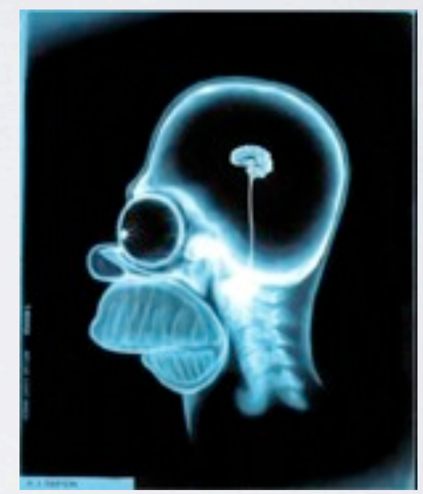
QUANTITATIVE REAL-WORLD INQUIRY TOPICS:

FIREWORKS, PICKLES AND X-RAY GUNS



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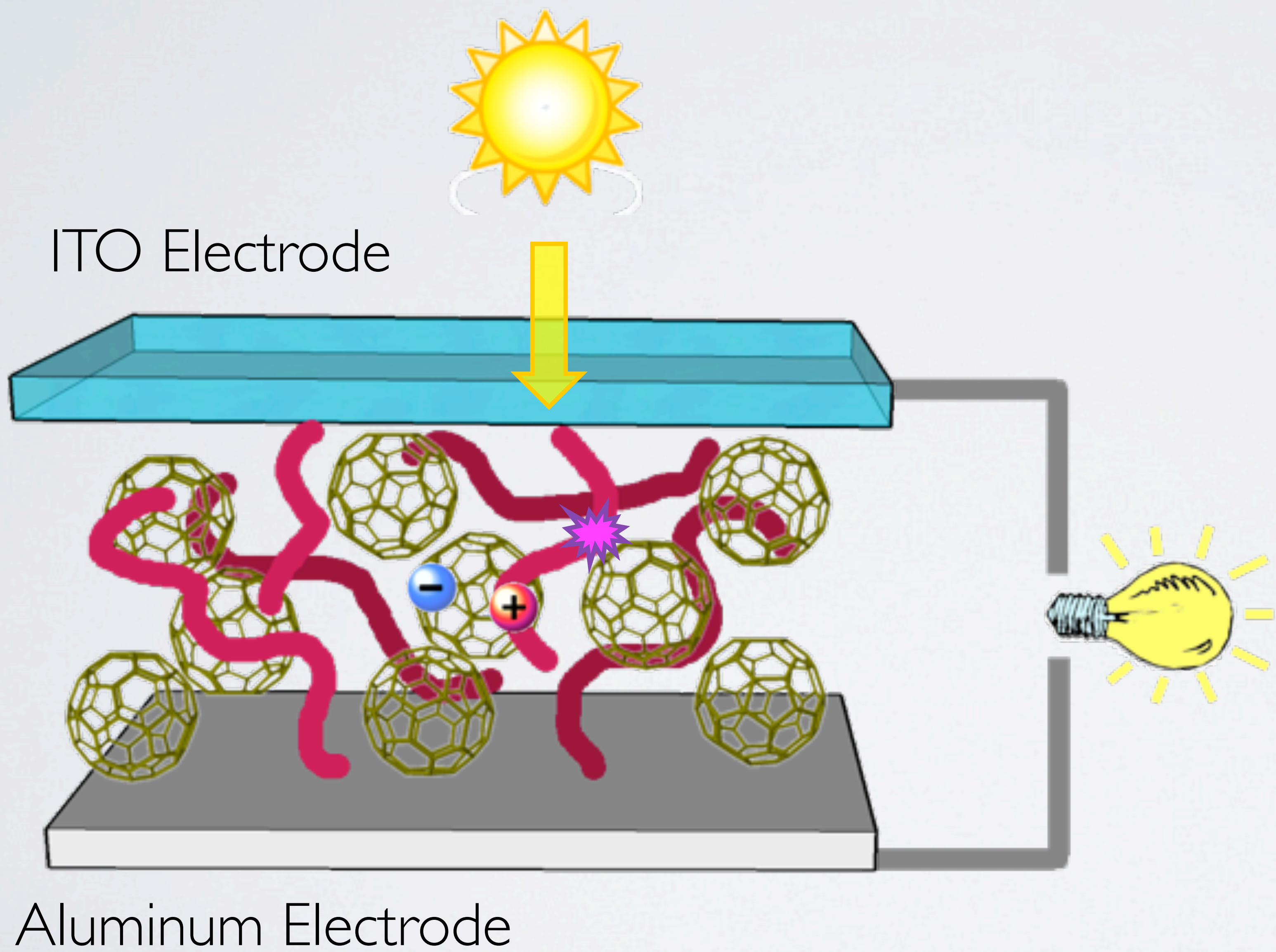
Materials Research Laboratory
Research Experiences for Teachers II

RET 1: THIN FILM FABRICATION AND MORPHOLOGY STUDIES OF BLADE COATED ORGANIC PHOTOVOLTAICS

Plastic Solar Cells

- Studied P3HT:PCBM active layer fabrication parameters, film morphology and crystallinity using AFM
- Dr. Alan Heeger won Nobel Prize in 2000 for his work in conductive polymers

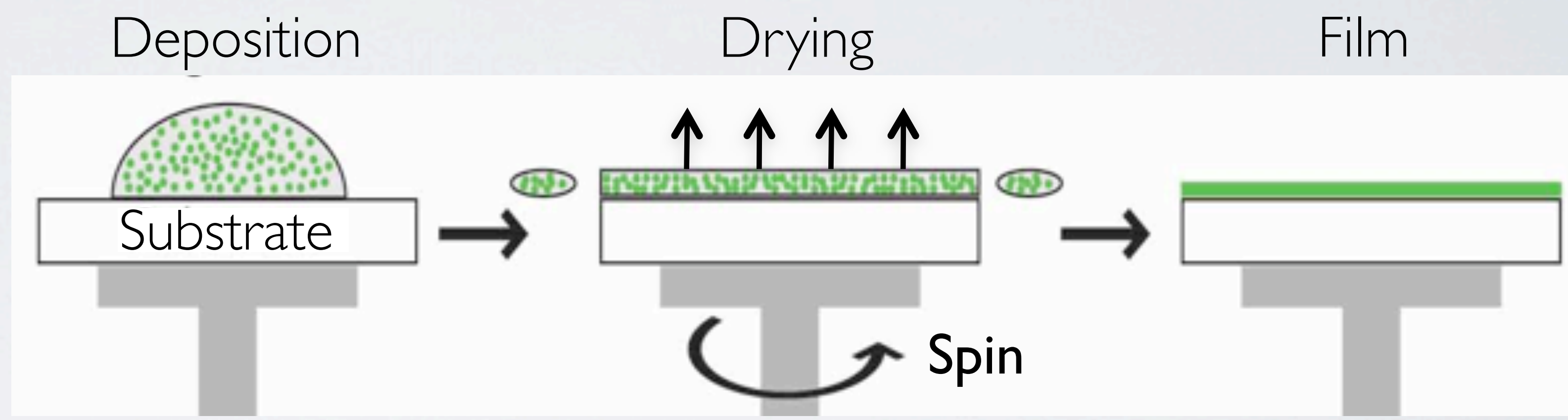
RET 1: THIN FILM FABRICATION AND MORPHOLOGY STUDIES OF BLADE COATED ORGANIC PHOTOVOLTAICS

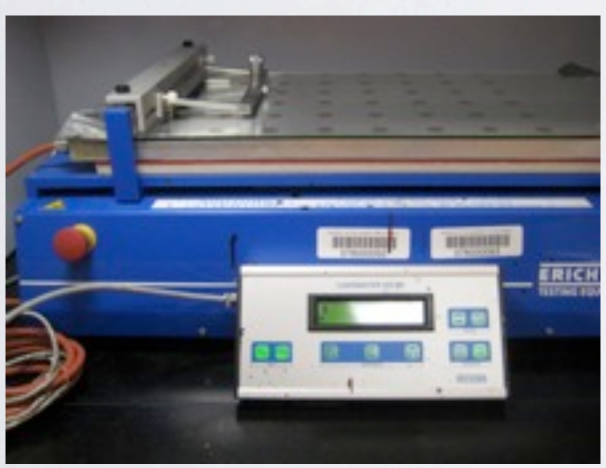


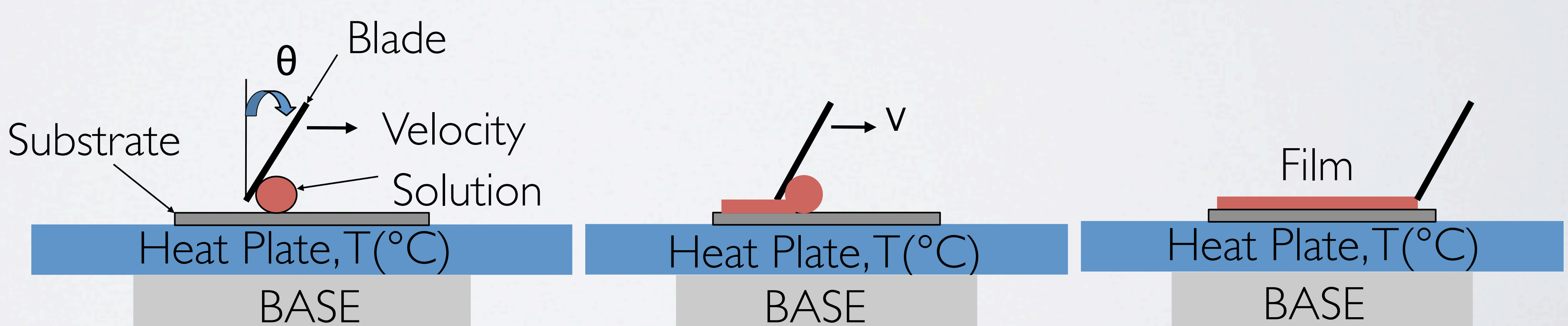
1. Light Absorption
2. Exciton Diffusion
3. Charge Separation
4. Charge Transport
5. Clean Energy

Courtesy of A. Ostrowski and B. Walker

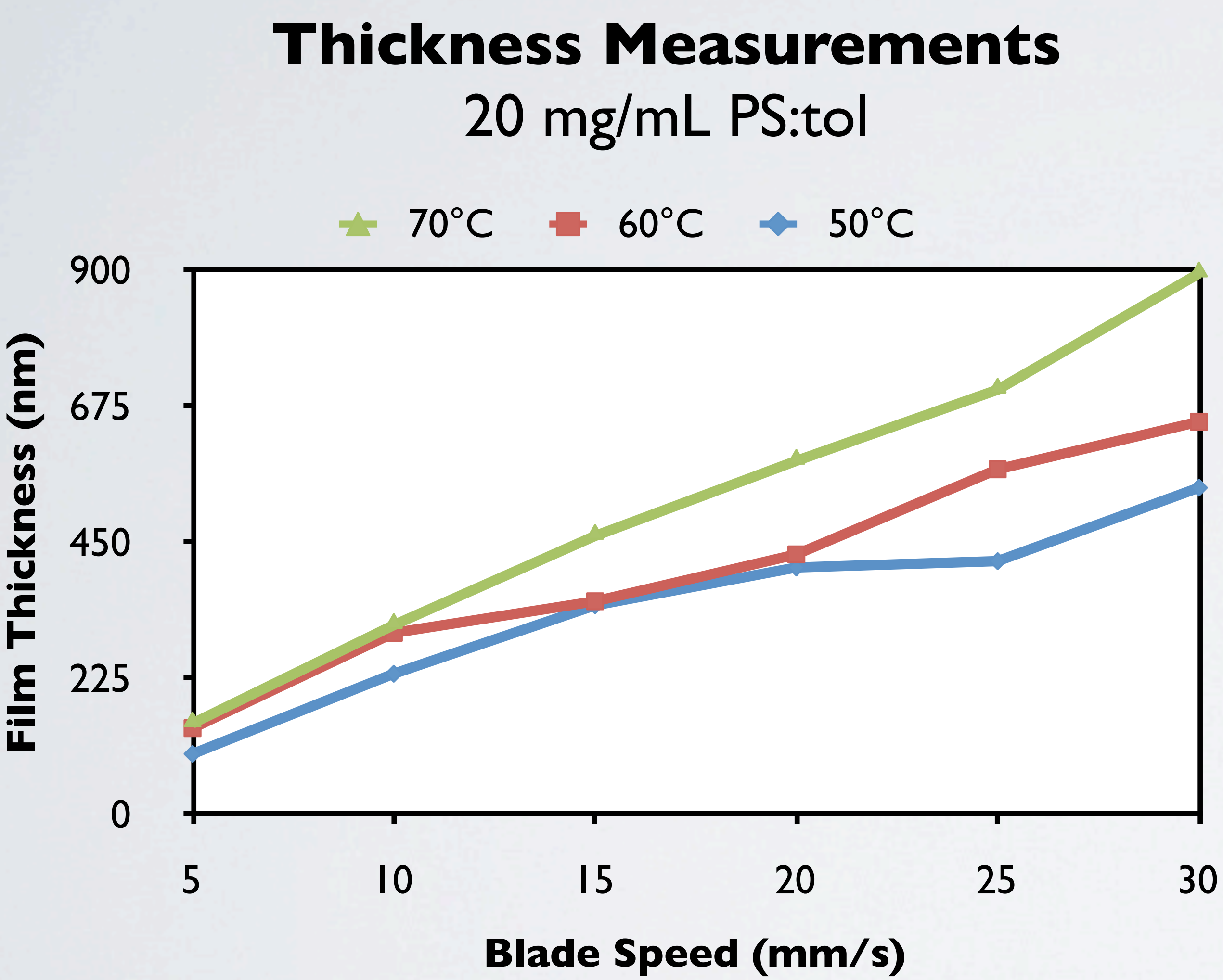
RET 1: THIN FILM FABRICATION AND MORPHOLOGY STUDIES OF BLADE COATED ORGANIC PHOTOVOLTAICS

