Requires math  (Horrors!)

Learning needs to be real.
Learning needs to be multisensory.

Visualize



Explore

Touch

Smell

Think

Active learning*

- Topics go beyond the textbook coverage
- Students are participants in the class
- Creates a dialogue
- Provides visualization of concepts
- Allows for discovery
- Presents complex concepts on a concrete level
- Relation to everyday materials and processes
- Students must prepare for class in advance
  - Do not read the textbook to the students

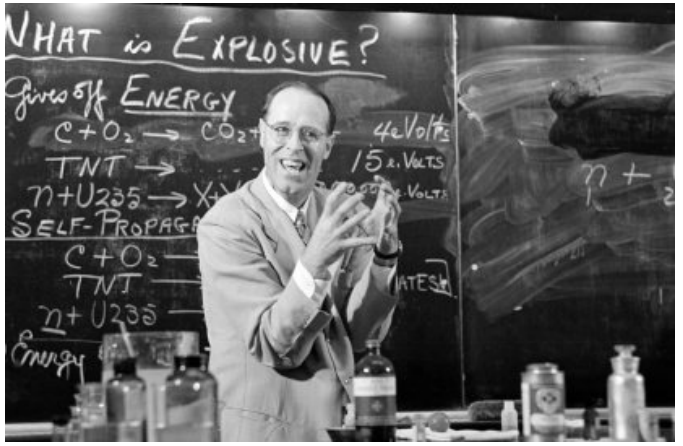
*Scott Freeman and colleagues, Proceedings of the National Academy of Sciences (*Proc. Natl. Acad. Sci. USA* 2014, DOI: 10.1073/pnas.1319030111)

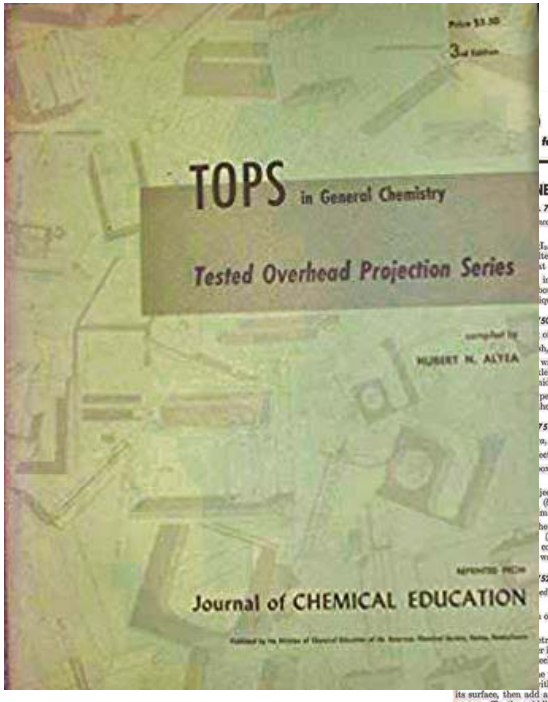
What can we do?

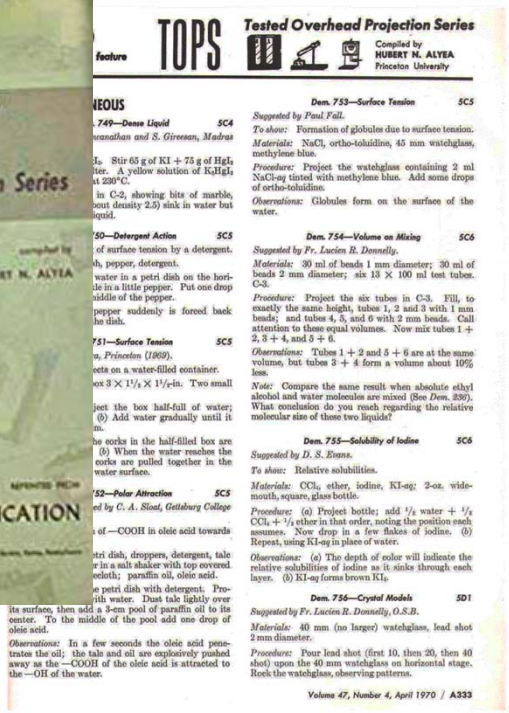
- Go beyond clickers and flipped classrooms
- Classroom instruction:
  - Demonstrations
  - Hands-on class activities
  - Small group activities
- Homework activities
  - Experiments to do at home
- Testing (Active Assessment)
  - Small scale experiments
- Whenever possible, don't walk into your classroom without a demonstration or an activity.

Small scale chemistry experiments:

Hubert Alyea starting in 1961 with his TOPS (Tested Overhead Projection Series) and, later, with his Armchair Chemistry experiments.






feature TOPS Tested Overhead Projection Series
Compiled by HUBERT N. ALYEA Princeton University

Dem. 753—Surface Tension 5C5
Suggested by Paul Fall.
To show: Formation of globules due to surface tension.
Materials: NaCl, ortho-toluidine, 45 mm watchglass, methylene blue.
Procedure: Project the watchglass containing 2 ml NaCl-aq tinted with methylene blue. Add some drops of ortho-toluidine.
Observations: Globules form on the surface of the water.

Dem. 754—Volume on Mixing 5C6
Suggested by Fr. Lucien R. Donnelly.
Materials: 30 ml of beads 1 mm diameter; 30 ml of beads 2 mm diameter; six 13 × 100 ml test tubes. C-3.
Procedure: Project the six tubes in C-3. Fill, to exactly the same height, tubes 1, 2 and 3 with 1 mm beads; and tubes 4, 5, and 6 with 2 mm beads. Call attention to these equal volumes. Now mix tubes 1 + 2, 3 + 4, and 5 + 6.
Observations: Tubes 1 + 2 and 5 + 6 are at the same volume, but tubes 3 + 4 form a volume about 10% less.
Note: Compare the same result when absolute ethyl alcohol and water molecules are mixed (See Dem. 230). What conclusion do you reach regarding the relative molecular size of these two liquids?

Dem. 755—Solubility of Iodine 5C6
Suggested by D. S. Evans.
To show: Relative solubilities.
Materials: CCl_4, ether, iodine, KI-aq; 2-oz. wide-mouth, square, glass bottle.
Procedure: (a) Project bottle; add 1/2 water + 1/2 CCl_4 + 1/2 ether in that order, noting the position each assumes. Now drop in a few flakes of iodine. (b) Repeat, using KI-aq in place of water.
Observations: (a) The depth of color will indicate the relative solubilities of iodine as it sinks through each layer. (b) KI-aq forms brown KI_3.

Dem. 756—Crystal Models 5D1
Suggested by Fr. Lucien R. Donnelly, O.S.B.
Materials: 40 mm (no larger) watchglass, lead shot 2 mm diameter.
Procedure: Pour lead shot (first 10, then 20, then 40 shot) upon the 40 mm watchglass on horizontal stage. Rock the watchglass, observing patterns.

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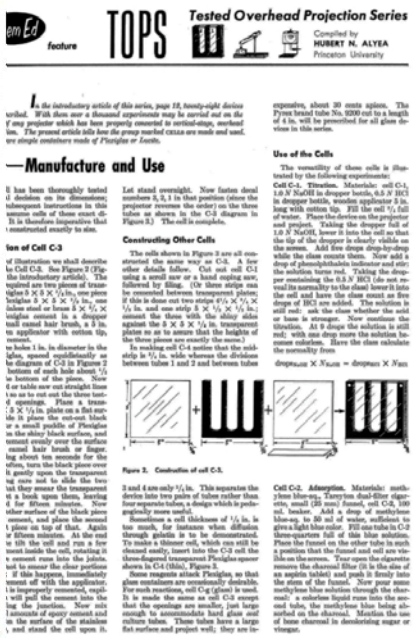

Chem Ed feature TOPS Tested Overhead Projection Series
Compiled by HUBERT N. ALYEA Princeton University

—Manufacture and Use

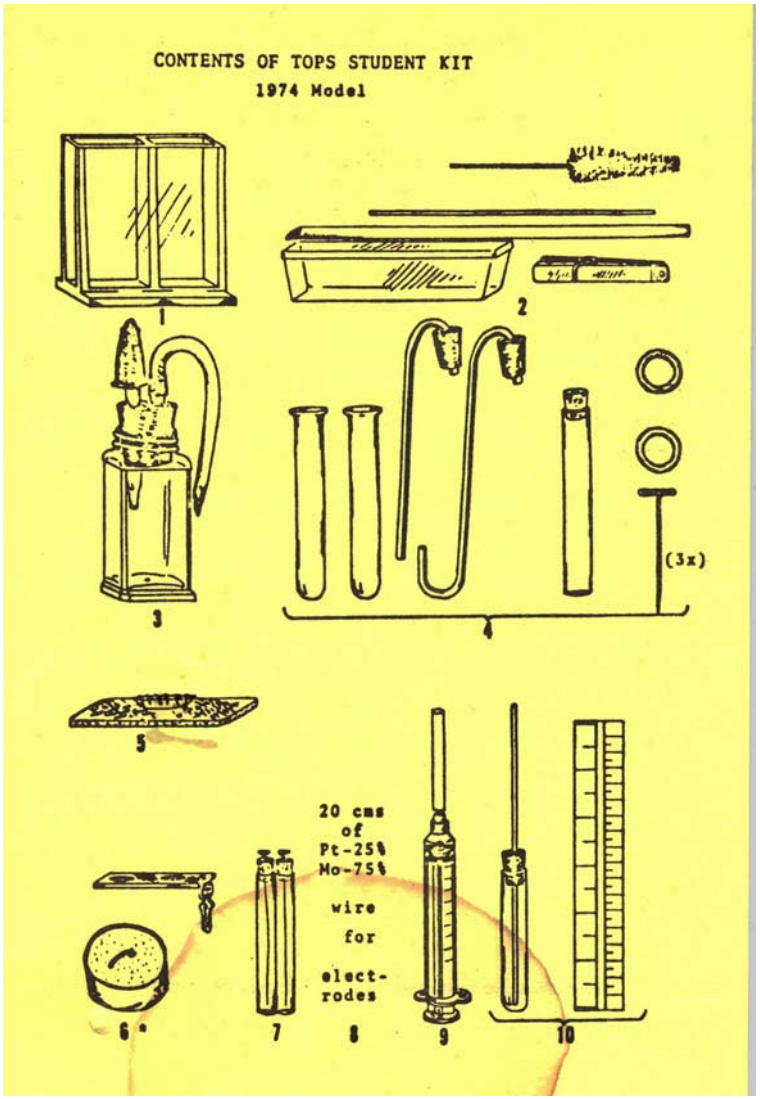
Constructing Other Cells

Use of the Cells

Figure 3. Construction of cell C-3.

