5E Lesson Plan

Charles Canestaro

Topic: Resistance and Resistivity

Title: Play-doh™ and the Nature of Resistance

Grade Level: New York Regents/Honors Physics 11th and 12th Grade

New York State Science Learning Standards (NYSSLS):

[1] HS-PS3-6. Analyze data to support the claim that Ohm's Law describes the mathematical relationship among the potential difference, current, and resistance of an electric circuit.

Science and Engineering Practices

- Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds
- Planning and Carrying Out Investigations. Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
- Analyzing and Interpreting Data Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
- Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9– 12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

Disciplinary Core Ideas:

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy
- Electrical power and energy can be determined for electric circuits.

Cross-Cutting Concepts

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena
- Mathematical representations can be used to identify certain patterns.
- Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

- Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Common Core State Standards - English Language Arts Standards-Science & Technical Subjects: Grade 11-12

[1] CCSS.ELA-LITERACY.RST.11-12.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

[2] CCSS.ELA-LITERACY.RST.11-12.4 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context.

Set-up/Place and Time:

This lesson will take approximately four 40 minute class periods to complete. The first 40 minute period is required for the engage portion of the lab as well as part 1 of the experiment. The next 40 minute block is dedicated to parts 2 and 3 of the lab, finishing with the students having written up an experimental procedure for calculating the resistance of the home-made Play-doh™, but not yet measuring it. The third 40 minute block is for building the model of electrical flow through a wire as well as conducting the rest of part 3, including the temperature dependence experiment. The final 40 minute block is for wrapping up part 3 of the experiment as well as answering the analysis questions.

Prior to the start of the lesson, all lab sheets must be copied, Play-doh™ must be made or purchased, insulating Play-doh™ must be made, wire leads for connecting circuits must be cleaned of any corrosion, volt-meters and ammeters should be checked to ensure they are working in proper order, and light-bulbs/LEDs should be checked to ensure they are functioning properly. Set up time should take between 10-20 minutes.

Background:

Students:

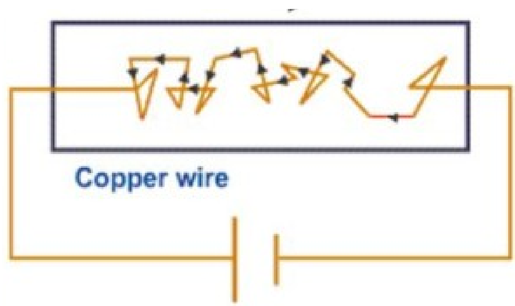
This lesson should directly follow a lesson involving Ohm's Law, for example "Notebook Circuits" or "Discovering Ohm's Law." Students should be familiar with series and parallel circuits. In addition, they should be able to apply Ohm's Law: V=IR to solve for current, voltage, and resistance in a circuit. Although it is not necessary that students have investigated resistance in series and parallel combinations, it would be advisable to also teach this prior to the lesson. Students should **not** have received any formal instruction in the factors which determine electrical resistance or the concept of resistivity prior to this lesson, as they will be discovering them throughout the lab, **not** confirming them. Students should be able to measure voltage and current in a circuit using a voltmeter and ammeter. See appendix on last page for a diagram of circuit connections.

Teacher:

Resistance is a measure of how easy or difficult it is for electricity to flow through a circuit. For an ohmic resistor (a resistor which obeys Ohm's Law V=IR, or in other words a resistor in which current flow is directly proportional to voltage applied), the resistance can be determined by the equation:

$$R=\frac{\rho L}{A}$$

Where ρ is called the resistivity of a material, *L* is the length of the resistor, and *A* is the cross-sectional area of the material. The resistivity of a material is a property of how easily electrons can flow through the material given a voltage. Resistivity is also temperature dependent. A model for considering the nature of resistivity can be described as "Atomic Plinko." See picture below for the model.



If we think of resistance as the "number of collisions per second" that occurs with an electron in a material, we can build a working model of resistance.

- Length Direct Dependence: In a longer material, the electron will encounter move collisions and therefore encounter a greater resistance. Thus, longer materials have a greater resistance.
- Area Indirect Dependence: Like cars going down a highway, the more available paths or room for the electron, the easier it is for the electron to travel through the material, thus larger area wires have less resistance.
- Material Dependence: This can be modeled as the spacing of the atoms/electrons in the wire. In a material with a low resistance, we can model this as atoms spaced very far apart. In a material with a high resistance, space the atoms in the picture above close together. In reality, resistivity is not a property of atomic spacing, but the propagation of current through free-electrons in the material which is dependent on the material itself, so another way of modeling the electron flow is the "ease" with which an electron can pass through a material (e.g. high resistivity=large number of collisions, low resistivity=low number of collisions).