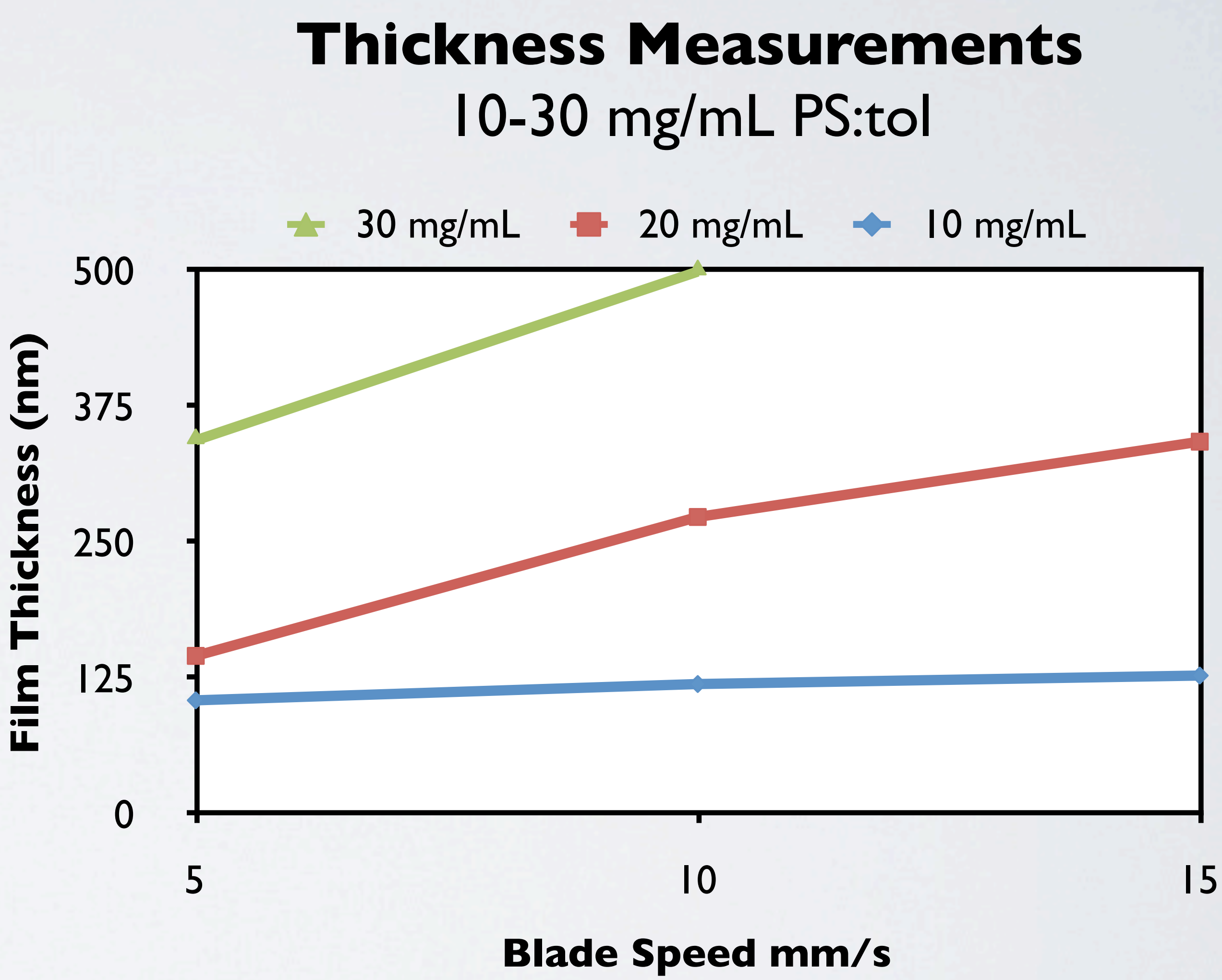






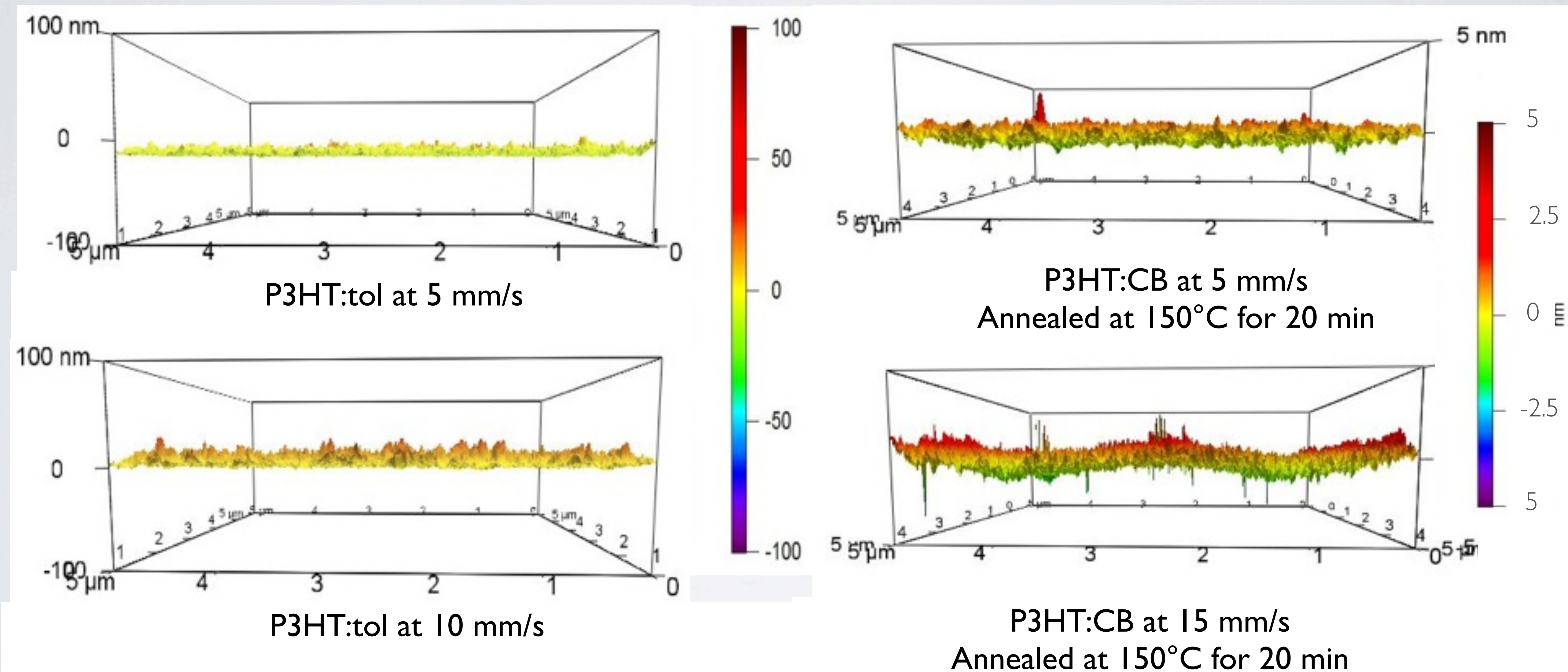
Blade Coating: Thickness is directly proportional to substrate temperature, blade speed and concentration





Film Morphology: Depends on concentration; slower blade speed and annealing decrease roughness

AFM Roughness Measurements



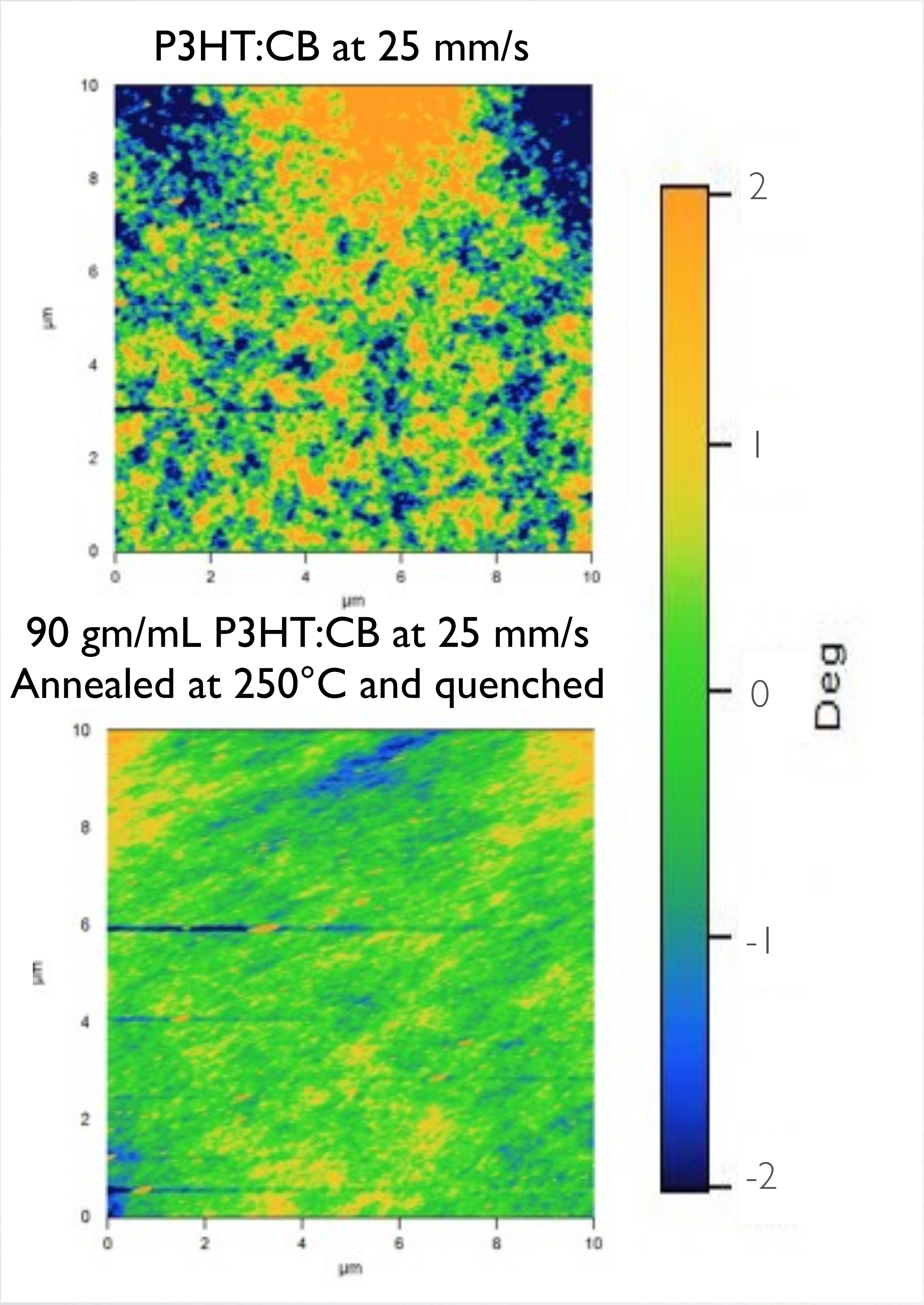
P3HT:tol at 5 mm/s

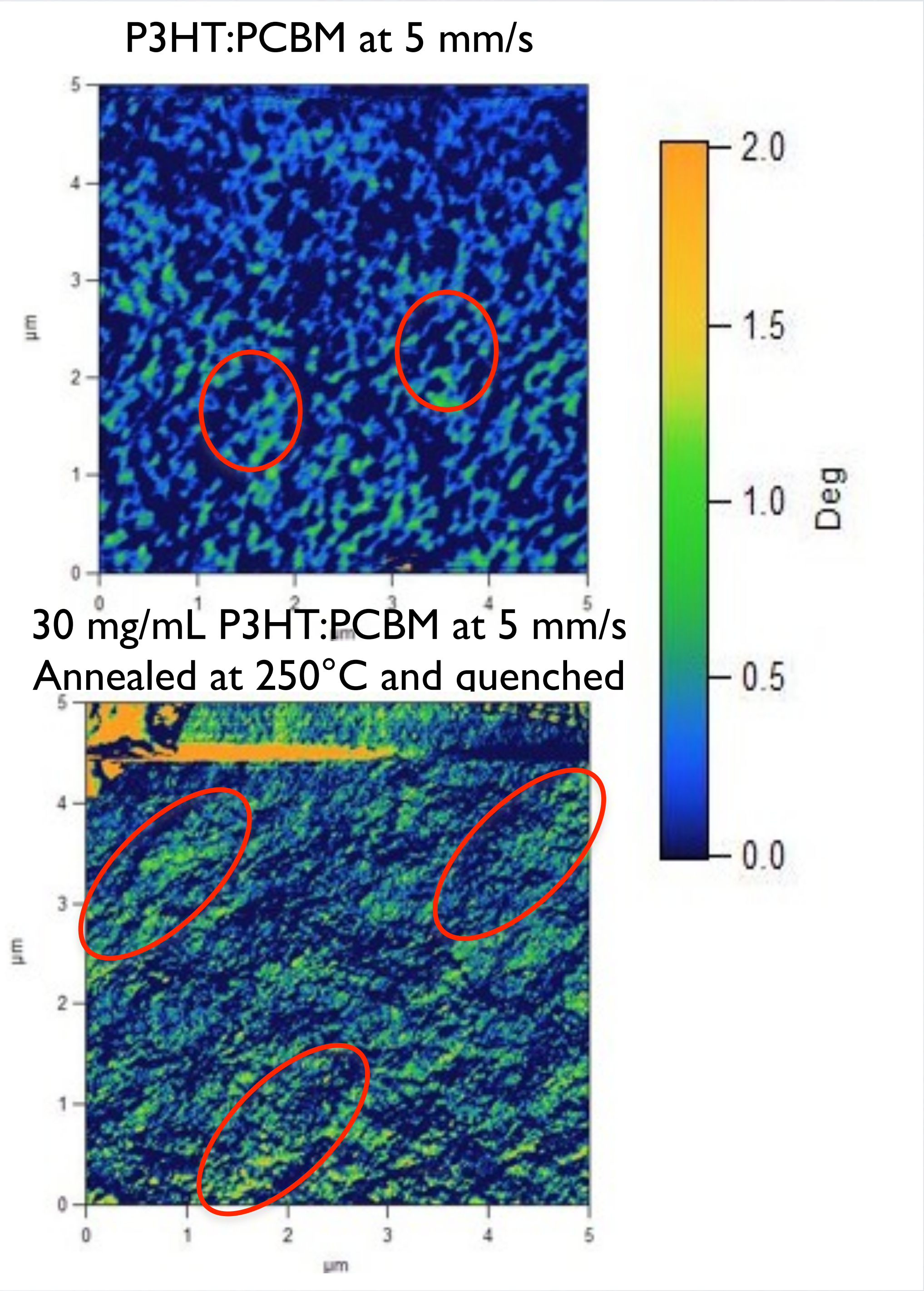
P3HT:CB at 5 mm/s
Annealed at 150°C for 20 min

P3HT:tol at 10 mm/s

P3HT:CB at 15 mm/s
Annealed at 150°C for 20 min

Crystallinity: Blade coating forms clustered P3HT channels, annealing and rapid quenching produces large and more uniform domains





RET I TO RET II

How do OPVs apply to middle school physical science?