- **For his TOPS, Hubert Alyea utilized a number of custom made apparatus.**
- **Everything was made to be projected on a modified overhead projector.**

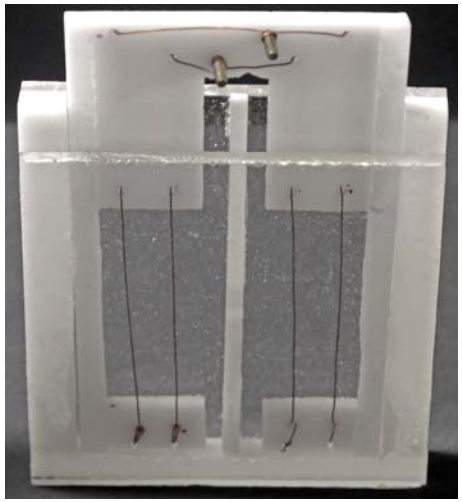
Twin cell



Microburners

Gas reaction bottles

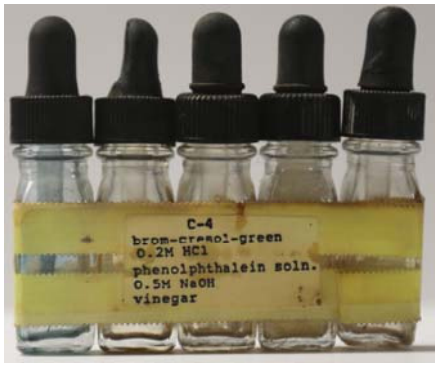
Reaction cell



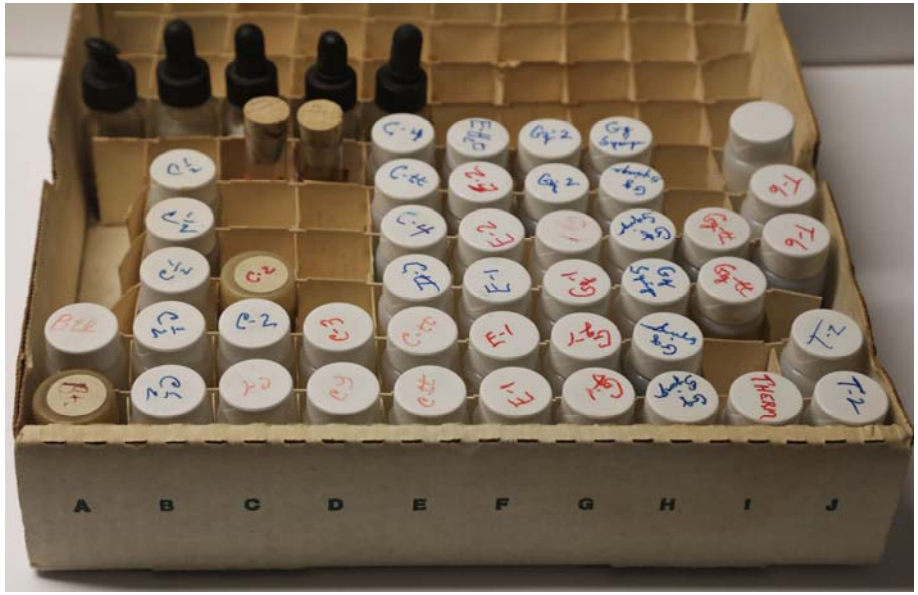
Electrolysis cell

Alyea Tops

- Liquid reagents were placed in dropper bottles.
- Dropper bottles for a particular experiment or set of experiments were taped together.
- Solid reagents were placed in vials and grouped together.

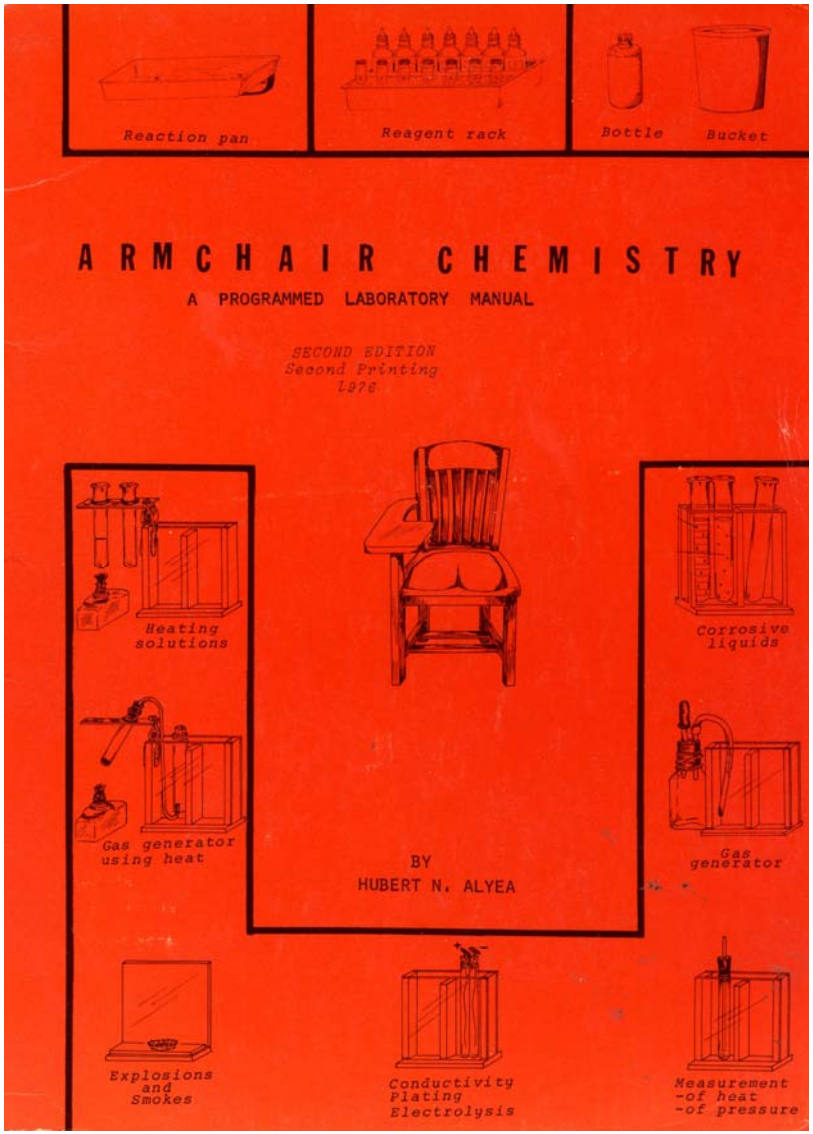


Liquid reagent set



Solid reagents

- For his Armchair Chemistry experiments, Alyea used a lot of the same apparatus.
- These experiments did not have to be projected.
- Setting up and maintaining TOPS and Armchair Chemistry was time consuming and was relatively expensive (mainly for the number of dropper bottles required.)

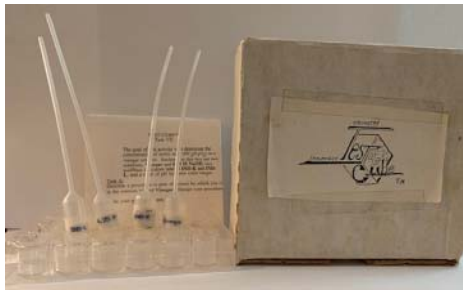


Small scale chemistry experiments:

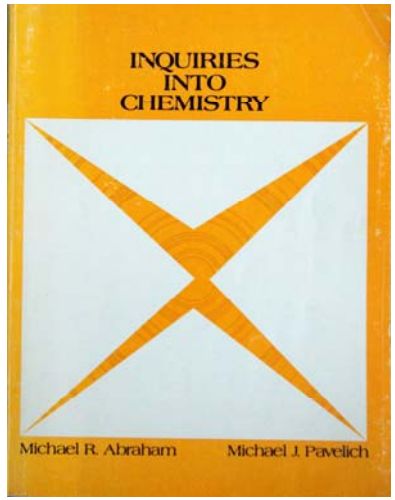
- The availability of inexpensive and readily available materials such as Beral pipettes and well plates made microscale more accessible in the classroom.

Small scale chemistry experiments:

- Development of suitable questions and techniques by Wilbur Bergquist's "Test Cubes"



- Abraham and Pavelich's open inquiry experiments in their *Inquiries Into Chemistry*
- Bob Silberman's *Small-Scale Laboratory Assessment Activities*



- **The experiments and techniques from classroom activities can be used for**
  - **Hands-on testing in classroom exams**
    - **Initiated in my classes in 1993 through 1998**
    - **Used as part of the 2001 and 2002 New Jersey's Rutgers University Academic Challenge competition**
  - **Laboratory practical exams**
  - **Hands-on sessions at professional conferences and in workshops with teachers, students, and the public**
    - **Participants can rotate between experiment stations**

Elements

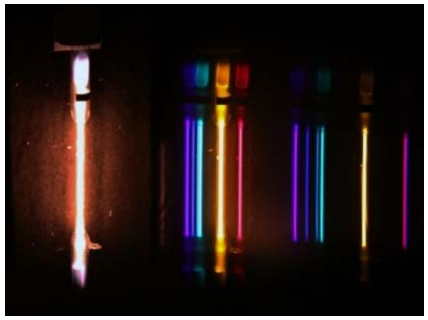
How are elements formed?
NOVA: Forging the Elements in "Origins: Back to the Beginning"
https://www.youtube.com/watch?v=621maypRngs
(55 minutes in length). "The origin of the elements" starts at about 34 minutes into the video)
or see The Elements: Forged in Stars at
https://www.youtube.com/watch?v=B-LXUHJmzzc

Pass meteorite samples around the classroom

Pass element samples around the classroom

Build a spectroscope

Use Flinn C-Spectra or other holographic diffraction grating.



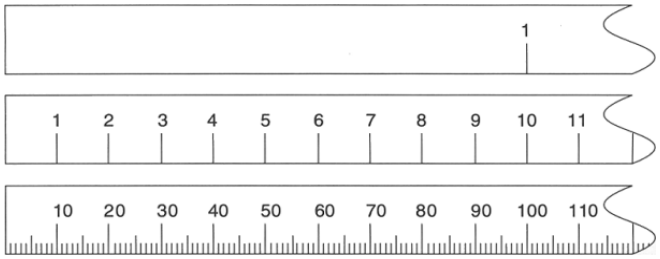
View Spectra using spectrum tubes

Homework: find spectra of elements in your environment.

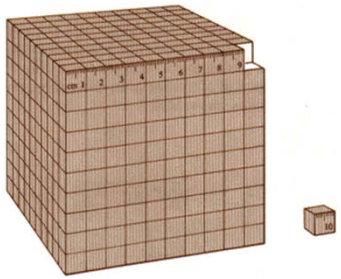
Measurement

- **Do you waste time teaching measurement?**
- **Don't define measurement, get the students to measure things**
- **They will get some measurements wrong, but will learn**

Ancient measurement standards in Regensburg, Germany



"Silver" and "gold" pennies (copper coins). Masses are essentially unchanged
http://www.chymist.com/copper%20silver%20gold.pdf



Some references for measurement are:
Powers of Ten https://www.youtube.com/watch?v=0fKBhvDjuy0
Absolute Zero https://www.youtube.com/watch?v=E9U3dh4Capg

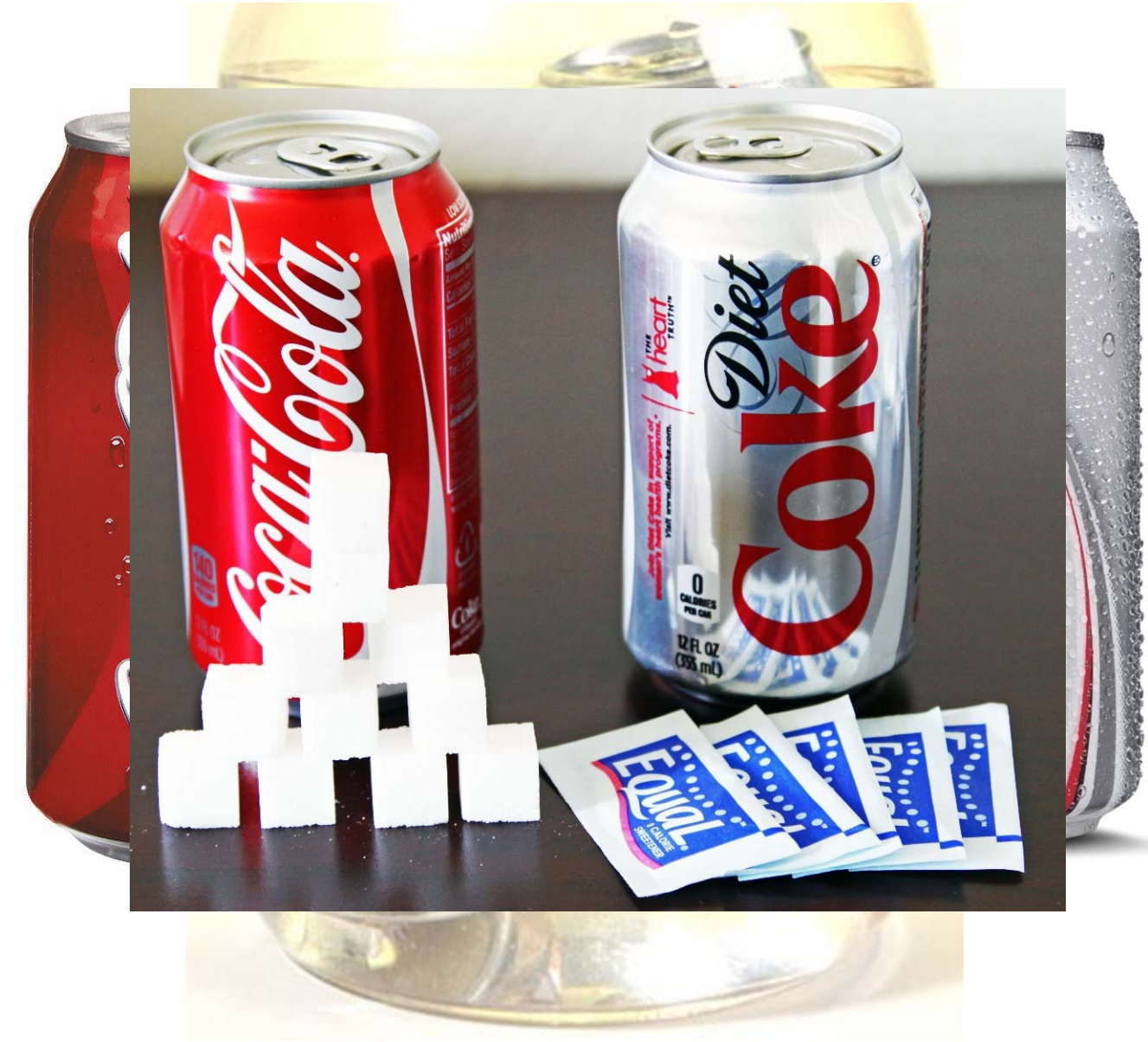
Density

Density-for-the-sake-of-density does not necessarily teach the concept.