- Temperature Dependence: As a material gets hotter, the atoms in it move around more due to the Equipartition Theorem. In our model, if the material is hotter, the electron will encounter more collisions trying to get through all these rapidly jiggling electrons in the material. Thus, hotter materials have a greater resistance.
    - Note 1: This model is also used to later extend in the lab to explain the phenomenon of an incandescent light bulb lighting up as well as electrical safety in a house. We can use this model to say that if more collisions are taking place, there is electrical friction occurring, which creates heat.
    - Note 2: Play-doh displays the **opposite** temperature dependence effects due to it's chemistry. Although hotter objects have a larger resistance and colder objects have a lower resistance, Play-doh will have a higher resistance when cold and a lower resistance when hot. This is because play-doh is essentially ionized salt water and conducts electricity through free ions in the dough. When colder, less free ions are available, overcoming the temperature effects of resistance. Similarly, when hotter, more free ions are available, allowing play-doh to better conduct electricity. This is why we choose to use a light-bulb for temperature dependence as an inquiry lab using hot and cold play-doh would lead to incorrect models without considering play-doh's chemistry.

None of these analogies explain the linear dependence of each variable. It is left to the student through the lab activity to discover the linear dependence of each variable. This is why this model should be developed/utilized toward the end of the lesson during the **Elaborate/Extend** portion.

Note #2: Although we use the word collisions, electrons do not collide with other electrons. When electrons get near other electrons, they exert a repulsive force on each other given by Coulomb's Law. We use the term collision colloquially as it distracts from the lesson to go into too much depth on the nature of electric repulsion during this lesson.

Justification:

This lesson was developed as a means to allow students to self-discover the factors which influence the electrical resistance of a material as a way of building a deeper conceptual model then if simply told the factors by the instructor. Understanding the nature of electrical resistance is of critical importance for studying the causes of common electrical fires in the household, understanding the limitations of extension cords and transmission of electricity across large distances, and extending to the theory of superconducting materials which will play a crucial role in society over the next century.

This lesson integrates Math, Science, Technology, and Engineering. Students will be creating graphs of Resistance as a function of length, area, and material to determine the relationship (direct, indirect, no relationship). Students will be using multi-meters to measure the current and voltage in a circuit, which is important technology all students should become comfortable using. Finally, students will have to construct, revise, and reconstruct circuits as they perform the lab which is indicative of the engineering process.

Due to the overwhelming fear encountered by students with circuits in introductory physics, Play-doh™ was chosen as the medium to help remove the stigma from circuitry. By using something moldable that students are familiar with, it allows students to jump into making circuits and collecting data without the fear of making a mistake or shocking themselves.

This lesson integrates Science, Technology, Engineering, and Mathematics. The science of the lesson is the physics of resistance and resistivity. Without the usage of voltmeters and ammeters, measurement of voltage and current in the circuits would be impossible. This technology is of critical importance to teach to students due to the usefulness later in life concerning household circuitry. Students will be performing two engineering tasks during the lab which are vital to the success of the lab and understanding gained. The first will have students design a model of what they believe the inside of a dimmer switch looks like. As they go through the lab and have new experiences, they will revise and refine their model to be more accurate. The second engineering design is the creation of molds for making Play-doh™ resistors with a uniform diameter. Students again will revise and redesign as necessary to build a mold which allows for accurate data collection. Mathematics is of crucial importance for the mastery of learning objectives. Students must be able to create and interpret graphs to understand the underlying relationships between resistance, length, area, and material. Without any one of these pieces, the lab would not be successful. This lab also aids many students in their future courses in technology and mathematics in that it reinforces the essential skill of measure voltage and current with a meter and it helps teach students to utilize graphs to model and interpret data.

Objectives:

- "I Can complete a complex, multi-step experiment to demonstrate that resistance is directly proportional to length"
- "I Can complete a complex, multi-step experiment to demonstrate that resistance is indirectly proportional to the Cross-Sectional Area of the material"
- "I Can state that an object's resistivity is in intrinsic property of the material"
- "I Can measure current and voltage in a circuit"
- "I Can utilize Ohm's Law (equations, concepts, and symbols) to determine resistance in a circuit"

- "I Can compare and contrast the physical differences between two resistors of different resistance"
- "I Can build a model for resistance based upon collecting and interpreting data"
- "I Can design a dimmer switch and justify its function"
- "I Can critique the design of household appliances (e.g. toasters)
- "I Can analyze data to demonstrate that Play-doh is an ohmic resistor (i.e. obeys Ohm's Law)

Materials:

- Play-doh™: Store-bought or homemade. See http://courseweb.stthomas.edu/apthomas/SquishyCircuits/conductiveDough.htm for a great recipe
- Insulating Play-doh™: See http://courseweb.stthomas.edu/apthomas/SquishyCircuits/insulatingDough.htm for the recipe
- Plastic Knives
- Rulers
- Two pieces (per group) of metal rod (can be easily stripped and cut from 12 gauge electrical wire)
- Source of variable potential difference (3V to 9V). Also can simply use a 9V battery
- Multi-Meter or separate volt-meters and ammeters
- Alligator clips-4 sets per group
- Graph Paper
- Pencil Circuit Set-up (graphite, clips, led) Make sure to use an artist's graphite pencil to construct the circuit.
- Sandpaper (120 grit, 180 grit, or 220 grit)
- Small (5 Watt) novelty lightbulbs with stands

Assessments:

- **Formative**
    - Questions given throughout lab by instructor (anecdotal notes)
    - Pre-lab questions, including revisions throughout
    - Student Drawing and construction of a dimmer switch
    - Student solutions to analysis questions (post-lab)
    - Student construction of graphs and identification of relationships
- **Summative**
    - Exam on circuitry to conclude unit
    - New York Regents Exam in Physics

References:

- This lesson was inspired/adapted from the work of Jim Overhiser and Julie Nucci through the Cornell Institute of Physics Teachers (CIPT). See https://xraise.classe.cornell.edu/perch/resources/natureofresistancearchived.pdf for their original lesson which has excellent supplemental materials and pictures which add tremendously to this lesson!

- NY State Regents Physics Reference Table: http://www.p12.nysed.gov/assessment/reftable/physics-rt/physics06tbl.pdf

Engage:

Hand out the lab. Start class with a demonstration of a rheostat. The first demonstration to perform is to have a standard lightbulb hooked up to a dimmer switch. Turn the bulb on and turn the dimmer switch. Have students write down their observations in the pre-lab. Students should be asked to attempt to draw what they think the inside of the dimmer switch looks like.

Next, show the following two videos: (or use a different video showing a hot wire or electrical fire of your choosing).

[1] Video on household electrical fires found at https://www.youtube.com/watch?v=YfqciXDBT7c&t=125s Show the first minute or so of the clip.

[2] Video of wires melting from high current: https://www.youtube.com/watch?v=FrTAsDYefiQ Show just the first minute.

Discuss the objectives of the lesson. Students will learn the factors which effect electrical resistance in wires. In addition, by the end of the lesson, they will understand how a dimmer switch works as well as considerations to take to make your home safer from electrical fires.

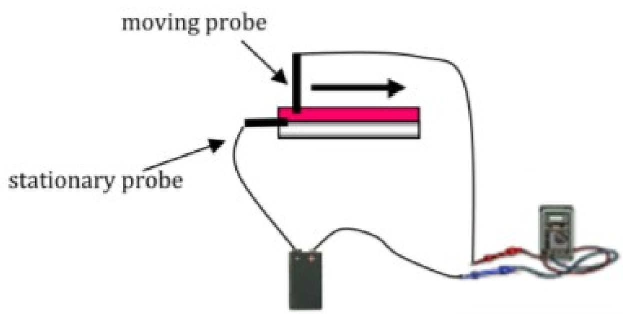
Before starting the explore portion of the lab, it is imperative that proper use of a volt-meter and ammeter be discussed. In addition to the discussion, provide “cheat-sheets” (given in the lab packet for students) that students can reference to ensure that they are using them correctly.

Explore

Students will be divided into X groups of 3. If known, group by learning style so that all tactile learners are grouped together. As they are the most hands-on leaners in the class, you want to ensure all students are contributing to the lab. This is based upon experience where in a circuitry lab like this, the tactile learners can take over the data collection for the group. By grouping by learning style, every diverse learner has a way to express his/herself and demonstrate mastery of the learning objectives.

Part 1: Determination of the effect of length on Resistance

In part one of the activity, students will construct circuits connecting a piece of Play-doh™ to a 9V battery. Exposure to air and current dries out the Play-doh™, which will adversely affect the measurements. Minimize the time the Play-doh™ is out of the container to keep it moist. When taking electrical measurements, take as little time as possible between measurements and immediately disconnect the circuit when finished taking data. Students will use a “four point probe” to collect data as accurately as possible for this lab. A drawing demonstrating the connections between the Play-doh™ and electrical components is provided below. Note to students that since voltage is the “push” of electrical current through the circuit created by the battery, it is independent to the circuit. As such, as long as the voltage is determine to be 9V (checked by a multi-meter), the 9V will be constant throughout the experiment. Students should be reminded to lightly sand the copper probes as they easily corrode from the current and salt. Also ensure that the probe is making a good connection within the Play-doh™ as after a few experiments it can easily be sitting in a void in the Play-doh™. Each probe should be inserted about halfway into the Play-doh™ and measurements should be taken immediately to [1] avoid draining the battery and [2] reduce error as corrosion begins immediately which can alter resistance.