Research University

Middle School

RET I TO RET II

Big Ideas	Physical Science Topic	Lab Module
Photon Absorption	Atomic Structure	Flame Test and EM Spectrum
Conductivity	Periodic Table Bonding	Solution Conductivity
Spectroscopy	Solar System Stars & Galaxies	Astronomical Spectroscopy

RET I TO RET II

Atoms, periodic table, bonding, and astronomy topics are very abstract, qualitative and intangible for middle school students

Primary Goal

Adapt qualitative topics into quantitative hands-on activities

Secondary Goals

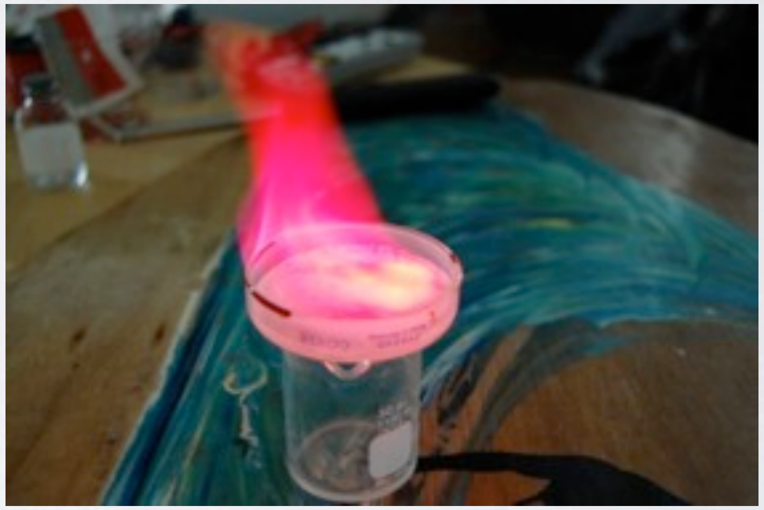
- Accessible to middle school students
- Incorporate formal lab reports requiring reading, writing, math AND science
- Provide real-world examples and applications
- Cover standards and prepare for 8^{th} grade CST
- Begin to incorporate Common Core Standards

LAB 1: FLAME TEST AND ELECTROMAGNETIC SPECTRUM

FLAME TEST AND EM SPECTRUM

1. Part of atomic structure chapter, but includes topics in electromagnetic spectrum and conservation of energy
2. Conduct flame test of unknown samples

Flame Test Solution #	Color Description	Estimated Wavelength (nm)
1	Pink	λ = 650 nm
4	Green	λ = 530 nm
6	Blue	λ = 480 nm



2. Calculate frequency ($\nu = c/\lambda$) and energy ($E = h\nu$)

c = 3000 nm/s → (Middle School Level)

c = 3×10^8 m/s → (High School Level)

h = 40 kJ s/mol → (Middle School Level)

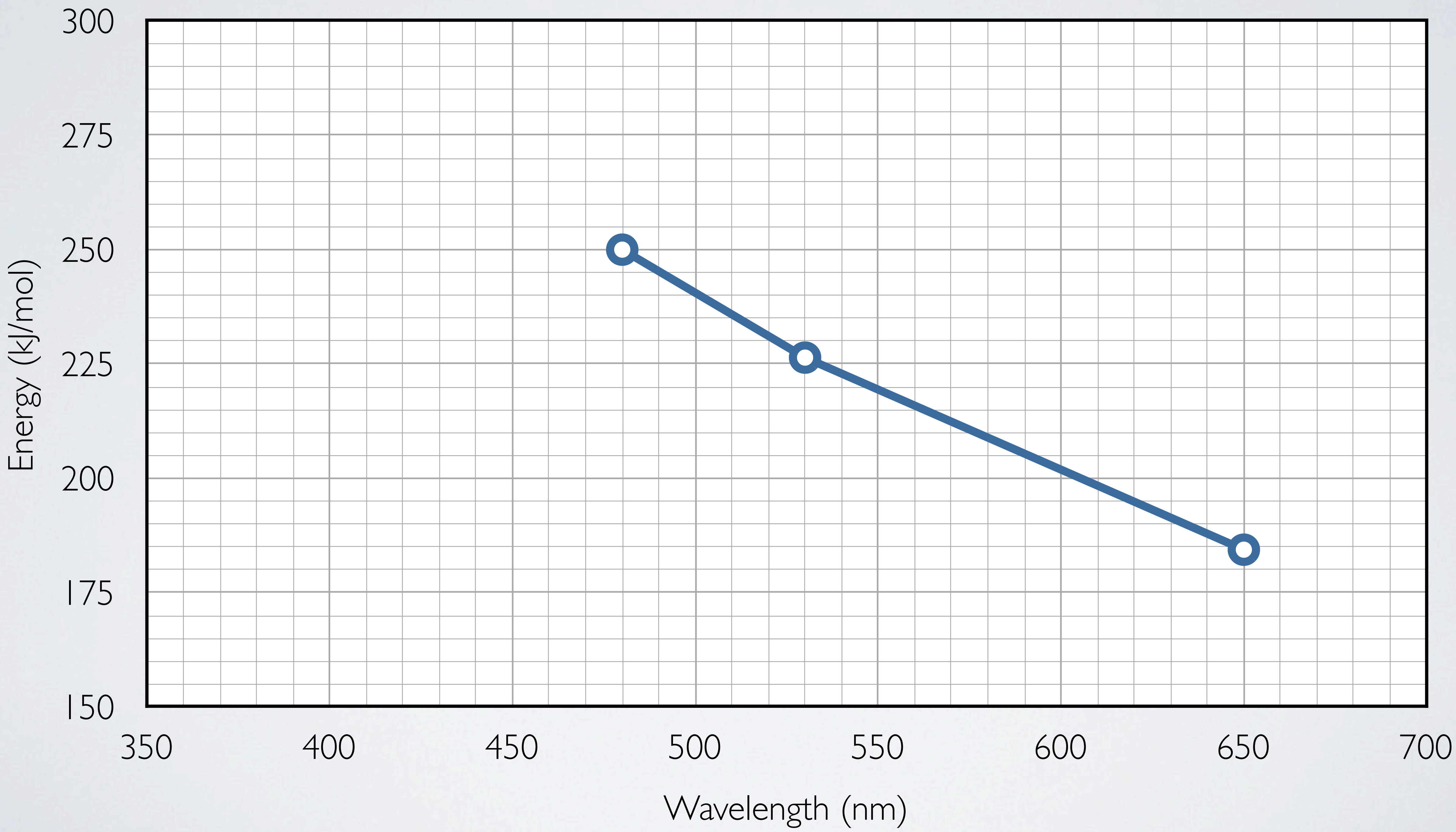
h = 6.626x10-^{34} J s → (High School Level)

Middle School Level	High School Level
Frequency (s^{-1})	**Frequency (s^{-1})**
$\nu = \frac{c}{\lambda} = \frac{3000\ nm/s}{650\ nm}$	$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8\ m/s}{6.5 \times 10^{-7}\ m}$
$\nu = 4.61\ s^{-1}$	$\nu = 4.61 \times 10^{14}\ s^{-1}$
Energy (kJ/mol)	**Energy (J/photon)**
$E = \nu h$	$E = \nu h$
$E = (4.61\ s^{-1})(40\ kJ\ s/mol)$	$E = (4.61 \times 10^{14}\ s^{-1})(6.626 \times 10^{-34}\ J\ s)$
$E = 184.6\ kJ/mol$	$E = 3.058 \times 10^{-19}\ J$

3. Compare calculated values to known values to identify samples

Element	Li	B	Na	K	Cu	Sr
Energy (kJ/mol)	181.2	228.6	203.4	279.1	252.6	190.5
Energy (J/photon)	3.012×10^{-19}	3.155×10^{-19}	3.369×10^{-19}	3.786×10^{-19}	4.185×10^{-19}	4.623×10^{-19}

4. Plot data and identify relationships between wavelength and energy



5. Apply new understanding to examine fireworks and FLAMING PICKLE experiment

FIREWORKS!

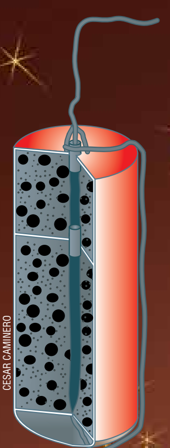
By Kathy De Antonis

Fireworks are one of the most spectacular outdoor shows. They produce amazing bursts of colors that take a variety of shapes. But how do they work? How do they burn into so many colors and patterns? And why, if not handled properly, can they cause serious injuries or even death?

What's inside a firework?

The source of most fireworks is a small tube called an aerial shell that contains explosive chemicals. All the lights, colors, and sounds of a firework come from these chemicals.

An aerial shell is made of gunpowder, which is a well-known explosive, and small globs of explosive materials called stars (Fig. 1) The stars give fireworks their color when they explode. When we watch fireworks, we actually see the explosion of the stars. They are formed into spheres, cubes, or cylinders that are usually 3–4 centimeters (1–1½ inch) in diameter.



CESAR CAMINERO

Figure 1. Structure of an aerial shell. The black balls are the stars, and the gray area is gunpowder. The stars and the powder are surrounding a bursting charge, which also contains black powder.

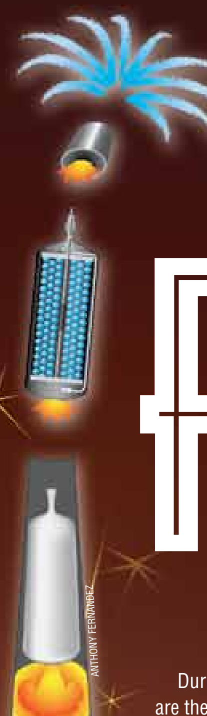
Each star contains four chemical ingredients: an oxidizing agent, a fuel, a metal-containing colorant, and a binder. In the presence of a flame or a spark, the oxidizing agent and the fuel are involved in chemical reactions that create intense heat and gas. The metal-containing colorant produces the color, and the binder holds together the oxidizing agent, fuel, and colorants.

At the center of the shell is a bursting charge with a fuse on top. Igniting the fuse with a flame or a spark triggers the explosion of the bursting charge and of the entire aerial shell.

How fireworks explode

The explosion of a firework happens in two steps: The aerial shell is shot into the air, and then it explodes in the air, many feet above the ground.

To propel the aerial shell into the air, the shell is placed inside a tube, called a mortar, which is often partially buried in sand or dirt. A lifting charge of gunpowder is present below the shell with a fuse attached to it. When this fuse, called a fast-acting fuse, is ignited with a flame or a spark, the gunpowder explodes, creating lots of heat and gas that cause a buildup of pressure beneath the shell. Then, when the pressure is great enough, the shell shoots up into the sky.



ANTHONY FERNANDEZ

After a few seconds, when the aerial shell is high above the ground, another fuse inside the aerial shell, called a time-delay fuse, ignites, causing the bursting charge to explode. This, in turn, ignites the black powder and the stars which rapidly produce lots of gas and heat, causing the shell to burst open, propelling the stars in every direction.

During the explosion, not only are the gases produced quickly, but they are also hot, and they expand rapidly, according to Charles' Law, which states that as the temperature of enclosed gas increases, the volume increases, if the pressure is constant (Fig. 1). The loud boom that accompanies fireworks is actually a sonic boom produced by the expansion of the gases at a rate faster than the speed of sound!

If the stars are arranged randomly in the aerial shell, they will spread evenly in the sky after the shell explodes. But if the stars are packed carefully in predetermined patterns, then the firework has a specific shape—such as a willow, a peony, or a spinner—because the stars are sent in specific directions during the explosion.

ISTOCK

The timing of the two fuses is important. The fast-acting fuse ignites first, propelling the shell into the air, and then the time-delay fuse ignites to cause the aerial shell to explode when it is high in the sky. If the timing of the fuses is not just right, the shell can explode too close to the ground, injuring people nearby.

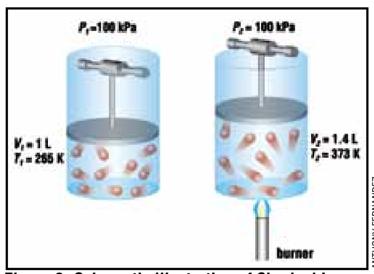
More often, light from fireworks is produced by luminescence. When fireworks explode in the sky, the gunpowder reactions create a lot of heat, causing the metallic substances present in the stars to absorb energy from the heat and emit light. These metallic substances are actually metal salts, which produce luminescent light of different colors when they are dispersed in the air.

carefully and have an adult in charge," says John Conkling, an adjunct professor of chemistry at Washington College, Chestertown, Md., and former executive director of the American Pyrotechnics Association.