Indiana Jones – Raiders of the Lost Ark

and students will explain it to you.

Coke vs. Diet Coke



Hot and Cold

Separate water by density

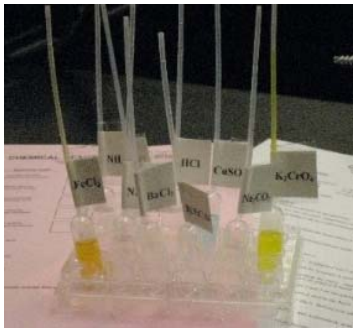
HOT

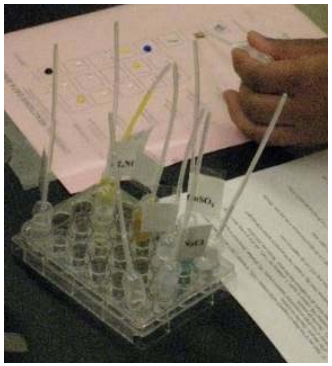
COLD

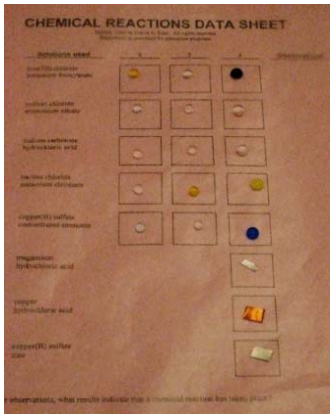
COLD HOT

Chemical Reactions

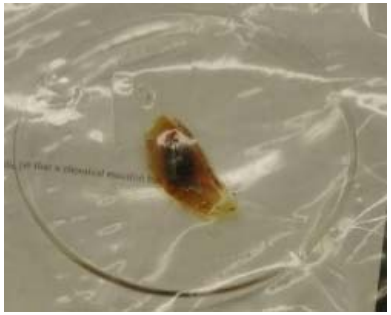
- **Chemical reactions**
  (A lab or classroom activity)
  Instructions at
  http://www.chymist.com/chemical%20reactions.pdf







- **Synthesis of Zinc Iodide**
  Tracking a chemical reaction in small scale in a zip-lock bag
  Instructions at
  http://www.chymist.com/zinc%20iodide.pdf



Conductivity Testing

- **If household current is used, fit the apparatus with a momentary switch.**

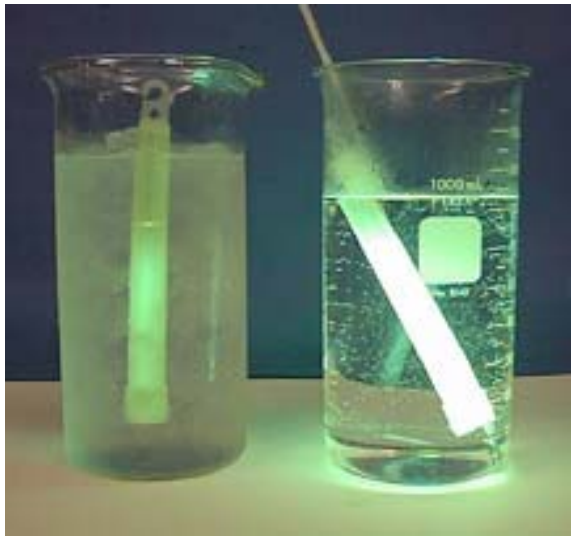
- **Use a battery powered conductivity tester.**

Flinn Scientific Conductivity Tester (Cat. No. AP1493) or build your own.

Instructions at http://www.chymist.com/conductivity.pdf

Kinetics

Lightsticks and temperature



Alka Seltzer: An Intro to kinetics

- **Vary particle size**
- **Vary temperature**

Alka Seltzer: Limiting reagent

Note: $NaHCO_3$ is present in excess (ask "Why?")

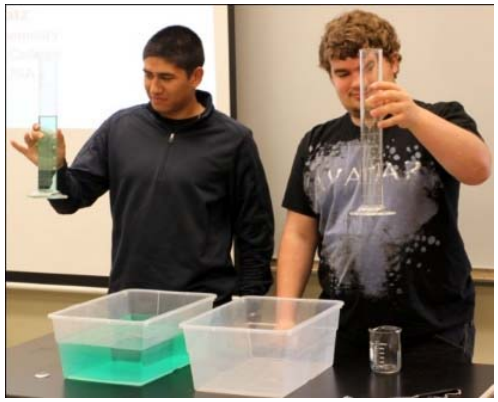
http://www.chymist.com/AlkaSeltzer.pdf

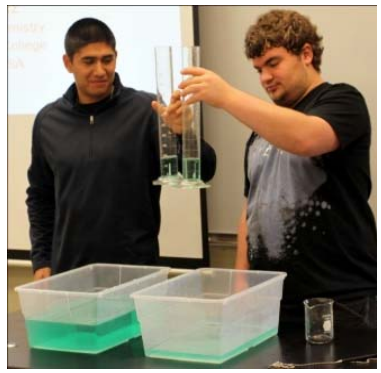
Equilibrium

Equilibrium simulation

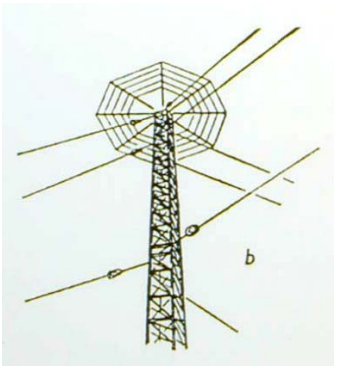
- **Start with 2 beakers equal size (400 mL)**
  (Ask for predicted result.)
- **Repeat with 2 beakers unequal size (100 mL and 400 mL)**
  (Ask for predicted result.)
- **Measure every few cycles**

http://www.chymist.com/Visualizing%20Equilibrium.pdf

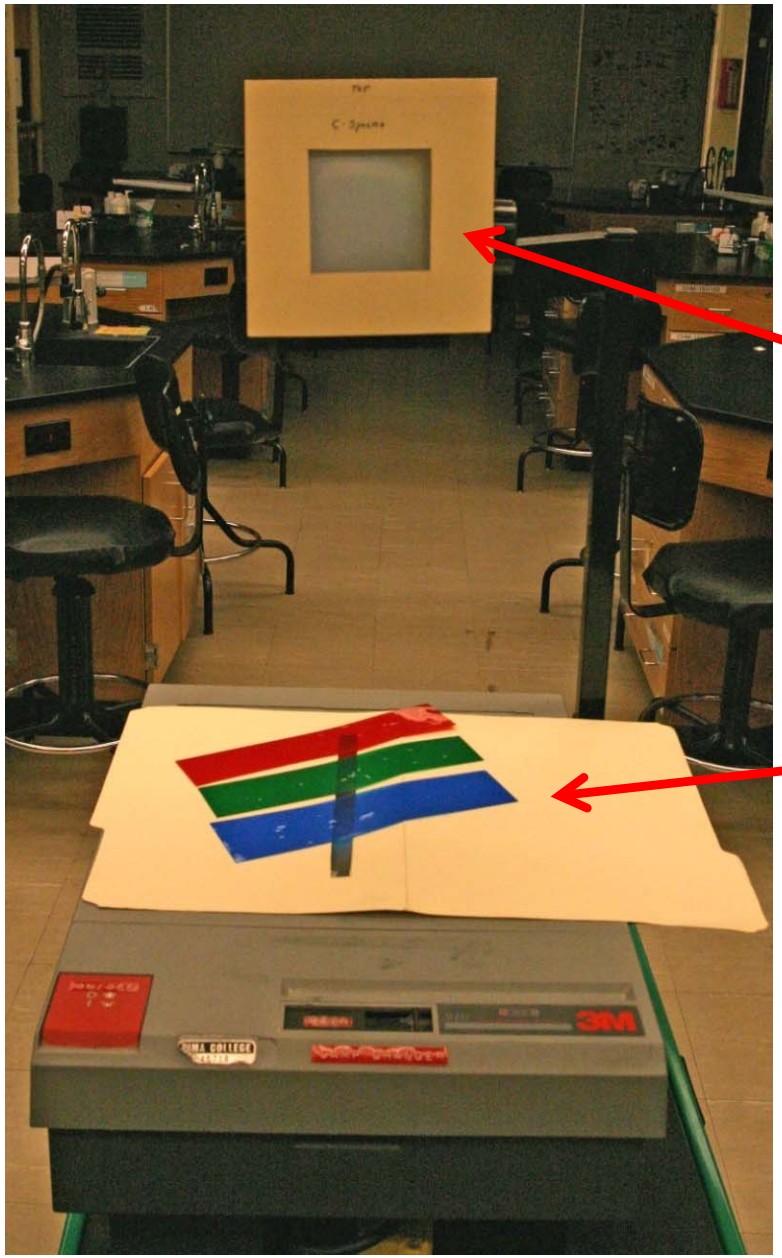




The Visual Electromagnetic Spectrum



Visible Light



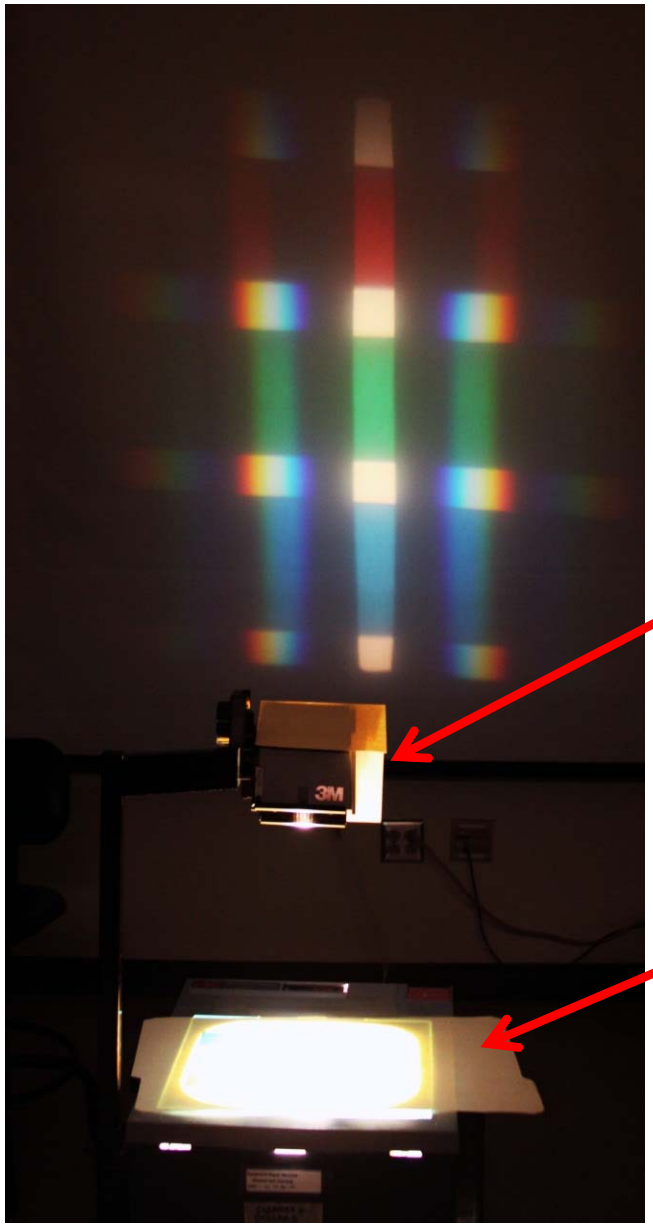
An overhead projector spectroscope

Holographic diffraction grating (Flinn C-Spectra)