Color	Compound
red	strontium salts, lithium salts lithium carbonate, Li_2CO_3 = red strontium carbonate, $SrCO_3$ = bright red
orange	calcium salts calcium chloride, $CaCl_2$
yellow	sodium salts sodium chloride, NaCl
green	barium compounds + chlorine producer barium chloride, $BaCl_2$
blue	copper compounds + chlorine producer copper(I) chloride, CuCl
purple	mixture of strontium (red) and copper (blue) compounds

Table 1. Colorant compounds used in fireworks and the colors they produce.

HTTP://WWW.SCIFUN.ORG/ ; PROF. BASSAM Z. SHAKHASHIRI, UNIVERSITY OF WISCONSIN-MADISON



ANTHONY FERNANDEZ

Figure 2. Schematic illustration of Charles' Law. When the pressure of a volume of gas is constant, an increase in temperature leads to a proportional increase in the volume of the gas. The gas molecules move faster at higher temperatures.

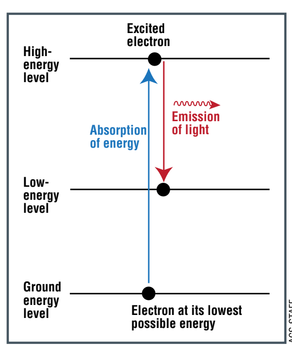
Where do fireworks' colors come from?

What makes fireworks so special is the beautiful colors they produce. These colors are formed in one of two ways: luminescence and incandescence.

Incandescent light is produced when a substance is heated so much that it begins to glow. Heat causes the substance to become hot and glow, initially emitting infrared, then red, orange, yellow, and white light as it becomes increasingly hotter. When the temperature of a firework is controlled, the glow of its metallic substances can be manipulated to be a desired color at the proper time.

This light is produced by electrons inside the metal atoms (Fig. 3). These electrons absorb energy from the heat, which causes them to move from their original ground-energy state to an excited state. Then, nearly immediately, these electrons go to a lower energy state and emit light with a particular energy and characteristic color.

The color of the light emitted by the electrons varies depending on the type of metal or combination of metals. So, the colors are specific to the metals present in the fireworks. The metal-containing colorants for some common fireworks are listed in Table 1.



ACS STAFF

Figure 3. Principle of luminescence. Heating atoms causes electrons to move from their ground-energy level to a higher energy level (blue arrow). When the excited electrons move to a lower energy level (red arrow), they emit light with a specific energy and characteristic color.

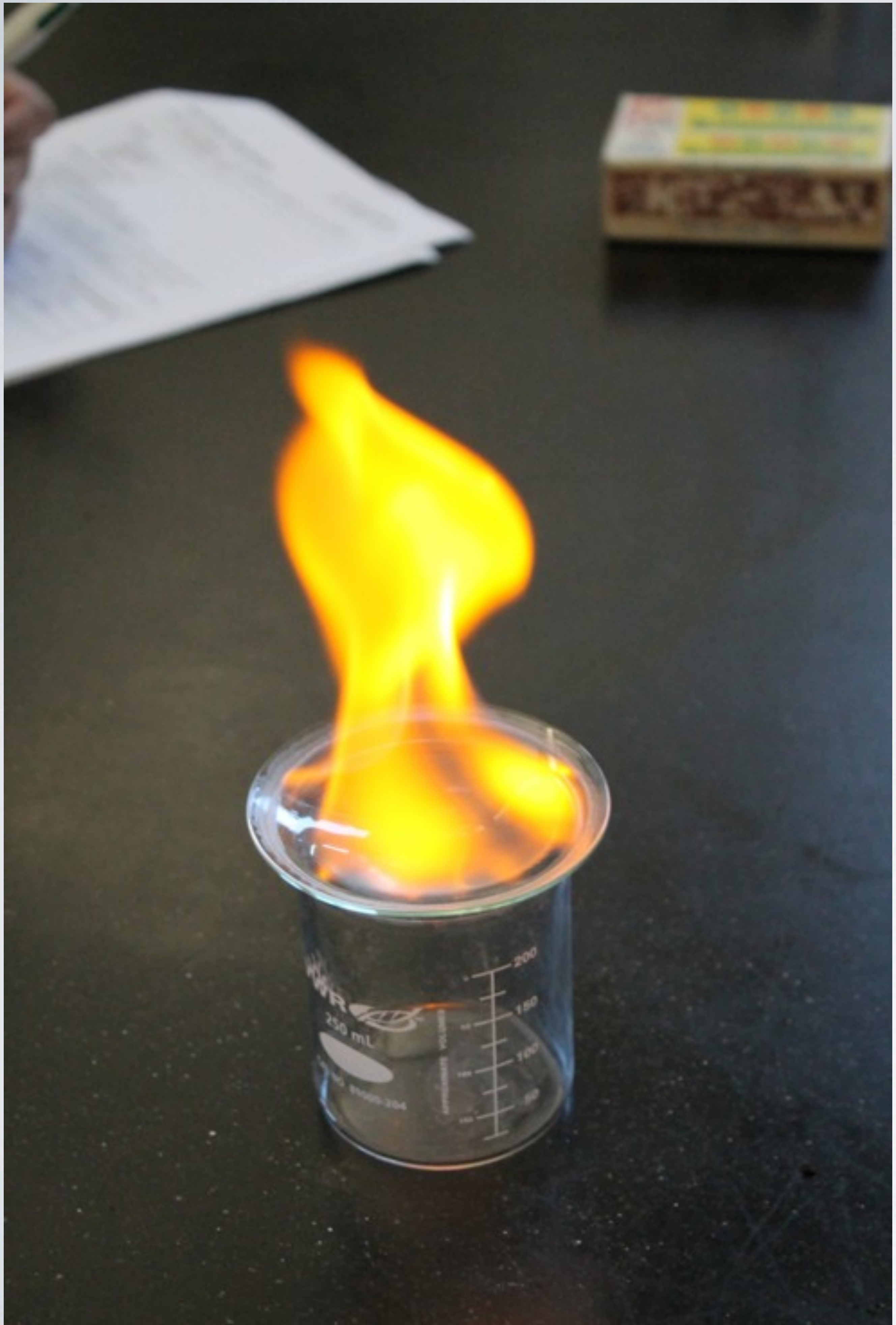
Fireworks' safety

Fireworks are a lot of fun to watch, but they must be handled with great care because they can be dangerous. "When using fireworks, one should follow the label directions very

Knowing the rules and regulations is important, too. According to Conkling, fireworks that are publicly available in stores are legally allowed in 41 of the 50 U.S. states. So, you may not be able to purchase fireworks if your state does not allow it.

Also, regulations require that consumer fireworks should have no more than 50 milligrams (about 1/500th of an ounce) of gunpowder. This may seem like a relatively small amount. But don't be fooled. Even 50 milligrams of gunpowder or less can cause serious injuries. "You would be surprised by how powerful fireworks can be," says Doug Taylor, president of Zambelli Fireworks, one of the largest fireworks companies in the United States.

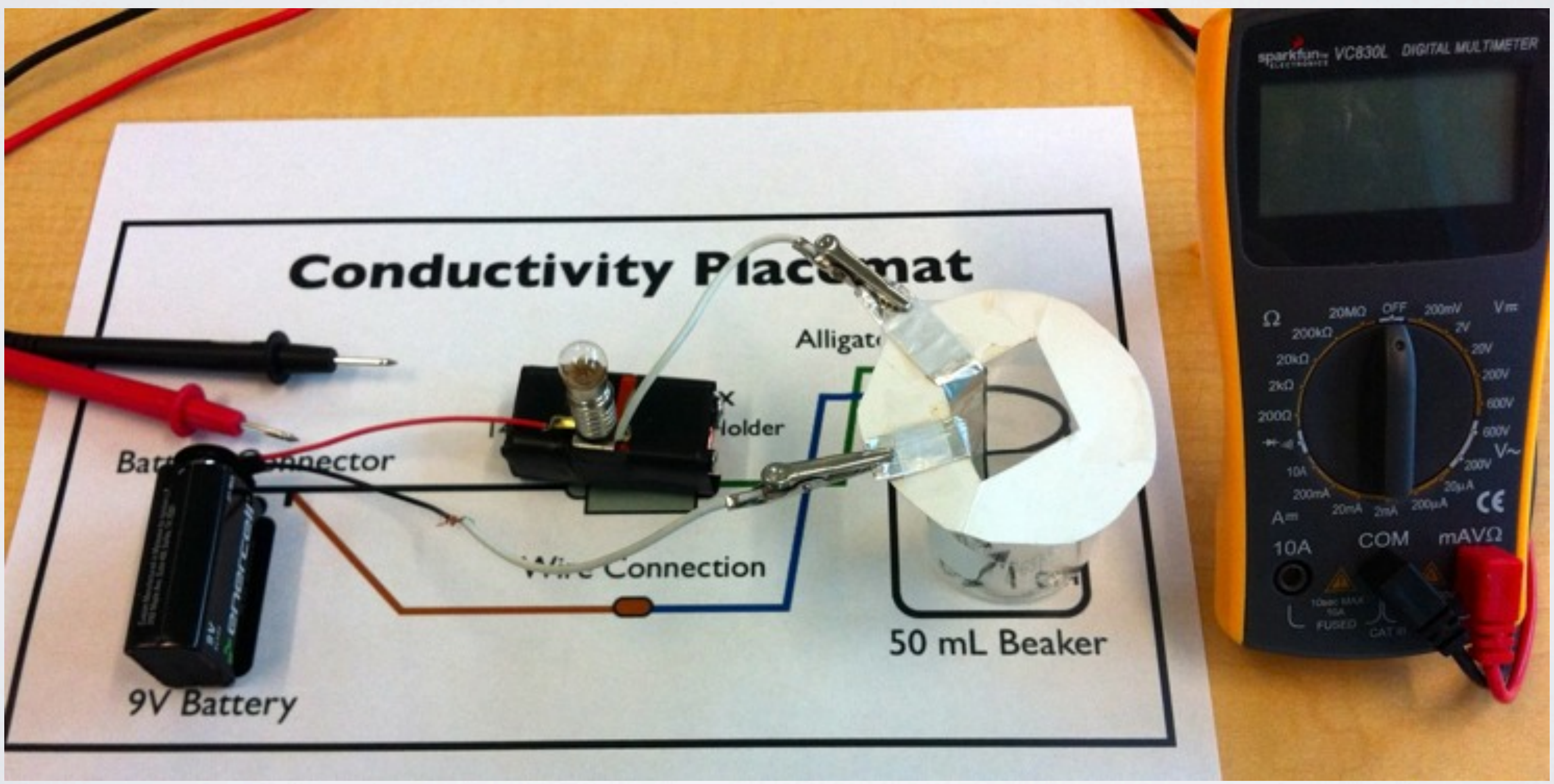
Some fireworks contain more than the limited amount of 50 milligrams. Although they are illegal, such fireworks—which include the "cherry bombs" and "M-80s"—can be found in some stores or on the black market and cause even more damage.