Slit and colored filters

Instructions are available at http://www.chymist.com/overhead%20spectroscope.pdf

Visible Light



An overhead projector spectroscope

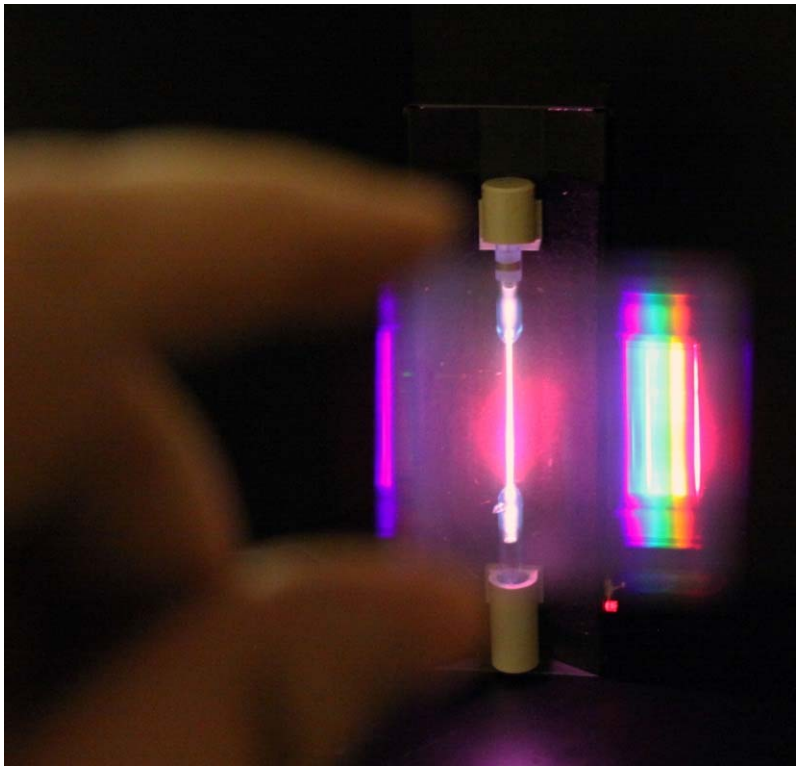
View absorption spectra

Holographic diffraction grating

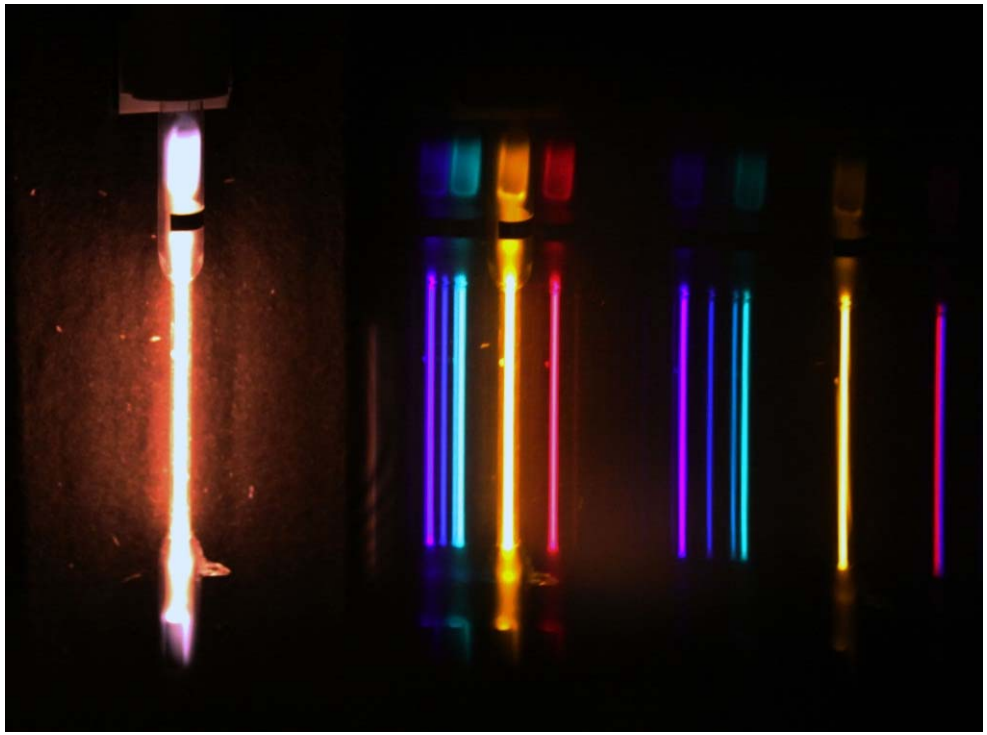
Slit and colored filters

The Electromagnetic Spectrum

Viewing spectra using holographic diffraction grating (Flinn Scientific C-Spectra)



Hydrogen spectrum



Helium spectrum

Colored Flames

Strontium – red

Lithium - red

Calcium – red/orange

Copper – green or blue

Barium – yellow-green

Potassium – violet

Sodium - yellow

Instructions at http://www.chymist.com/Colored%20flames.pdf

lithium

potassium

calcium

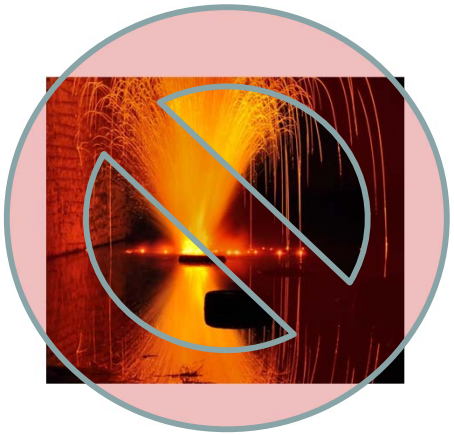
barium

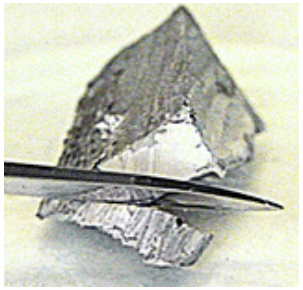
Alkali Metals: Li, Na, and K

Use small pieces of metals in a 600-mL or 800-mL beaker.

Cover with a fine wire gauze.

Project the reaction on a large screen.

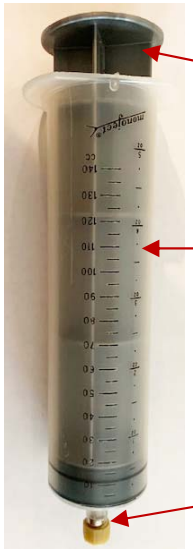


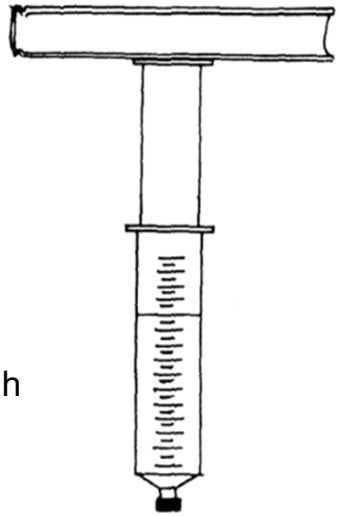


Project the cutting of the metal

Gases:
Experiments with a 140-mL syringe

- **Boyle's Law: PV = k**
- **Expand a marshmallow**
- **Boil water at room temperature**
- **Charles' Law: V/T = k**
- **Determine mass (density) of a gas**





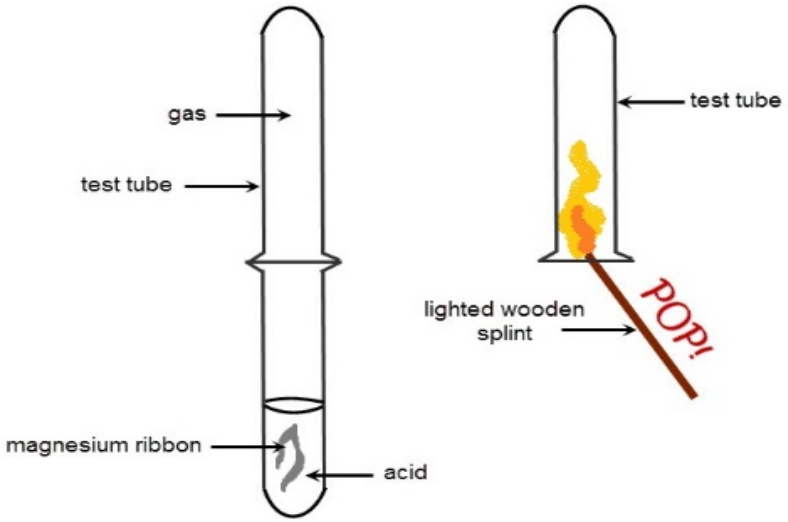
Use textbooks as weights

Instructions at
http://www.chymist.com/Exps%20with%20a%20140%20mL%20syringe.pdf

Hydrogen

Igniting a hydrogen filled balloon!

Best teaching moment is using a test tube.



Oxygen

Use hydrogen peroxide and yeast to generate oxygen in a large test tube or a small (50 mL or 125 mL) flask.

Insert a glowing wood splint.

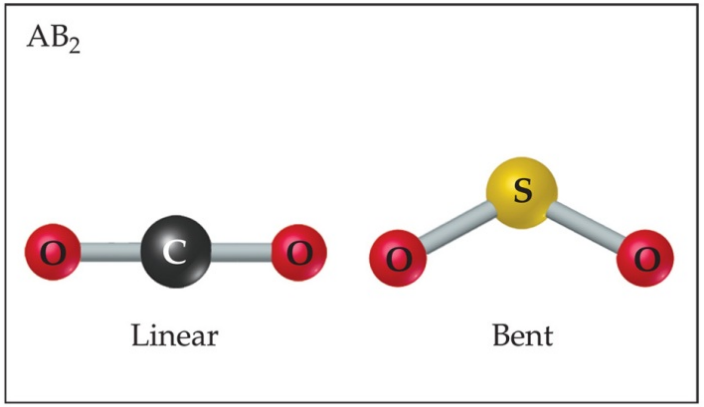
Carbon Dioxide

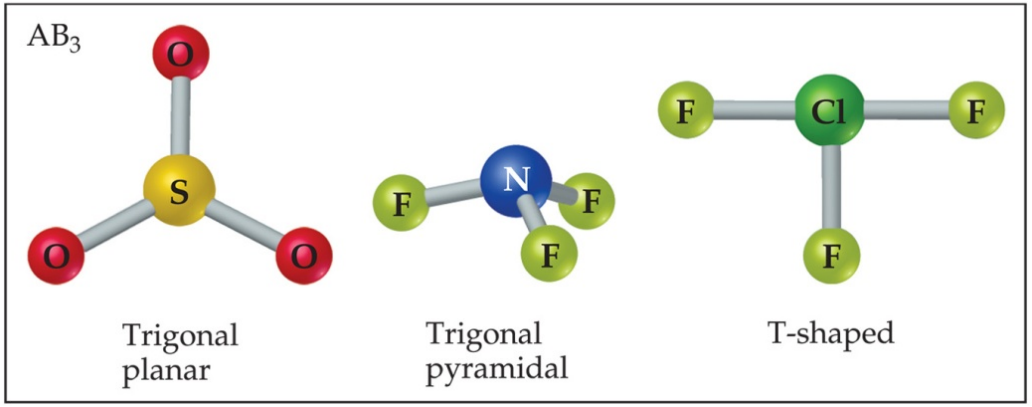
Use baking soda ($NaHCO_3$) and vinegar to generate CO_2

Insert a burning wood splint.

(Ask why CO_2 does not escape from the open beaker.)