200
150
250 mL

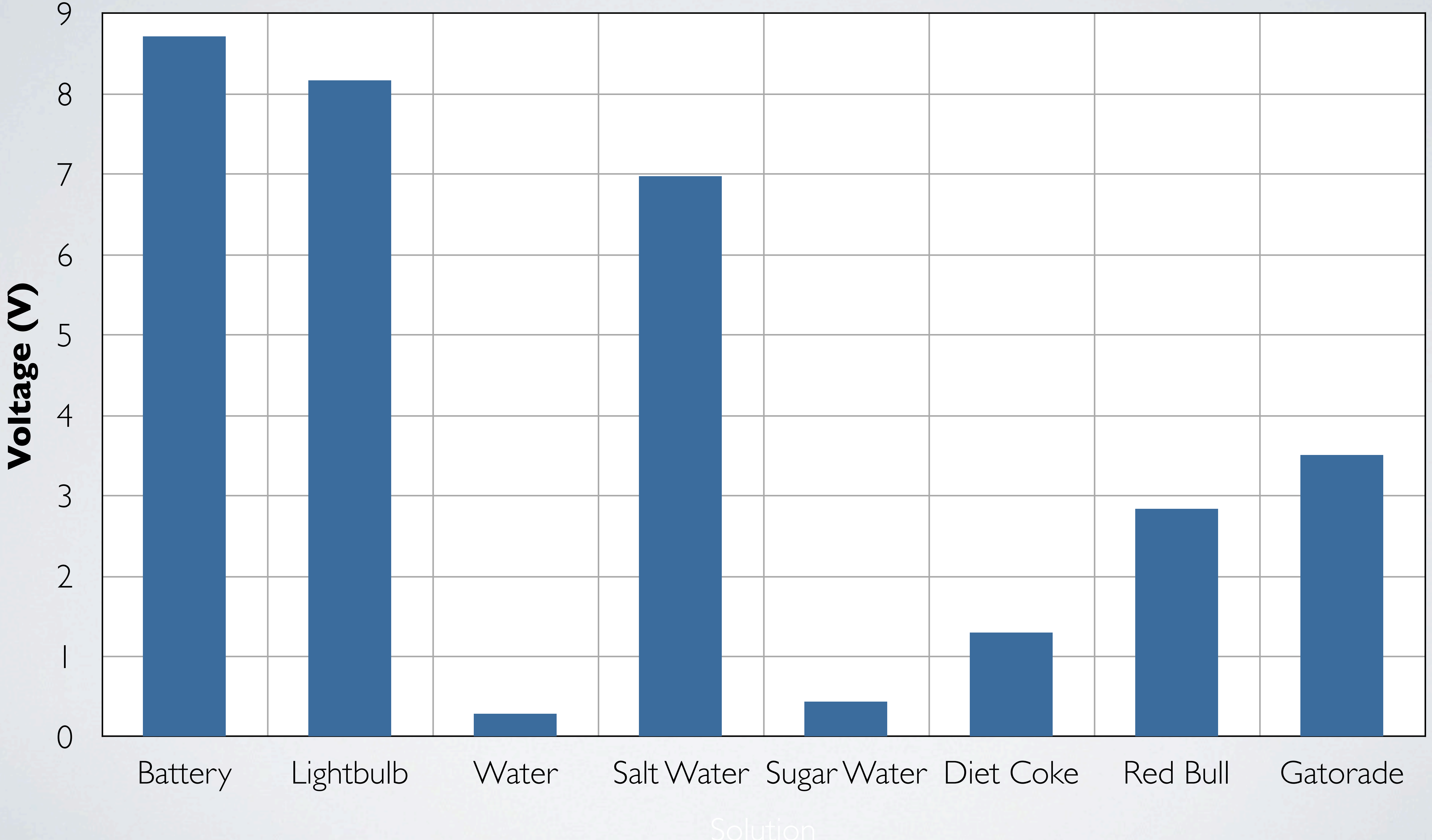
LAB 2: SOLUTION CONDUCTIVITY

SOLUTION CONDUCTIVITY

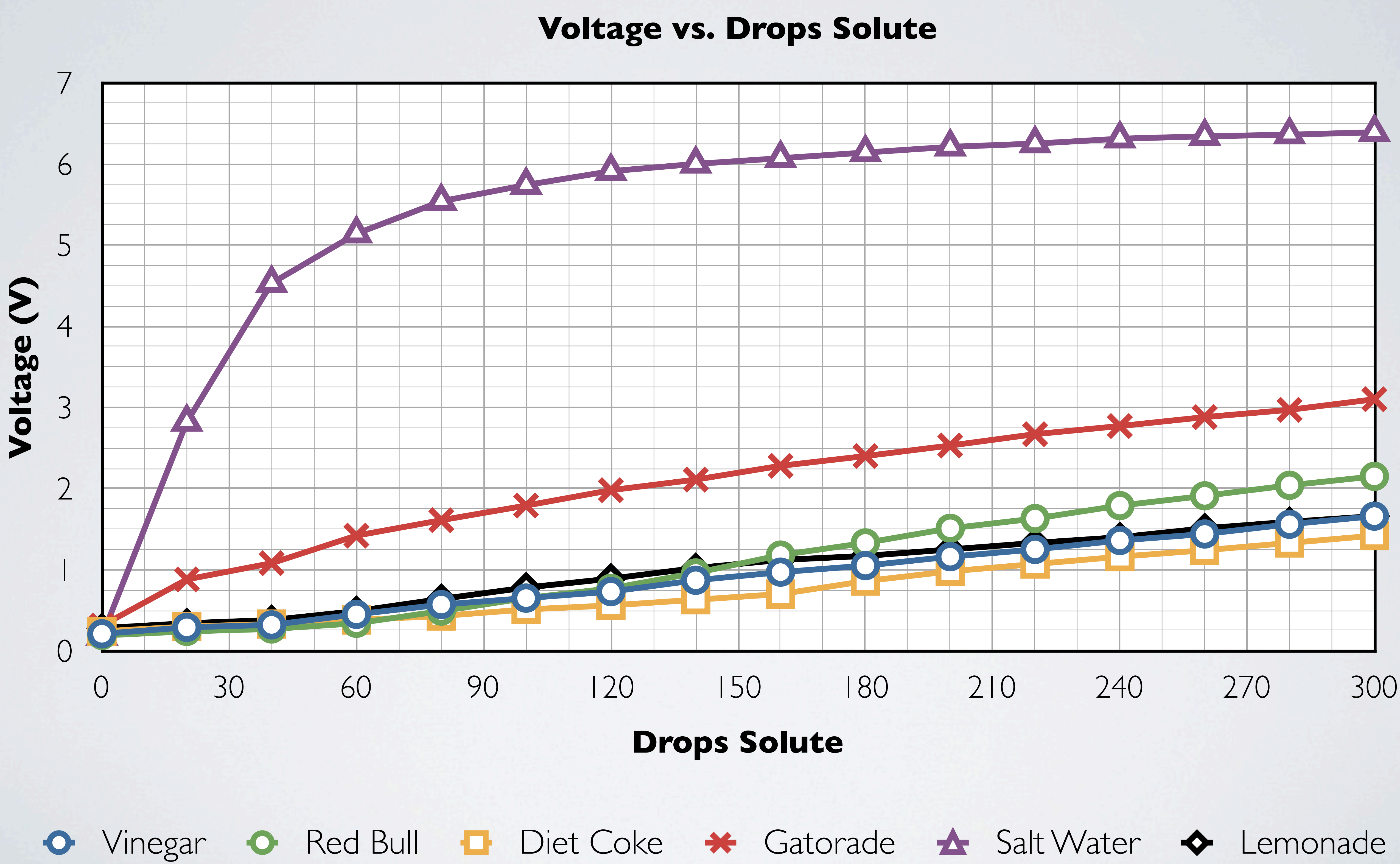
1. Culminating project highlighting topics in properties of elements, bonding, acid base chemistry, and solutions
2. Introduce circuitry and learn how to use multimeters

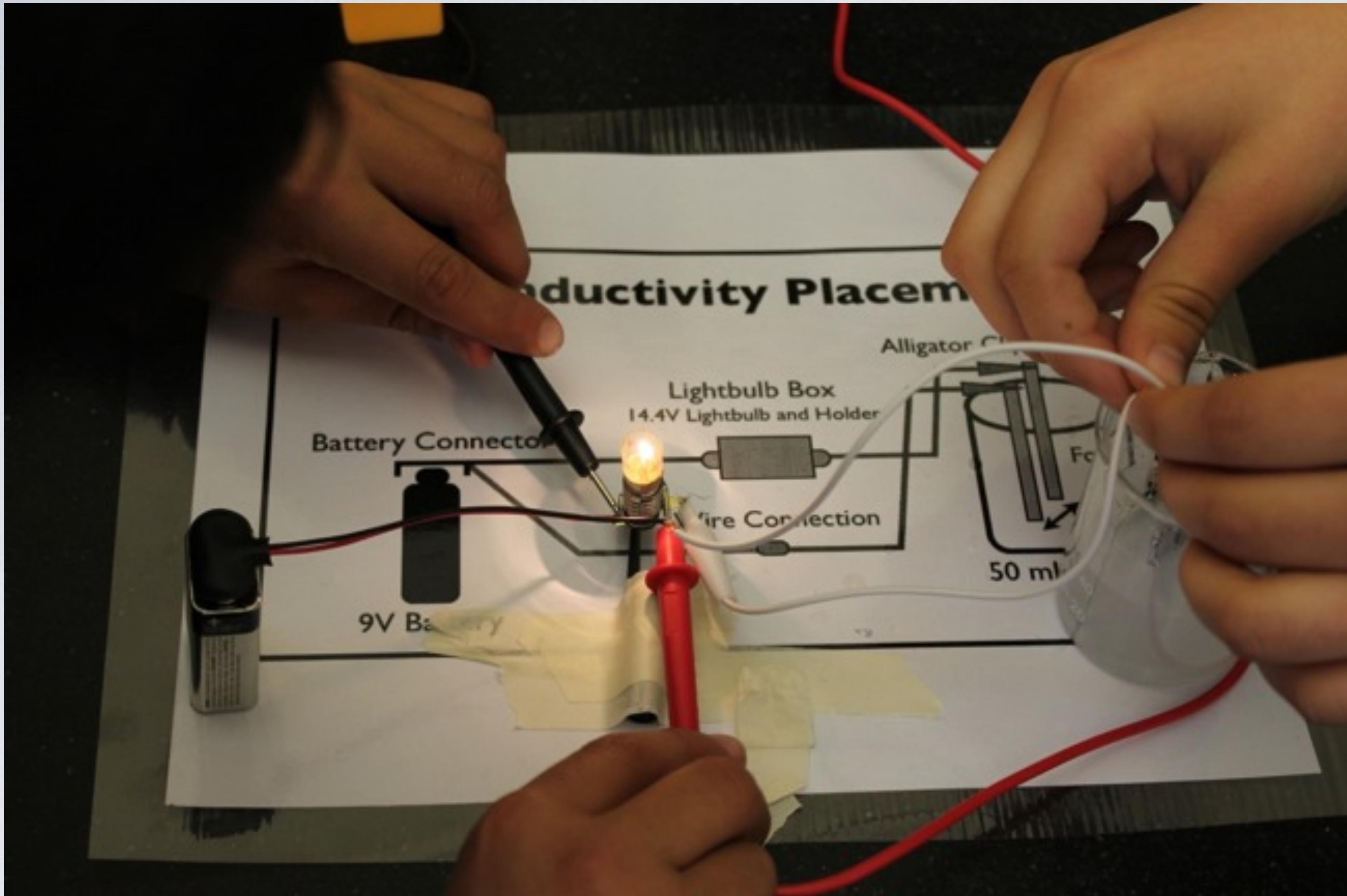


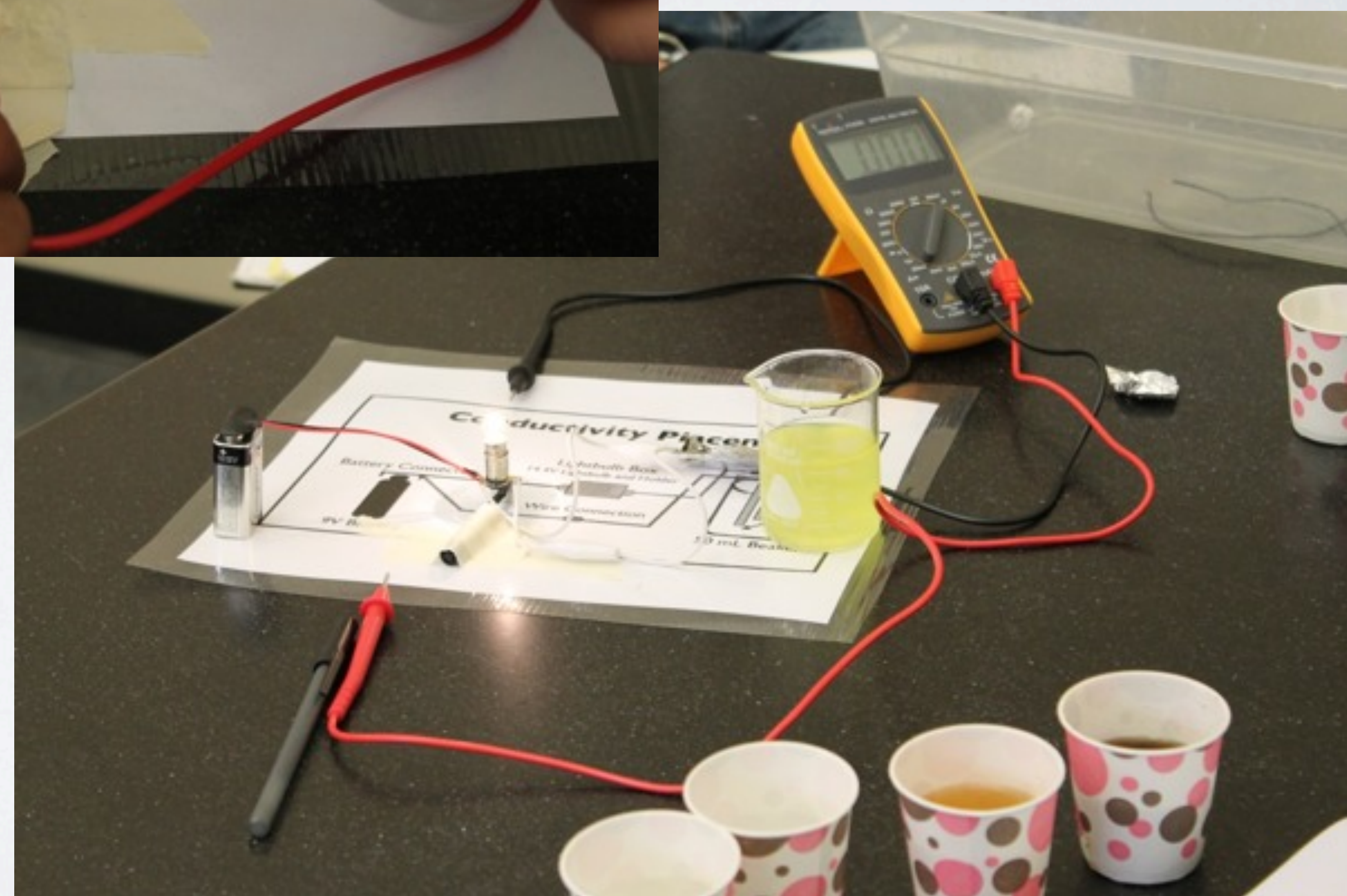
3. Test and compare conductivity of various solutions