Molecular Shapes
Using Modeling Clay and Toothpicks

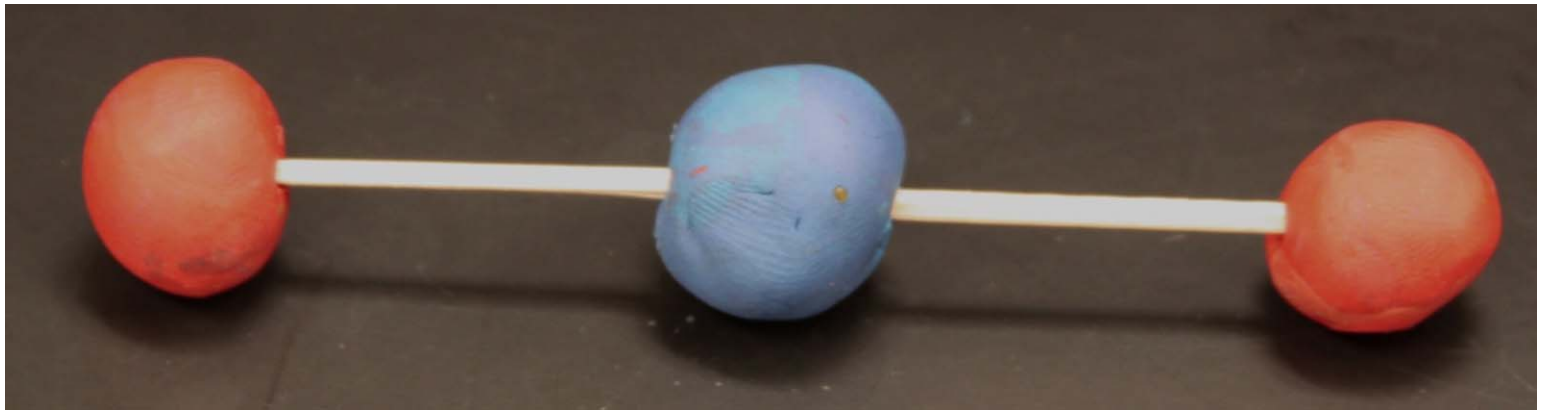




- The shape of a molecule plays an important role in its reactivity.
- Students cannot think in 3-D
- Manipulating "atoms" into molecular shapes formalizes VSEPR
- Teach shapes BEFORE Lewis dot structures

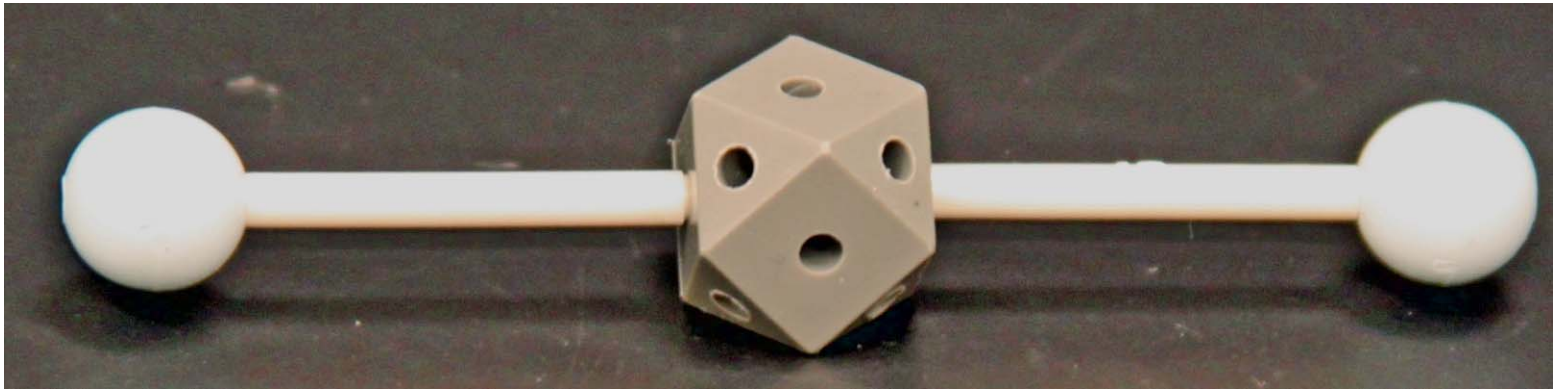
Molecular Shapes

Modeling clay and toothpicks to build shapes

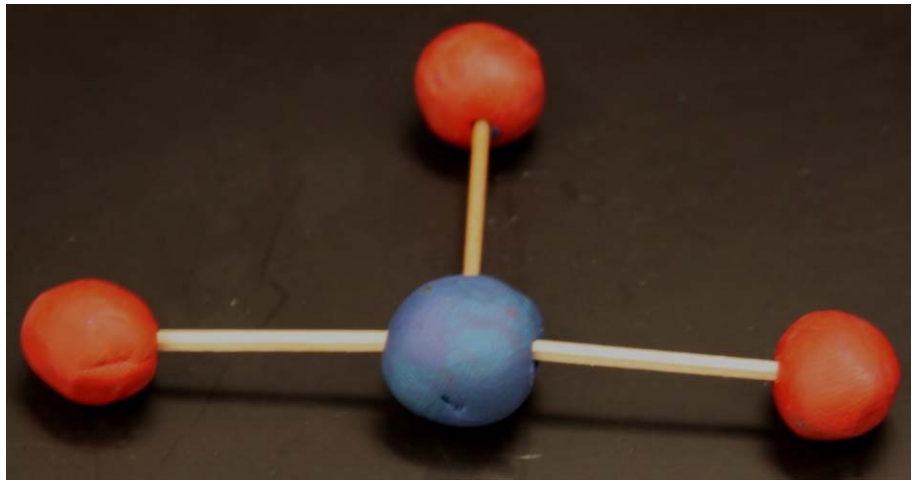


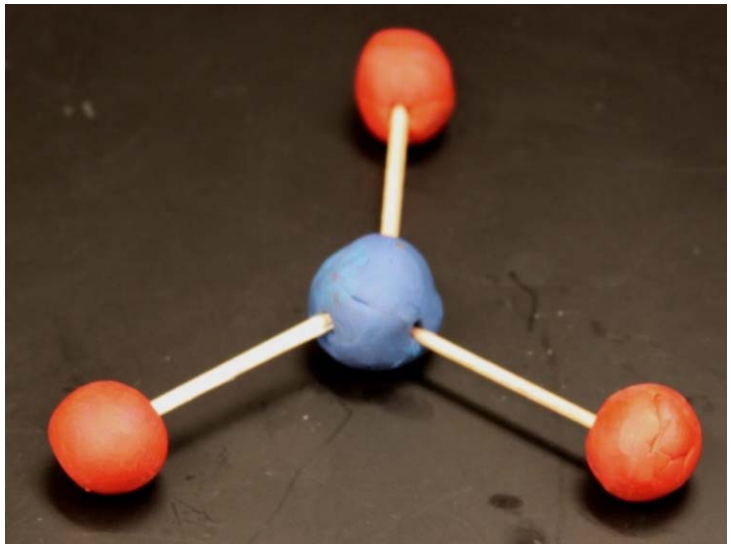
MX_2 – linear, 180° bond angle

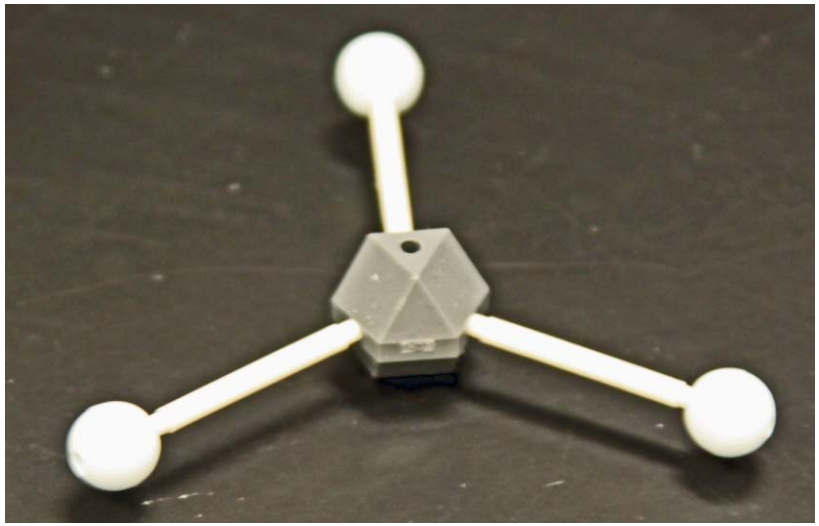
Characteristic of Periodic Table Group IIA



Molecular Shapes

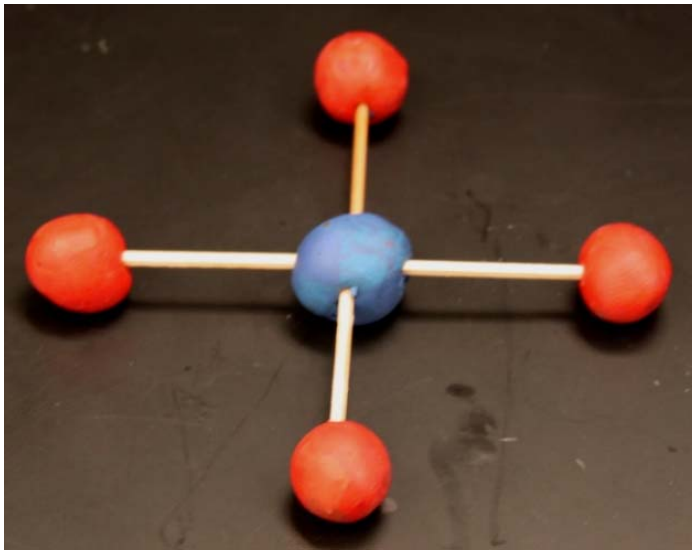


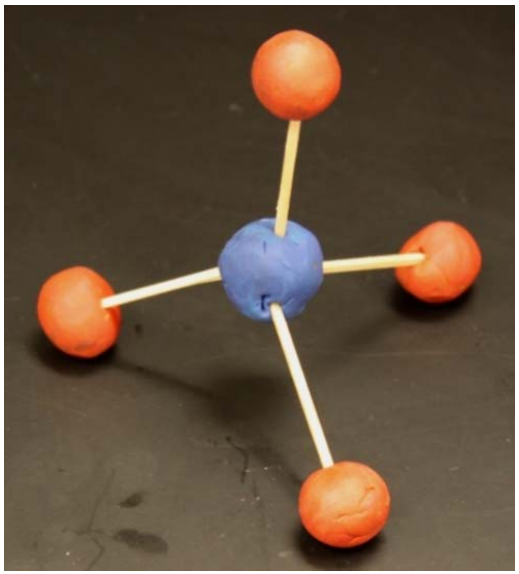


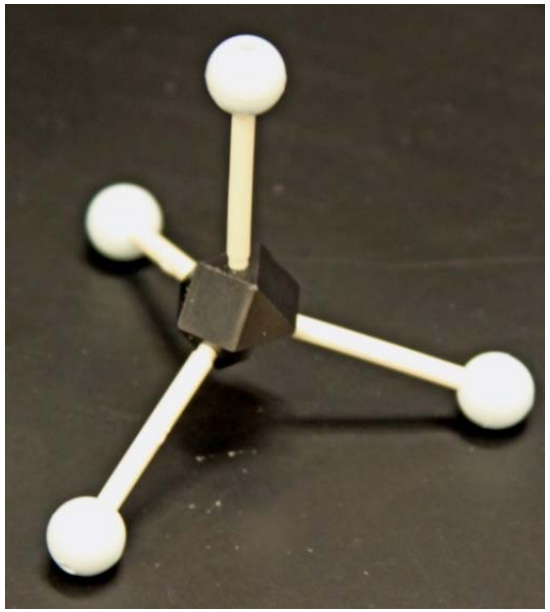


MX_3
triangular planar
(trigonal planar)
120° bond angle
Characteristic of Periodic Table Group IIIA