4. Identify relationship between voltage and concentration




Lightbulb Box
14.4V Lightbulb and Holder



Demonstrates electron excitation AND conductivity

✔ Lithium Chloride

✔ Calcium Chloride

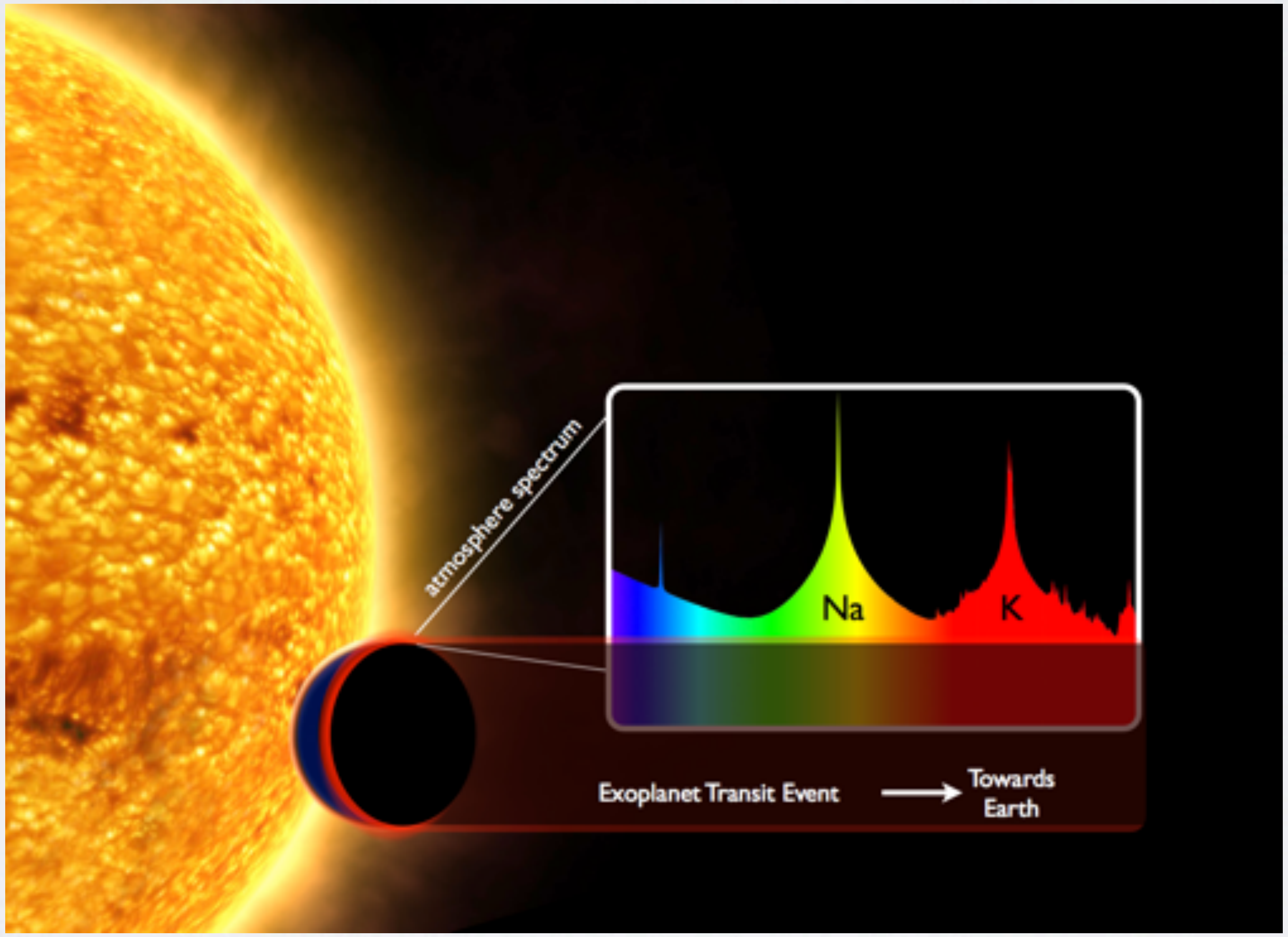
✔ Sodium Chloride

? Barium Chloride

? Copper Chloride

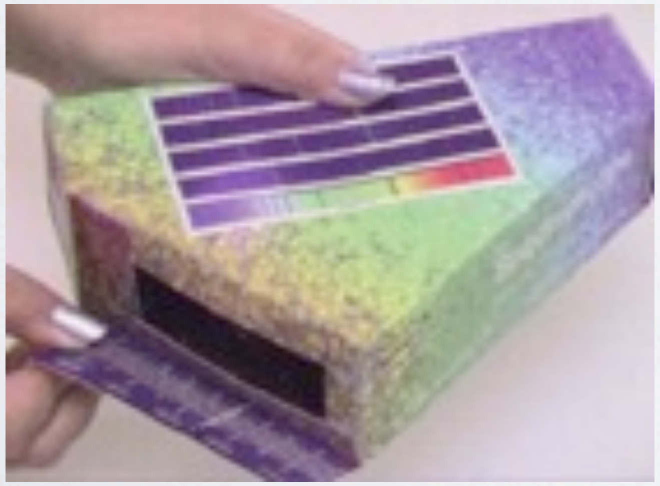
? Potassium Chloride

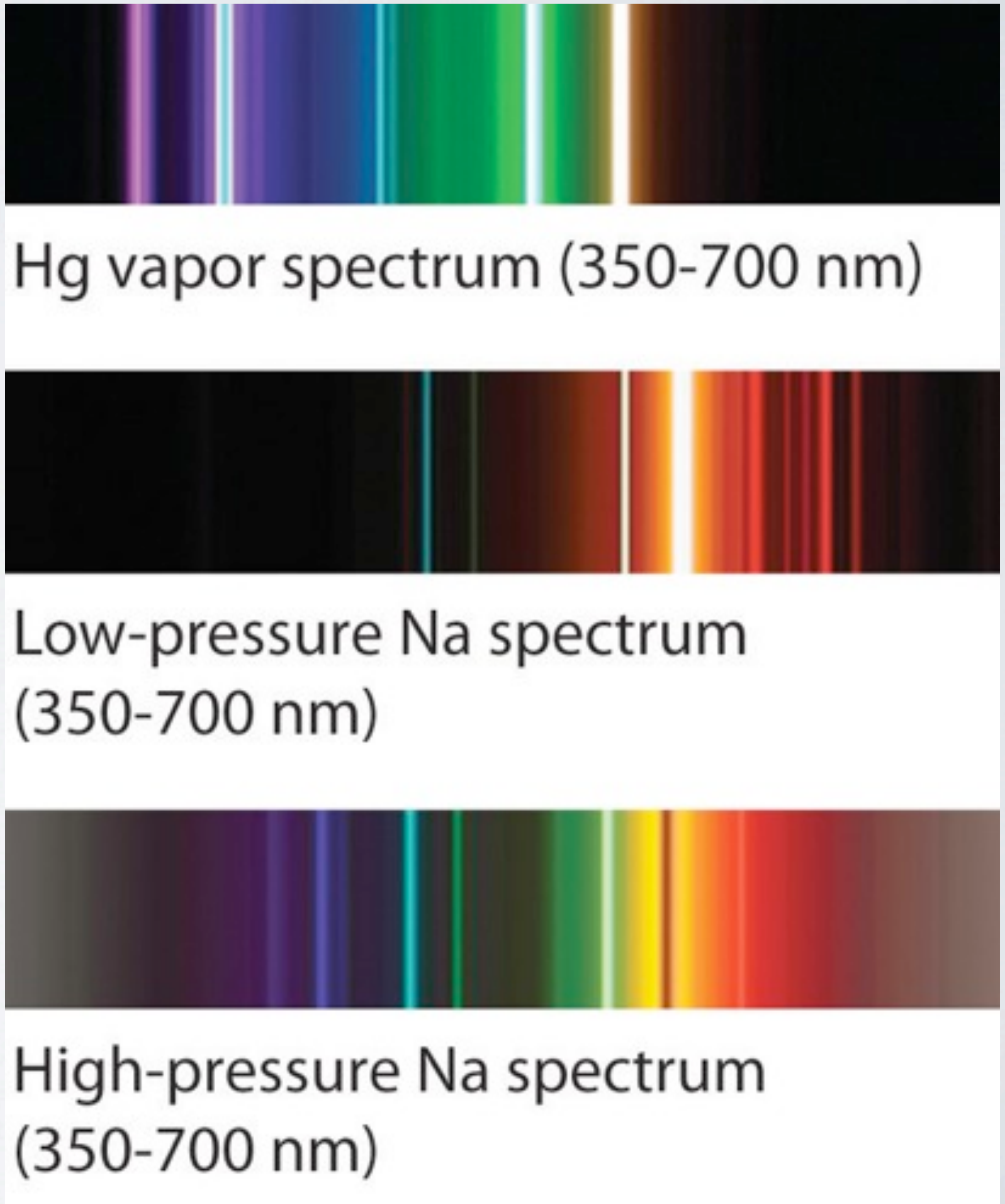
LAB 3: EXPLORING THE UNIVERSE WITH SPECTROSCOPY



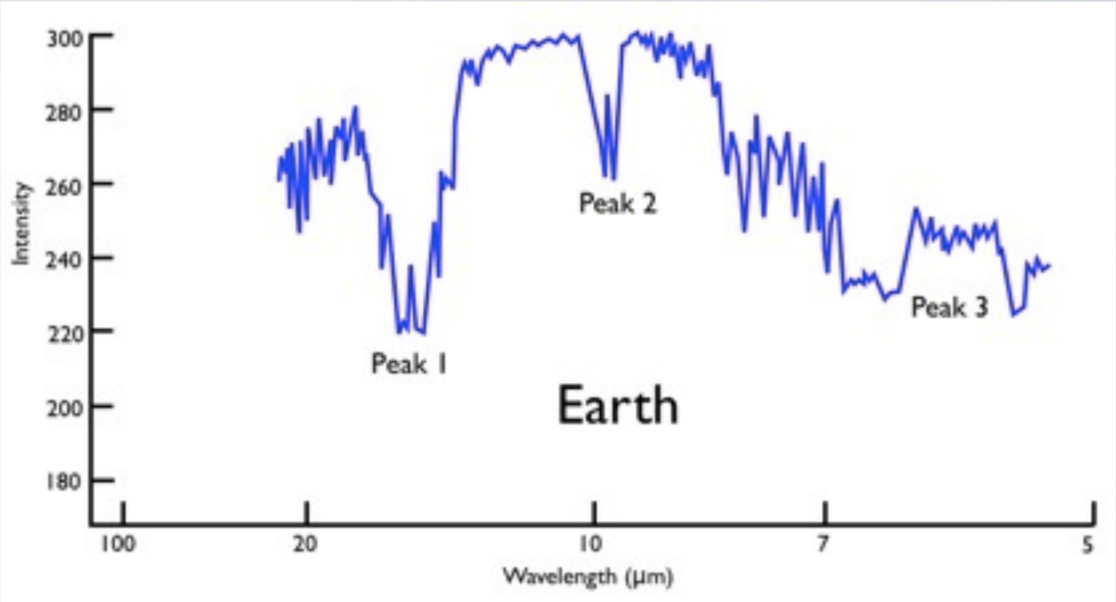
EXPLORING THE UNIVERSE WITH SPECTROSCOPY

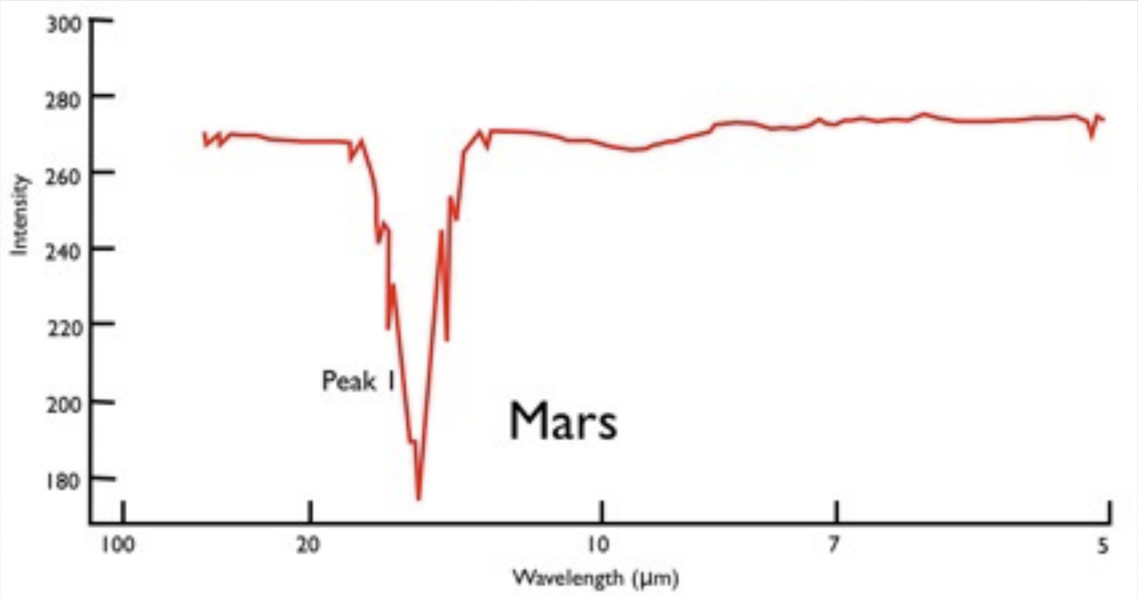
1. Part of Space Exploration unit, focusing on history and applied chemistry
2. Observe absorption spectra of incandescent, fluorescent, sunlight, black light, etc.

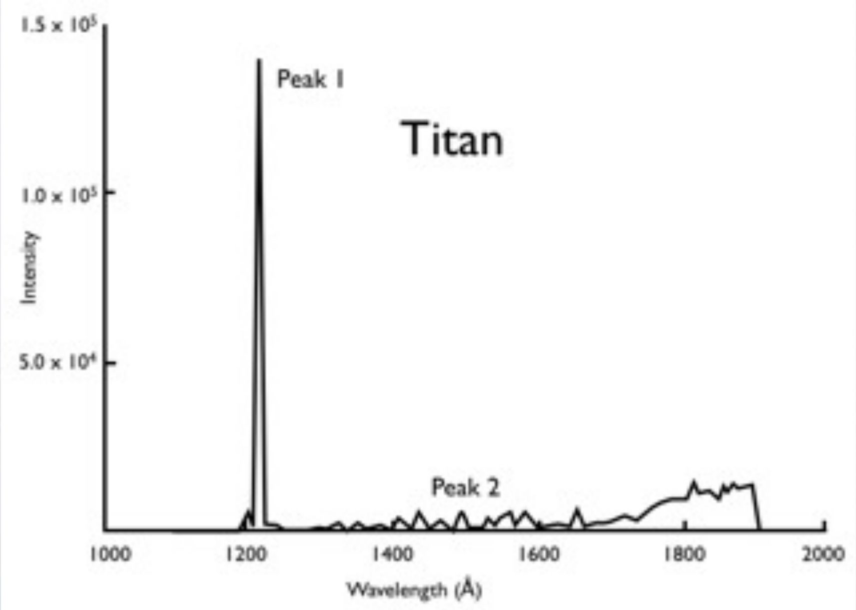


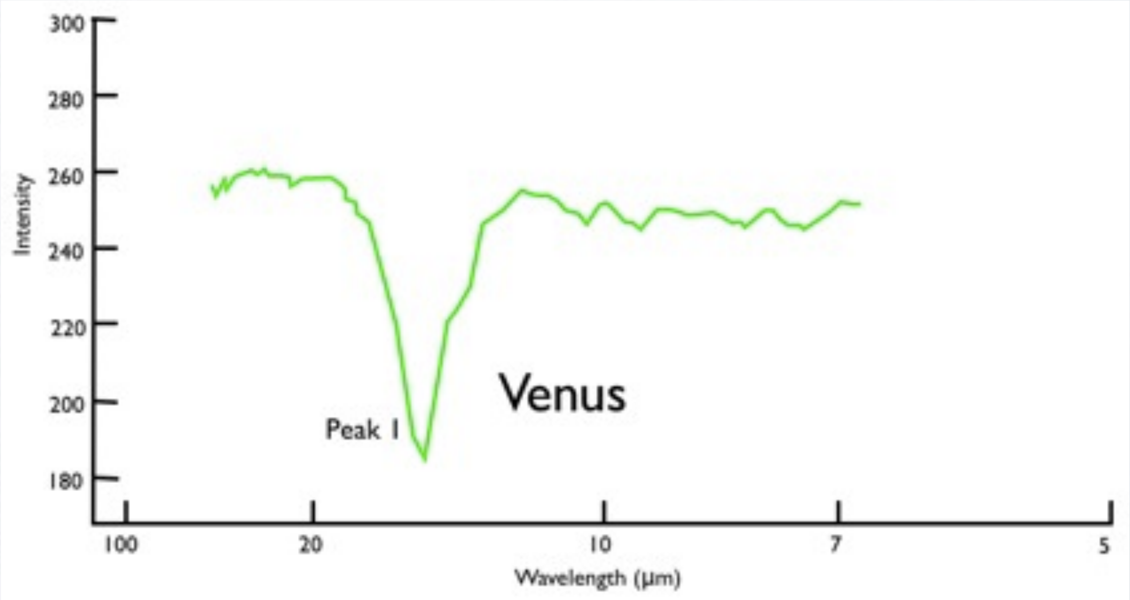


2. Incorporate actual data used to identify atmospheric composition of planets and moons







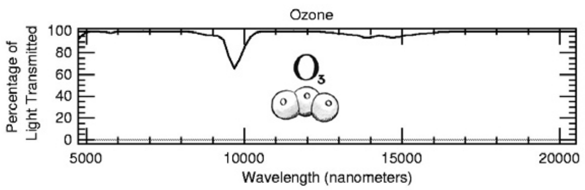


3. Complete *Chemical Fingerprints* Reading Activity

Research Reading: Chemical Fingerprints

The Search

The TPF will search directly or indirectly for the following chemicals.



Oxygen (O_2) and Ozone (O_3)

Oxygen is important to life on Earth. It is mainly produced as a byproduct of photosynthesis by green plants and certain other organisms.

Without life, oxygen would be rare on rocky planets. A small amount of oxygen can be created when ultraviolet radiation splits water vapor into hydrogen (H_2) and oxygen (O). The hydrogen is very light and can escape into space while the oxygen is left behind. But the oxygen would combine with rocks and minerals on the planet's surface in an "oxidizing" reaction to produce various compounds, such as rust. Gases released by volcanoes can also react with oxygen and remove it from the atmosphere. Geological processes usually work against the accumulation of oxygen.

Therefore, a planet with an oxygen-rich atmosphere is unusual without photosynthetic life to constantly replenish the supply. As Carl Sagan noted in a 1997 *Scientific American* article, "the great concentration of oxygen (20 percent) in Earth's dense atmosphere is very hard to explain by [any means other than life.]" The same would likely be true of planets orbiting other stars.

However, scientists do know of non-biological processes that can result in an oxygen-rich atmosphere. For example, ultraviolet light from the sun can break apart carbon dioxide molecules to form carbon monoxide (CO) and oxygen. Or, as stated previously, ultraviolet sunlight (or starlight) can break apart water molecules into hydrogen and oxygen.

So, the presence of oxygen alone—while exciting and significant—can't be taken as an unambiguous indicator of life. Furthermore, oxygen doesn't produce spectral lines that can be easily observed in the infrared part of the spectrum. However, another form of oxygen, ozone, made of three atoms of oxygen, does produce spectral features in the infrared.

The ozone layer, which is located in Earth's stratosphere, is important to life because it protects Earth from the Sun's harmful ultraviolet radiation. Ultraviolet radiation can cause skin cancer and cataracts in animals and can stunt the growth of many plants.

The presence of ozone in a planet's atmosphere is a reliable indication that normal oxygen is also present. Without oxygen, ozone could not exist. Ozone is not expected to be present in significant amounts unless oxygen is also present.

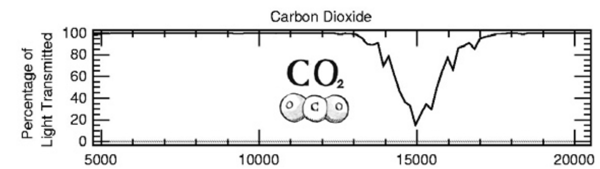
The detection of ozone along with other gases, such as nitrous oxide (N_2O) or methane, could be taken as convincing evidence that a planet is not only habitable—but that it is inhabited.

If we do not see oxygen or ozone features in a planet's spectrum, does that mean that life is not present? Earth's atmosphere has contained a significant amount of oxygen for only about the past 2 billion years. The earliest fossils suggest life existed 3.5 billion years ago. Indirect evidence for life on Earth may go back even further in time. This suggests that life was present on Earth for more than one and a half billion years before any sign of oxygen or ozone appeared in its atmosphere.

Where is it in the spectrum? Oxygen does not show up in the infrared part of the spectrum. But ozone produces spectral features at infrared wavelengths. One feature is located at about 9,500–9,700 nanometers.

Origins: Where Are the Aliens? || **Student Handout** NOVA

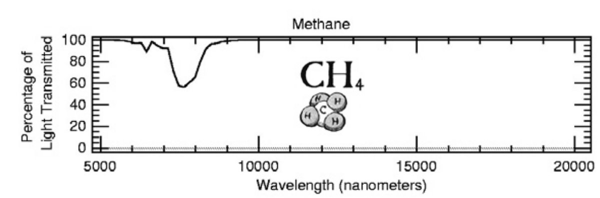
Research Reading: Chemical Fingerprints



Carbon Dioxide (CO_2)

Carbon dioxide is a gas that increases a planet's temperature by a process called the greenhouse effect. Carbon dioxide is also used (along with water) by plants to produce sugars used for energy. Oxygen is released into the air as a result. This process is called photosynthesis. Animals consume plants and oxygen and release carbon dioxide and water through respiration. If scientists found carbon dioxide, it would mean that the planet might be able to support plant life, but it is not a strong indicator of life by itself, since planets can have carbon dioxide atmospheres without life. Venus and Mars are examples of this.

Where is it in the spectrum? Carbon dioxide produces spectral features at various infrared wavelengths. A prominent feature is located at about 15,000 nanometers.

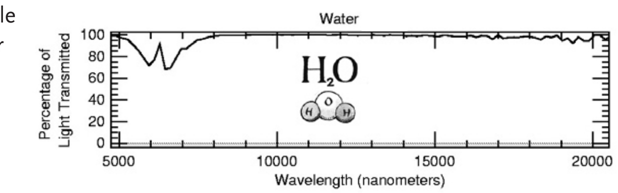


Methane (CH_4)

Scientists suspect that for roughly the first billion years of its history, life on Earth had not yet evolved oxygen-producing organisms. Instead, the microorganisms that dominated the planet tapped the energy in gases that leaked out of Earth's interior and some microbes created methane as a by-product. (Methane and nitrous oxide, another gas that can be associated with life, are not abundant in present-day Earth's atmosphere.)

On a planet with a similar geology to Earth, methane levels greater than about 100 parts per million would suggest a significant probability of the presence of life. But methane would be a more ambiguous discovery than oxygen, because planets of a different geological make-up might produce abundant methane without life. However, a spectrum that shows signs of both methane and oxygen would provide a very strong indication of life.

Where is it in the spectrum? Methane produces spectral features at infrared wavelengths. One of these is located at about 7,600 nanometers.



Water Vapor (H_2O)

Water vapor is one of the greenhouse gases that absorbs infrared radiation emitted from Earth's surface and helps warm the planet. Water vapor is also the source of all clouds, rain, and snow. It is an important influence on weather and climate.

If a scientist found water vapor in the atmosphere of another planet, it would be a good sign that there might be liquid water on its surface. Water is the most important ingredient for life on Earth, so another planet with water on it would be a promising place to look for life.

Where is it in the spectrum? Water vapor produces spectral features at many infrared wavelengths. One feature is located at about 6,000 nanometers.

Sources:

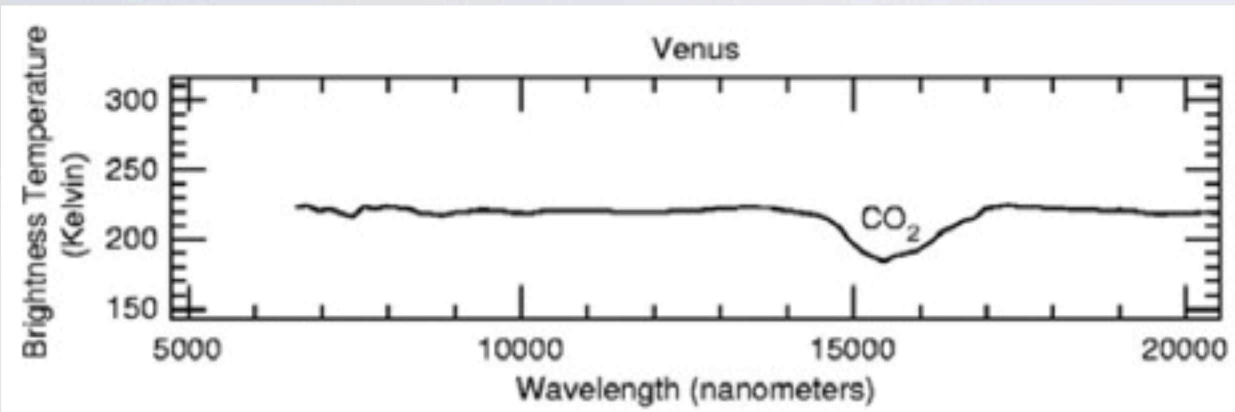
In Search of ET's Breath
www.nasa.gov/lb/vision/universe/newworlds/ets_breath.html

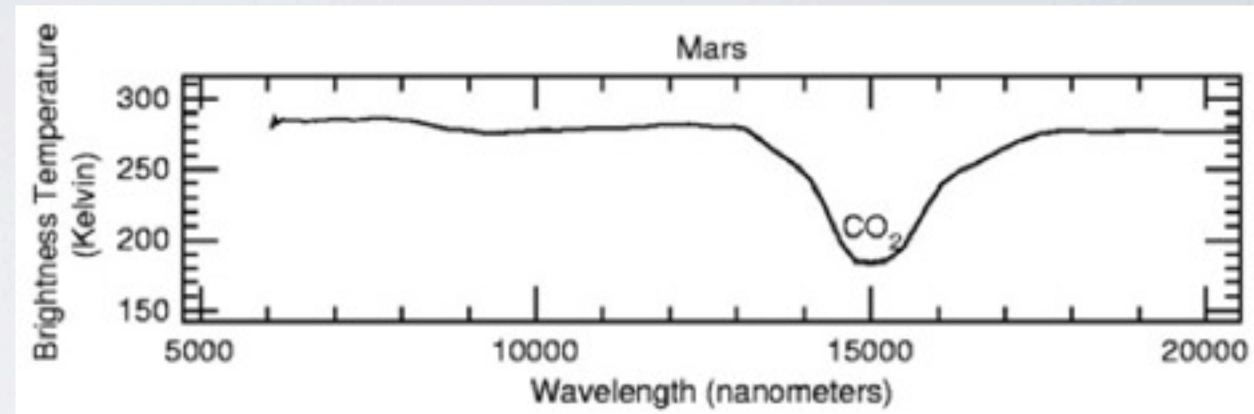
Looking for Life's Signatures
planetquest.jpl.nasa.gov/science/finding_life.html

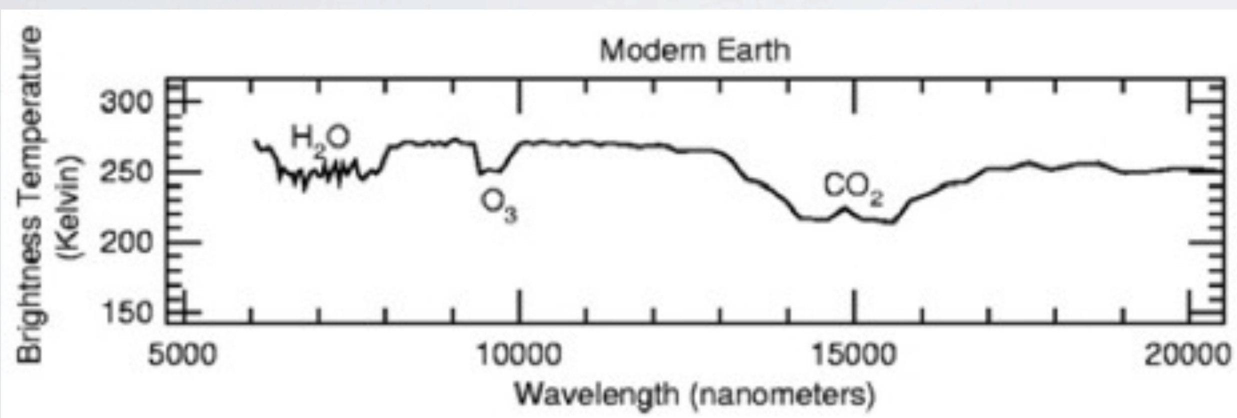
The Terrestrial Planet Finder, May 1999.
planetquest.jpl.nasa.gov/TPF/tpf_book/index.cfm