Molecular Shapes

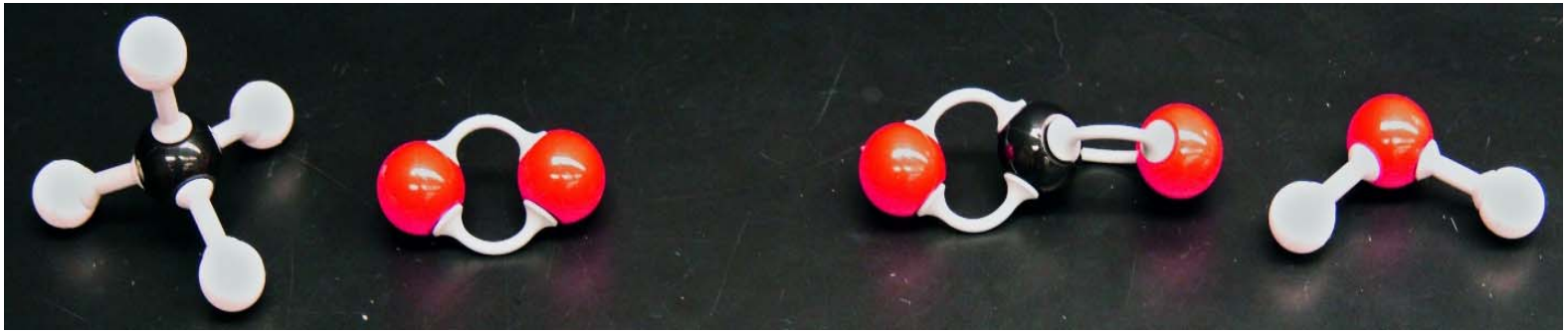






MX_4
tetrahedral
109.5° bond angle
Characteristic of Periodic Table Group IVA
Students must physically form a 3-D structure

Visual Stoichiometry



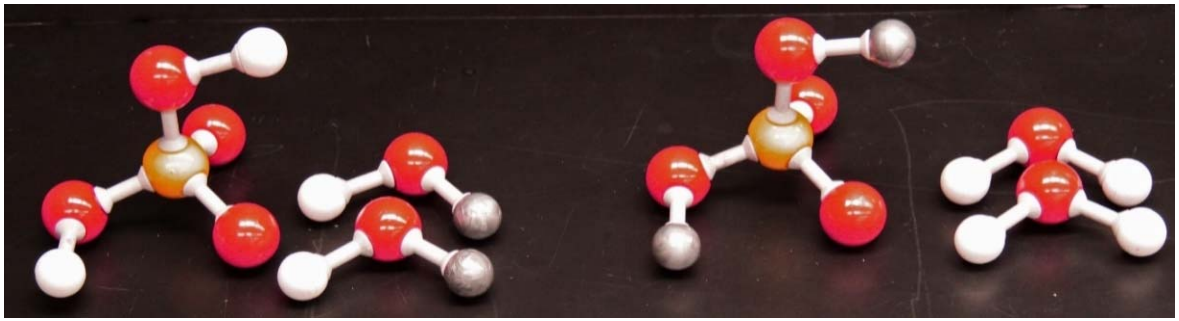
$CH_4 + O_2 \rightarrow CO_2 + H_2O$

(equation not balanced)

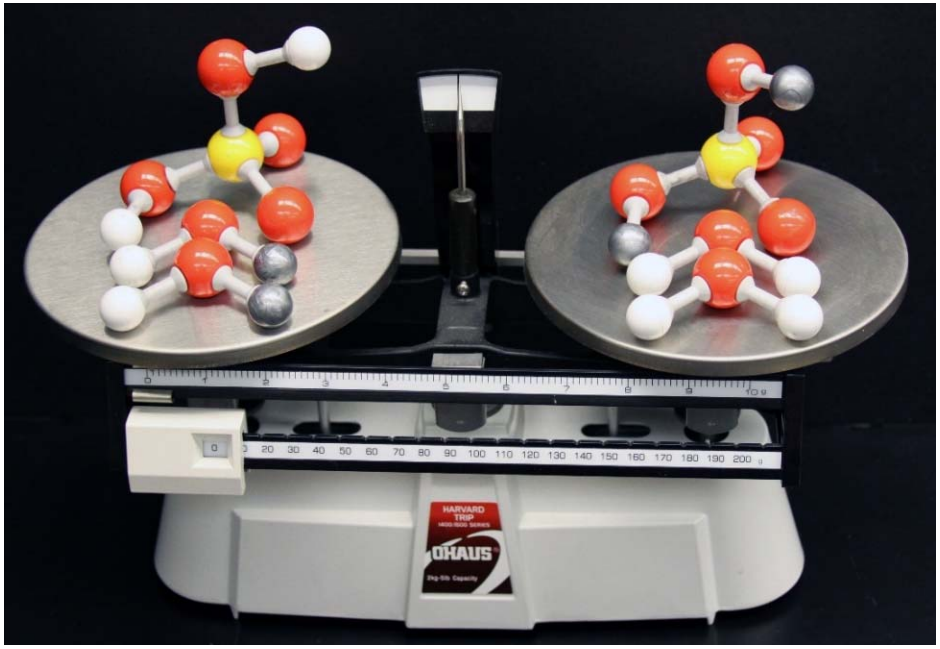
MolyMod Models are injection molded. Same "atoms" and "bonds" have the same mass

Instructions at http://www.chymist.com/Models%20mass%20and%20stoichiometry.pdf

Visual Stoichiometry



$H_2SO_4 + 2\,NaOH \rightarrow Na_2SO_4 + 2\,H_2O$

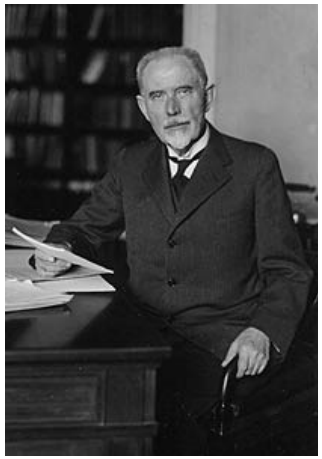


Acids and Bases

- **Svante August Arrhenius (1859 – 1927)**
  - **Acid produces hydrogen ions in water solution.**
- **Johannes Nicolaus Brønsted (*1879-1947) and* Thomas Martin Lowry (1874-1936)**
  - **An acid-base reaction consists of the transfer of a proton (or hydrogen ion) from an acid to a base**

pH

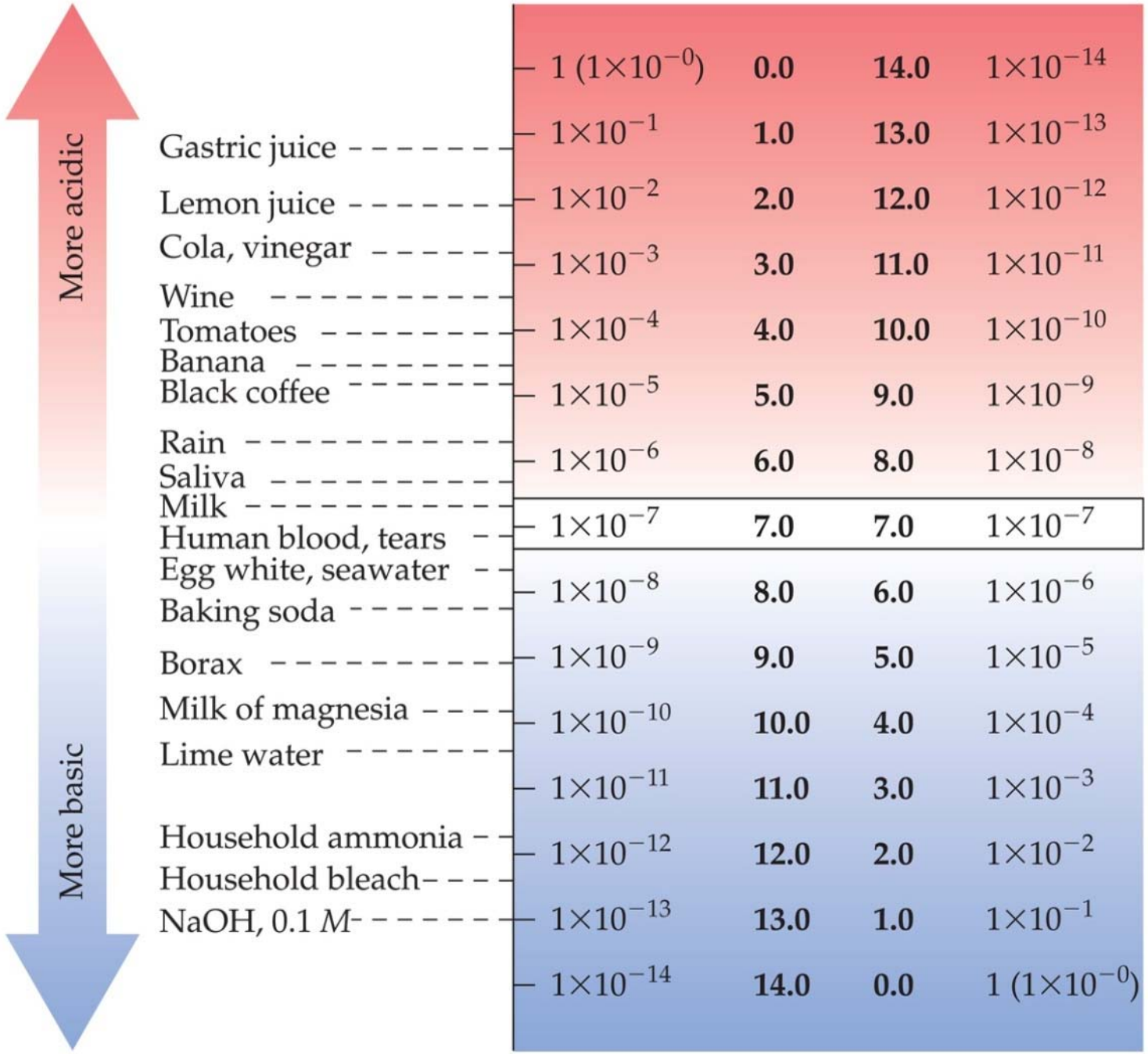
- First introduced by Danish chemist Søren Peder Lauritz Sørensen (1868-1939), the head of the Carlsberg Laboratory's Chemical Department, in 1909
- pH means 'the power of hydrogen'.
- Each value of pH means the H^+ concentration changes by a factor of 10
- As the H^+ concentration decreases, the OH^-



pH 1 strong acid | weak acid | pH 7 neutral | weak base | pH 14 strong base

he pH scale according to the late Dr. Hubert Alyea, Princeton University

pH values for some common substances



$[H^+]$ (*M*)	pH	pOH	$[OH^-]$ (*M*)
1 (1×10^{-0})	**0.0**	**14.0**	1×10^{-14}
1×10^{-1}	**1.0**	**13.0**	1×10^{-13}
1×10^{-2}	**2.0**	**12.0**	1×10^{-12}
1×10^{-3}	**3.0**	**11.0**	1×10^{-11}
1×10^{-4}	**4.0**	**10.0**	1×10^{-10}
1×10^{-5}	**5.0**	**9.0**	1×10^{-9}
1×10^{-6}	**6.0**	**8.0**	1×10^{-8}
1×10^{-7}	**7.0**	**7.0**	1×10^{-7}
1×10^{-8}	**8.0**	**6.0**	1×10^{-6}
1×10^{-9}	**9.0**	**5.0**	1×10^{-5}
1×10^{-10}	**10.0**	**4.0**	1×10^{-4}
1×10^{-11}	**11.0**	**3.0**	1×10^{-3}
1×10^{-12}	**12.0**	**2.0**	1×10^{-2}
1×10^{-13}	**13.0**	**1.0**	1×10^{-1}
1×10^{-14}	**14.0**	**0.0**	1 (1×10^{-0})

Acids, Bases, and pH

- **Acids, bases, and pH using red cabbage paper**
  - **Buffers for reference**
  - **Solutions of household products**

Instructions at
http://www.chymist.com/Visualizing%20pH.pdf

- **Illustrate indicator colors using serial dilutions to observe color changes**

Discuss pH's of various household materials

Phenolphthalein

Acid **Base**

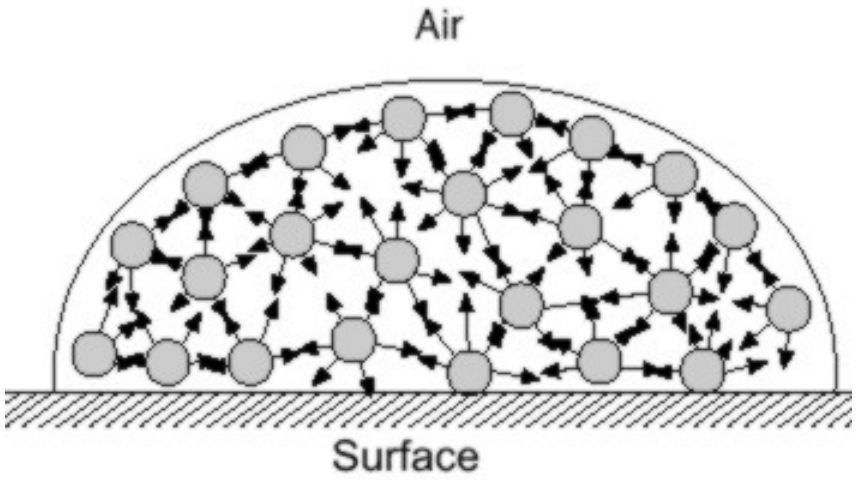
?