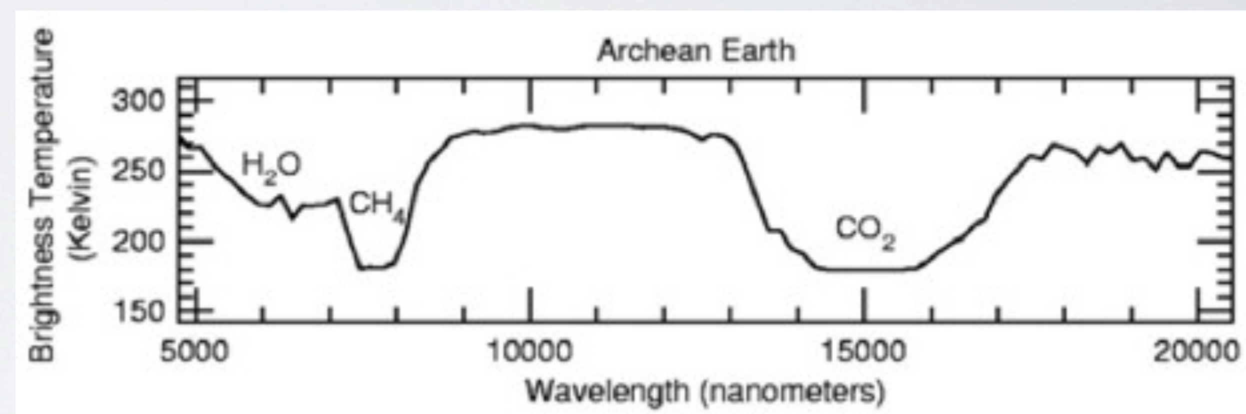
http://www.pbs.org/wgbh/nova/teachers/activities/pdf/3113_origins.pdf

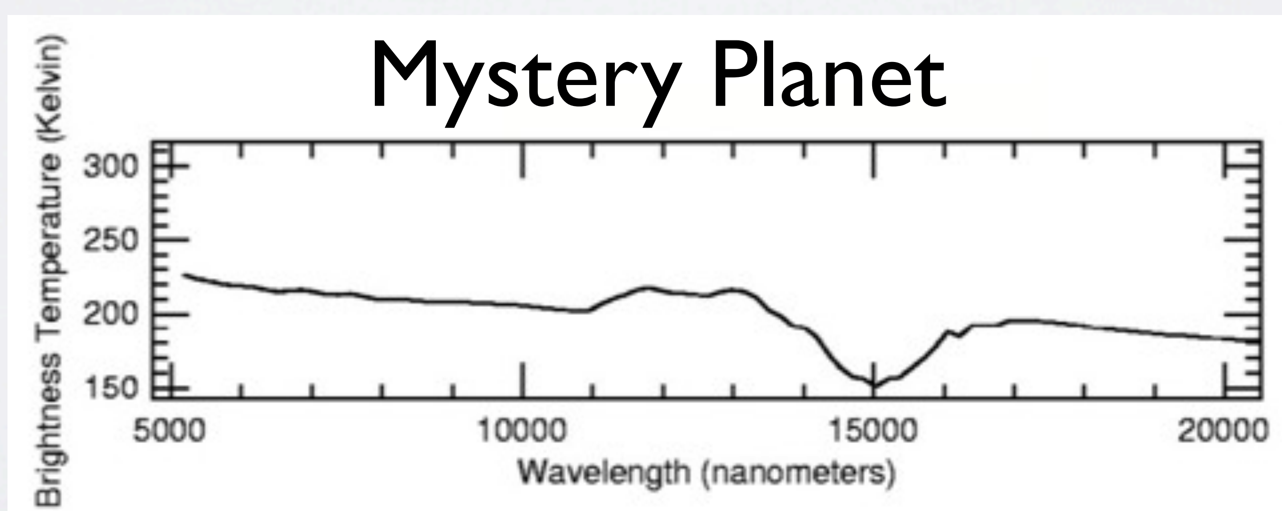
4. Identify atmospheric composition of Mystery Planet and determine if planet is suitable for life based, incorporating topics in exobiology lesson and space exploration











http://www.pbs.org/wgbh/nova/teachers/activities/pdf/3113_origins.pdf

ROCKET LAB…

ACKNOWLEDGEMENTS

Jesse Kasehagen

Chuong Vu

Marilyn Garza

Dr. Frank Kinnaman

Mike Brady

Dr. Michael Chabinyc Lab

Dr. Alan Heeger Lab

MATERIALS RESEARCH LABORATORY *the innovation engine for new materials* UC Santa Barbara

CALIFORNIA NANOSYSTEMS INSTITUTE

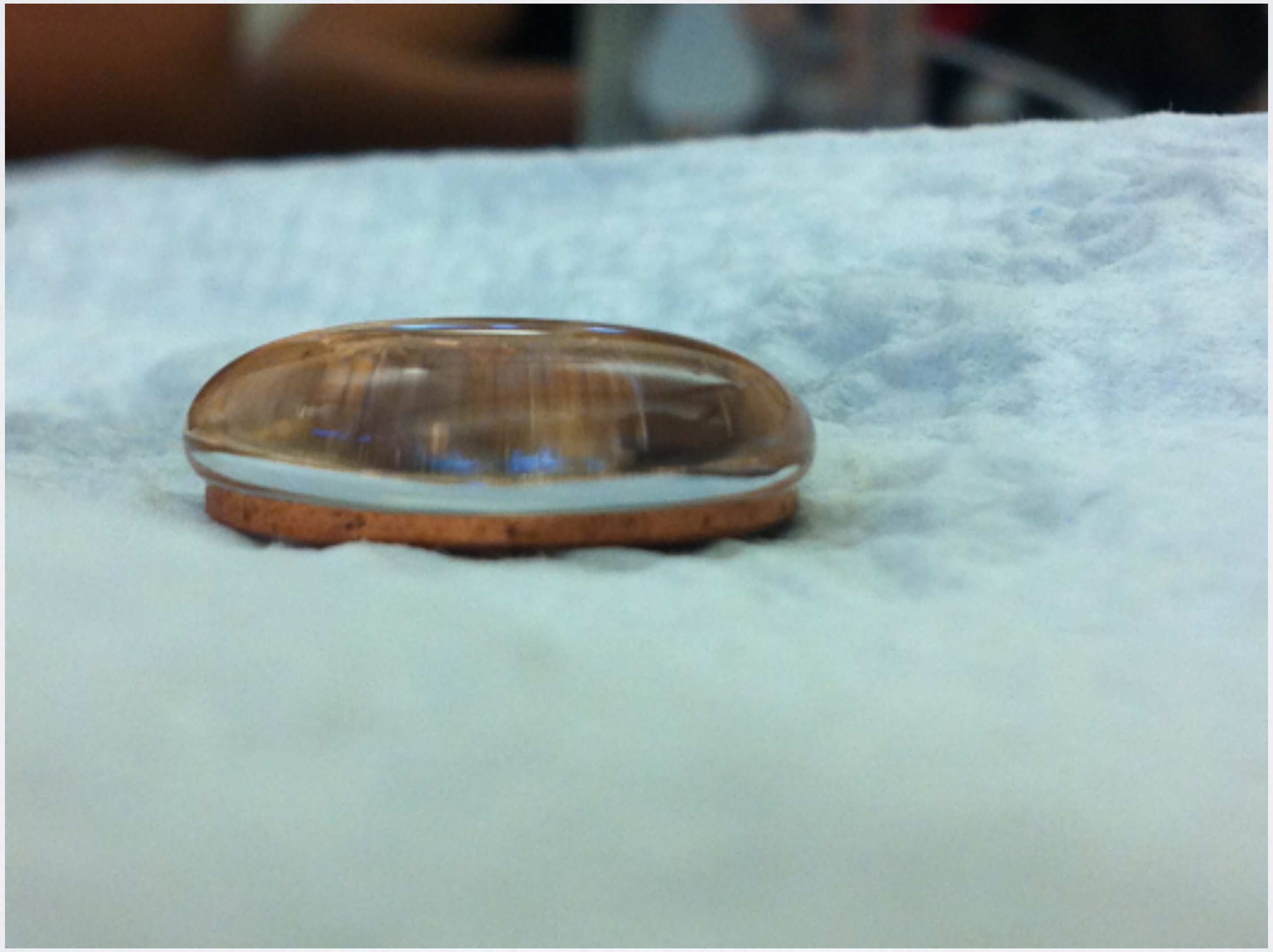
National Science Foundation WHERE DISCOVERIES BEGIN

LAB REPORT RUBRIC

	Exceptional	Strong/Good	Fair	Needs Improvement	Poor/Incomplete	Points
Objective and Introduction	25-21 points Provides complete background information; Writing demonstrates mastery of science content; Writing flows and has no grammar or spelling errors	20-16 points Provides partial background information; Writing has flow and minimal grammar and spelling errors	15-11 points Provides limited background information; Writing is choppy and includes grammatical and spelling errors	10-6 points Provides minimal background information; Writing is hard to follow and has many grammar and spelling errors	5-0 points Incomplete or incorrect background information; Writing does not flow and has many grammar and spelling errors	/25
Procedure and Data	10-9 points Data is clear and organized, including units; Procedure demonstrates mastery of sequence of steps	8-7 points Data is organized, but does not include units; Procedure shows basic understanding of steps	6-5 points Data is unorganized and does not include units; Procedure does not reflect understanding of steps	4-3 points Data is incomplete, unorganized and does not include units; Procedure is complete or shows lack of understanding	2-0 points Data is incomplete; Procedure is incomplete or incorrect	/10
Calculations and Analysis	15-13 points Calculations include work, correct answers and units; Graphs are precise and detailed	12-10 points Calculations include work, but are sloppy or have small mistakes and units; Graphs are precise and detailed	9-7 points Calculations and graph have errors and show minimal effort and understanding	6-4 points Calculations and graph are partially complete; Shows little understanding of content and effort	3-0 points Calculations and graph are incorrect and show no understanding	/15
Conclusion	10-9 points Conclusion provides final thoughts and identifies main objective was met	8-7 points Conclusion identifies objective was met but with partial understanding of content	6-5 points Conclusion identifies main objective was met, but shows limited understanding of content	4-3 points Conclusion does not state objective was met and little understanding of content	2-0 points Conclusion is incomplete or incorrect	/10
					Total	/60

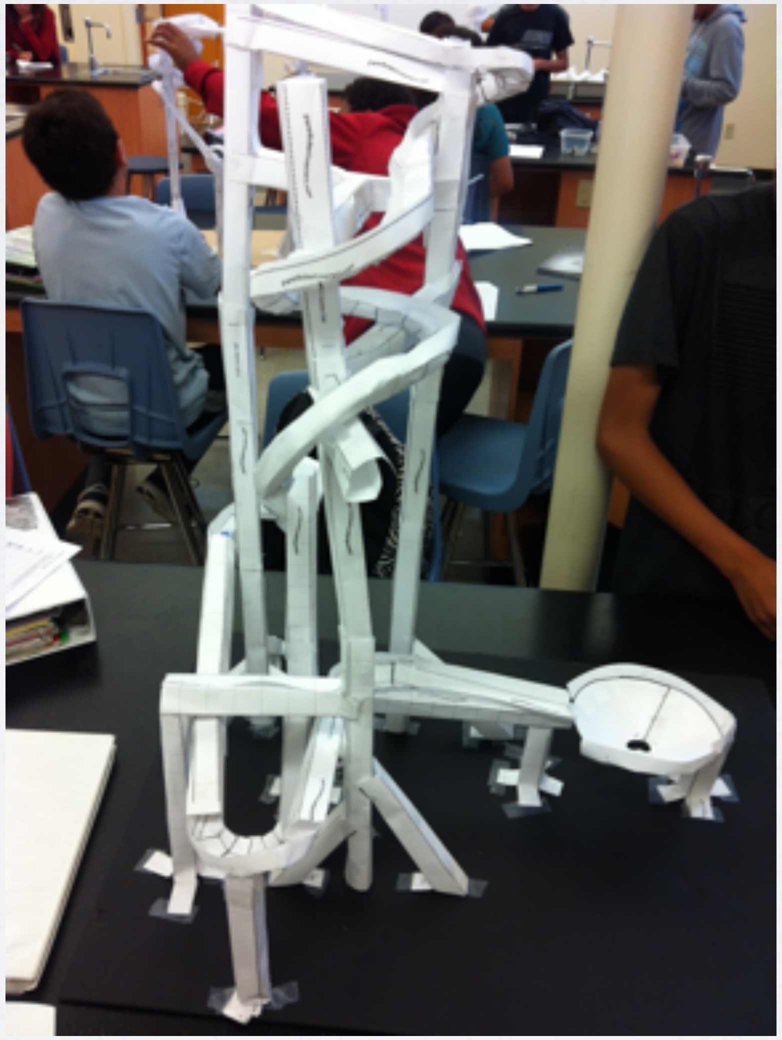
PENNY DROP LAB

Topics: Scientific method, data collection and analysis, variable parameters, lab materials, etc.



PAPER ROLLERCOASTERS

Topics: Average vs. instantaneous speed and graphing motion



BOAT BUOYANCY

Topics: Density, buoyancy, mathematical predictions and error analysis