You can turn phenolphthalein red with acid

Directions at http://www.chymist.com/phenolphthalein%20red.pdf

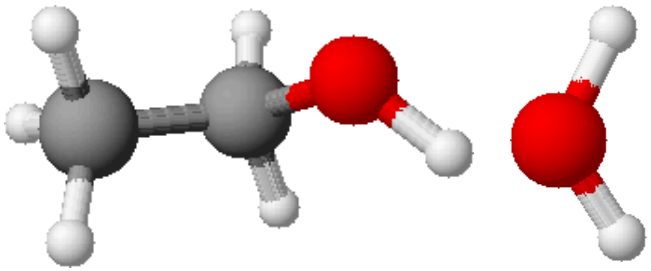
Intermolecular forces
Drops of water on a coin

How many drops of water can you put on a coin? Why?

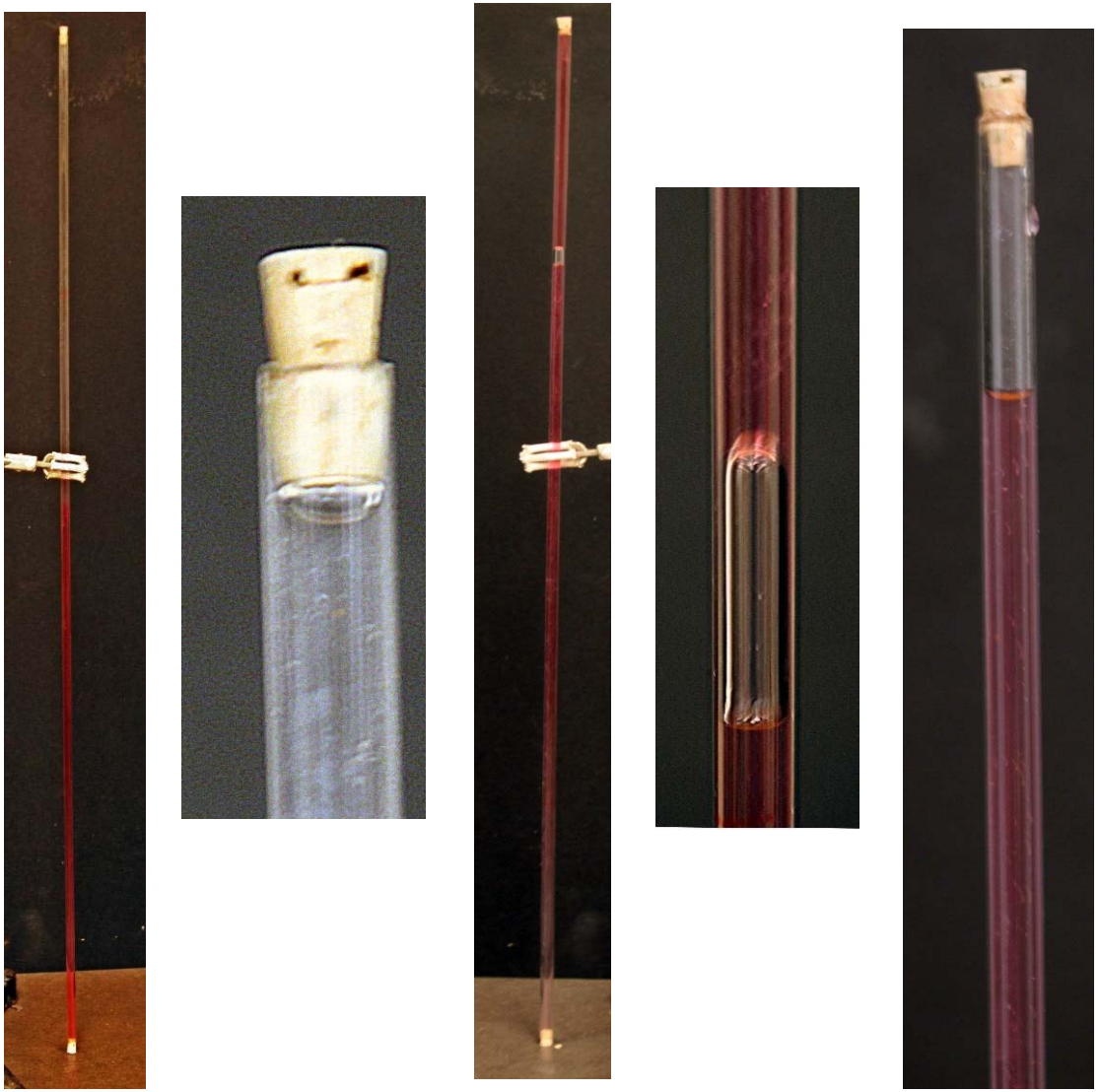


Repeat: Add a drop of dishwashing detergent to the water.
Use ethanol in place of water.

Intermolecular forces: Decrease in Volume



ethanol and water

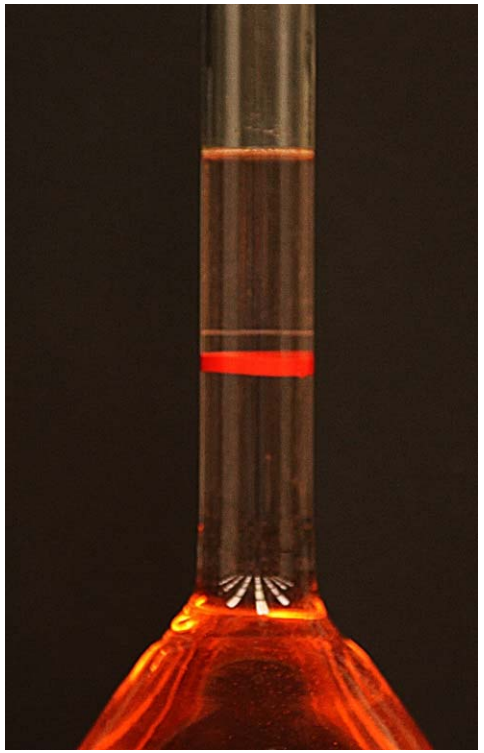


Instructions at
http://www.chymist.com/Decrease%20in%20volume.pdf


JAMESON
SELECT RESERVE
BLACK BARREL
1780
JAMESON
SELECT RESERVE
BLACK BARREL

Hydrogen Bonding
Increase in Volume

$$HCl + NaOH \rightarrow NaCl + H_2O$$

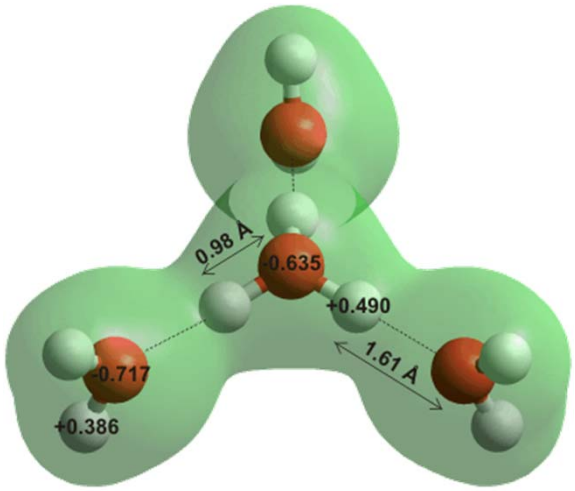


The volume increase is 18.5 mL/mol

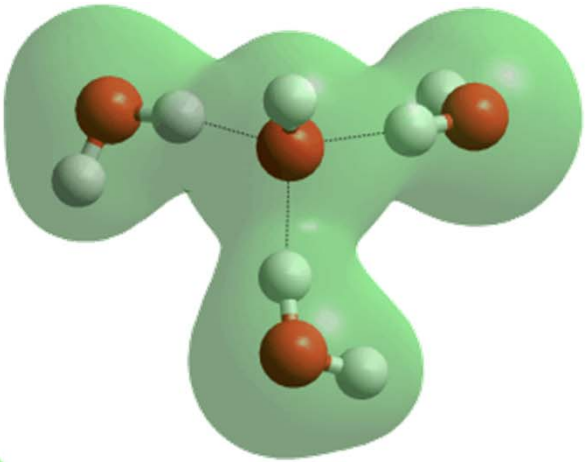
Reference: Sam Katz, and Jane E. Miller**,** *J. Phys. Chem.*, **1971**, *75* (8), pp 1120–1125

Instructions at http://www.chymist.com/Increase%20in%20Volume%202014.pdf

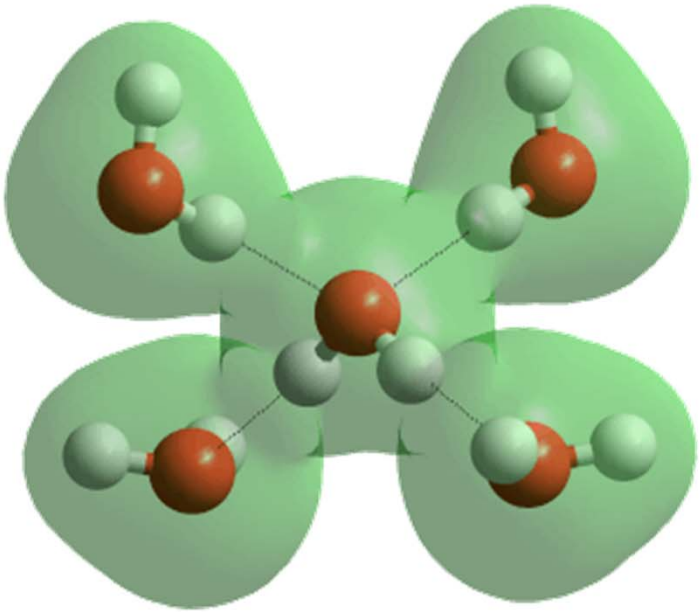
Hydrogen Bonding
Increase in Volume



Hydrated H_3O^+
O-O distance 2.59 Å



Hydrated OH^-
O-O distance 2.50 Å



H_2O
O-O distance 2.82 Å

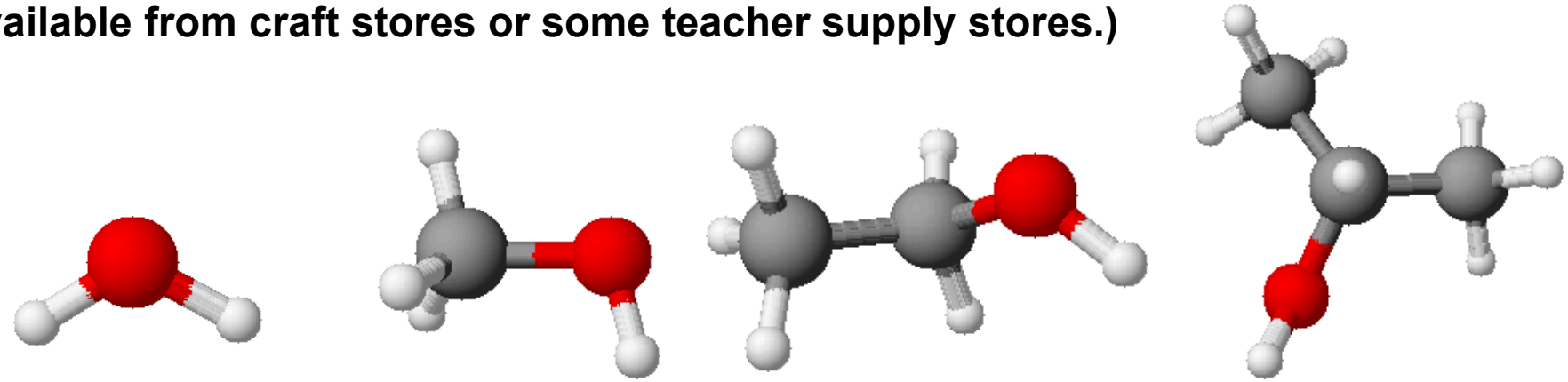
Source: Martin Chaplin, http://www1.lsbu.ac.uk/water/index.html

Intermolecular Forces:
Which Will Evaporate First?

What factors affect evaporation?

Spread these compounds on black slate chalkboards

(Available from craft stores or some teacher supply stores.)



water methanol ethanol 2-propanol

Effect of molecular weight:

$H_2O = 18$ $CH_3OH = 32$ $C_2H_5OH = 46$ $C_3H_8OH = 60$

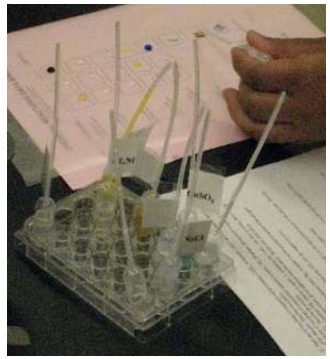
Effect of polarity

Instructions at http://www.chymist.com/evaporate.pdf

Active Assessment

Use microscale experiments as test questions

CHEMICAL REACTION QUESTIONS



The student must physically perform a small-scale reaction. Thus, the old "complete and balance the following reactions" type of questions now have a physical significance.

The materials for the reactions sets are placed in small boxes, plastic drinking cups or beakers, and labeled with an identification number.

More than one set may be needed depending on the size of the class.

Materials can be labeled using names OR formulas of the elements or compounds, but not both.

(Note that both the symbols and the names of the reacting substances are asked for in the problem.)

CHEMICAL REACTIONS

(36 points total - 12 points each)

Directions: Select 3 chemical reactions from the front desk (Please take them one at a time).

Run each reaction on a piece of wax paper using one or two drops of the liquid chemical solutions (or one or two drops of liquid and a piece of solid). Complete the information below for each reaction.

Please return the reaction materials to the front desk. Discard the waste materials by crumpling up the wax paper with the drops of chemical inside and place it in the trash.

Reaction Set No.: _____

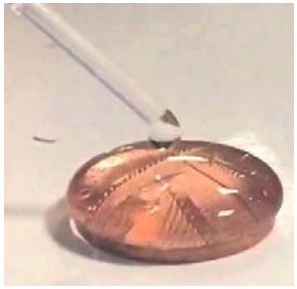
a) Symbols of reacting substances:

b) Names of reacting substances:

c) Evidence of a chemical reaction:

d) Write a balanced chemical equation for the reaction that occurred.

These questions, letters a) through e), involve doing or observing an experiment. The materials are available on the front desk. Select an experiment, take it to your desk and answer the question. You may answer up to two experiment questions. (10 points each)



a) You are given three pennies, pipettes, and three liquids/solutions: water, water-detergent, ethyl alcohol. How many drops of each liquid can you put on a penny? Explain the differences.

b) You are given a cotton ball that is wet with some ethyl rubbing alcohol. Touch the cotton ball to the back of your hand. What sensation do you feel? Explain.

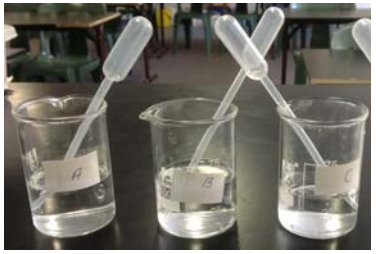
c) On the front desk is a paper cup containing water. It is being heated by a candle. Explain.

d) You are given a washable marker, a stick of porous chalk, and a cup containing a few mL of water. Draw a line on the chalk, about 1 cm from one end, using the marker. Stand the chalk up in the cup and observe the changes that are taking place (Note: the water is moving through the chalk by a process known as capillary action.):

i) What changes are occurring?

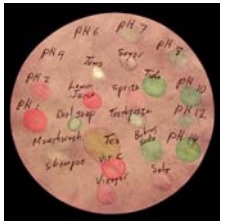
ii) Explain your observations using the principles of solutions and intermolecular forces.

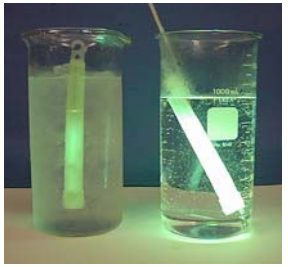
e) The bottles labeled 1, 2 and 3 contain distilled water, a solution of acetic acid, and a solution of sodium chloride. Which is which? Explain how you determined your answer. (Available materials are Na_2CO_3, $AgNO_3$ solution, an indicator, and any other materials as the instructors determine.)



Other experiment problems

- An acid-base indicator problem.
- pH of household products problem.
- A zip-lock bag problem.
- Kinetics problems.





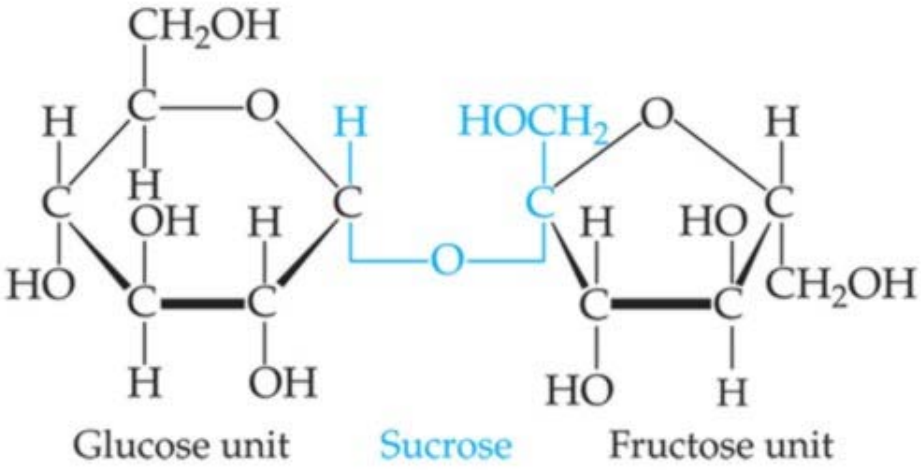
Some things to note

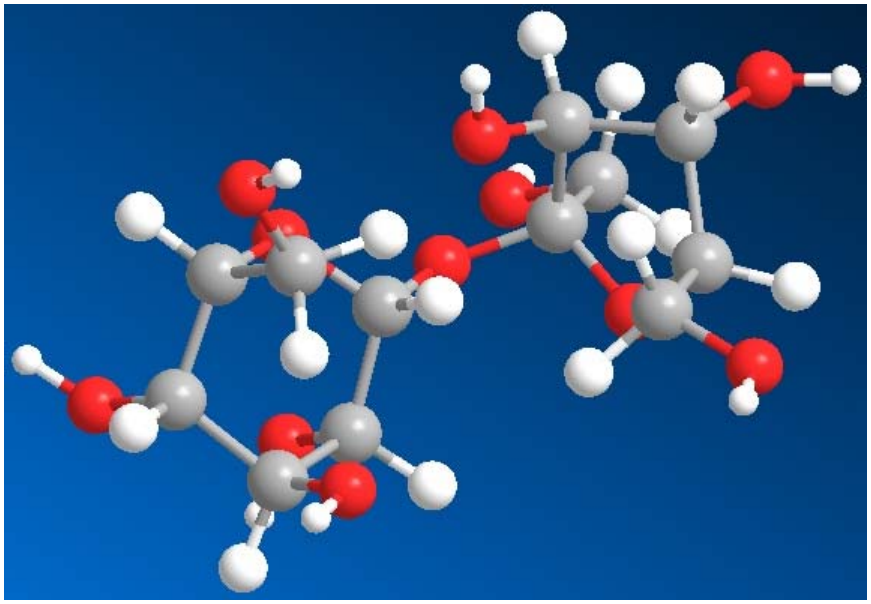
- **Works best with small classes – about 40 students or less.**
- **Students should have had previous experience with hands-on activities in the classroom.**
- **A negative result:**

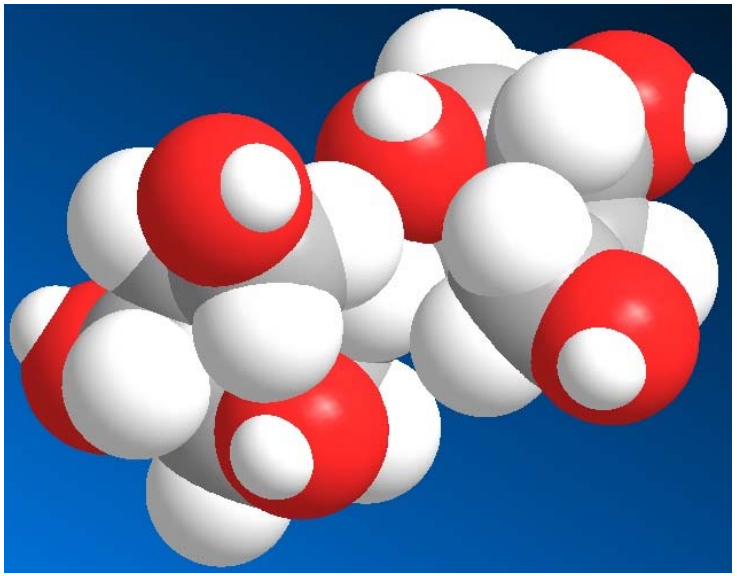
  Some students start to cut short quizzes about half-way through the semester.

Solutions:

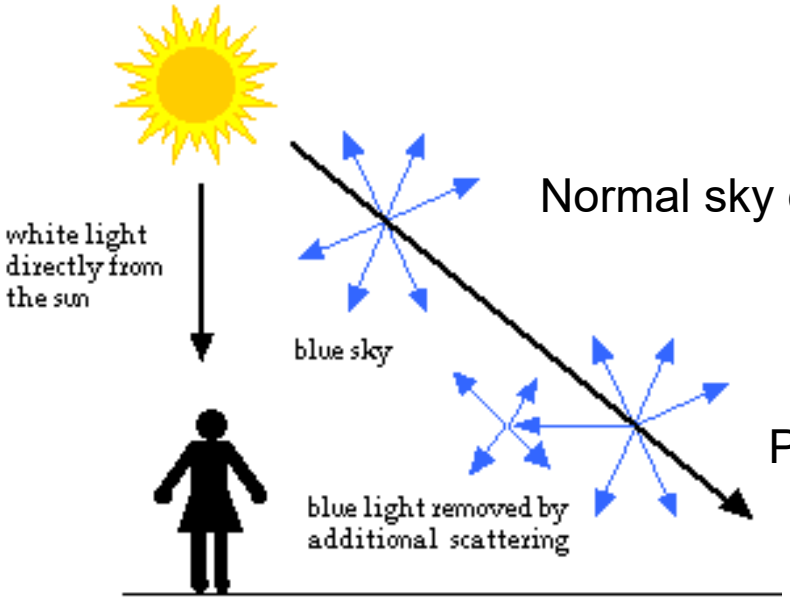
Why does a substance dissolve?





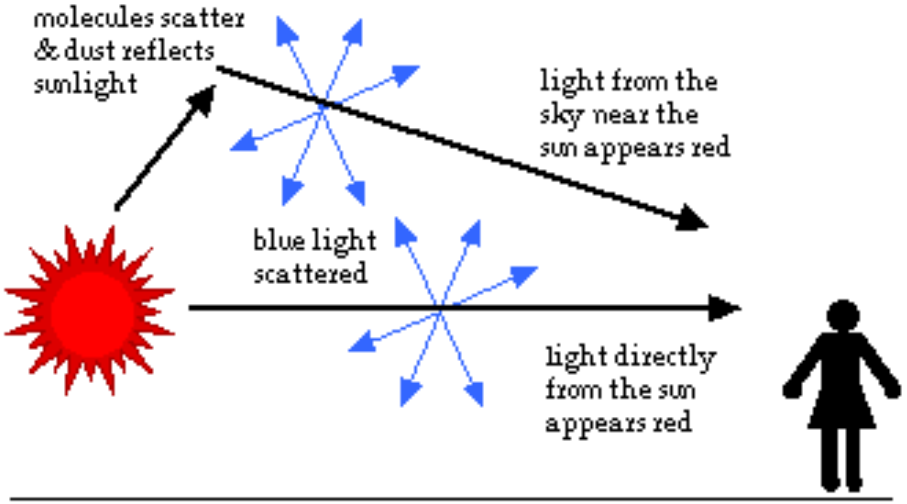


Why is the sky blue?



Normal sky color

Pale blue sky near horizon



Solution of sodium thiosulfate and HCl

Course syllabi and experiments can be found at

http://www.chymist.com

On the left-hand menu, click on
Compleat Chymical Demonstrator
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or
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Chem 121
Chem 125