Stress the importance of creating a uniform cylinder or rectangle of Play-doh™ as in the next section they will explore the relationship between area and resistance. Students should be encouraged to design their own molds to create as uniform a material as possible. Advise students to make small indentations throughout the Play-doh™, identifying 1cm intervals to ease data collection. Also make sure to check that their ammeters are wired in series before connecting their circuits so they do not overload the ammeter. See appendix for a diagram illustrating proper connections.

If students make a cylinder, remind them that the area can be round using diameter=2 x radius and the area can be found using $A=\pi r^2$. If they make a rectangle, area=base x height.

With a 9V battery, current values should range from around 50mA when the resistor is long to as high as 400-500mA when the resistor is 1-2cm long. If students get measurements greater than 500mA, there is most likely a short in the circuit or the ammeter is wired in parallel (most common). Reminder that 200mA=0.2A, and for calculations, students need their measurements to be in SI units. Resistance is calculated using Ohm’s Law, so each resistance should be found by taking 9 Volts divided by the current reading.

Explain:

The graph created should be roughly linear. Most importantly, as length increases, there should be a direct correlation with resistance. Try to identify any outliers and talk to students about their experimental procedure. At the very least, students should be demonstrating that current is decreasing as length becomes longer. Students should be guided to drawing a line of best fit for the data. A good question at this point is to ask what it would mean if they had a line that was steeper/shallower? (greater/less resistance).

Part 2: Determination of the effect of Area on Resistance

Explore:

The same precautions as before should be taken during this portion of the lab. Ensure that students are taking care to make sure that their cylinder has as constant of an area throughout as possible, while maintain a constant length. A good length to use is approximately 10cm. Students should be reminded to sand probes and re-check battery voltage before commencing.

Explain:

The relationship between area and resistance is indirect. As student begin to plot their points, ask them if they think the shape should be a line or a curve of best fit. A good question to elicit thought is to ask what would happen if the area were zero or if it were really big. If the line were linear, the line crosses the x and y axis at some point. Therefore, a resistor with “zero area” would have a finite resistance and there exists some area where the resistance becomes zero (and possibly even negative if you extend the line!). If the graph is instead a curve, then the resistance asymptotes to infinity with an area of zero and asymptotes to zero with an infinite area.

For Big Question #2, students should include some mentioning of less resistance in the argument they construct. While there are additional factors (such as heat in the wire), this one follows directly from their measurements.

Part 3: Resistivity

Explore:

The same precautions as before should be taken during this portion of the lab. Students can vary either area or length, although length is encouraged due to the ease of data collection.

The homemade Play-doh™ recipe is insulating Play-doh™. In order for a material to be a conductor it must contain free moving electrons or other free moving charged particles (ions). Play-doh™ is made with salt and when salt is dissolved in water is forms charged particles of sodium (Na) and chlorine (Cl). The sugar Play-doh™ thus will be an extremely weak conductor of electricity.

Explain:

The purpose of the picture here is to begin students thinking about the model of resistance. Their picture should show in some way or form the atoms in the Play-doh™ as well as showing how easy/difficult it is for the electron to pass through the two materials. In their model, they should show that it is somehow easier for the electron to make it through the store-bought Play-doh™ vs. the insulating dough.

Extend:

With a conceptual model of resistance developing, students will now hypothesize the relationship between temperature and resistance. For Play-doh™, there is a roughly linear relationship between temperature and resistance through most temperatures, source: https://physics.info/electric-resistance/

It is here where it is helpful to introduce the "Plinko" model of resistance (discussed during teacher background) and that a way of thinking of electrical resistance is visualizing how many "collisions" occur each second for an electron traveling through a wire. For students struggling with this concept, a refresher of the equipartition theorem (something along the lines of "what is different between a hot and cold gas) should get them thinking along a productive track.

The teacher can then perform the demonstration with the bare filament connected to the mini-bulb. By blowing on the filament, you slightly decrease the temperature, allowing more current to flow through the circuit, resulting in a noticeable change in brightness in the mini-bulb. When you then take a lighter to the filament, you increase its temperature, resulting in less total current flowing through the circuit. This is observed by a noticeable dimming of the mini-bulb. Together, these demonstrations can help students develop a model of electron flow through a material based upon its temperature, which can be an excellent tie in to the equipartition theorem if the students have prior exposure to chemistry.

From here, poll student opinions about why a wire heats up when electricity passes through it. Have students justify their claim using their experimental results and/or their developed model. Students

Groups should be encouraged to each try out a scenario and share the results with the class.

Part 6: Ultimate Circuit Construction Challenge!

The following are a list of suggestions to use for conducting your circuit challenge as a culmination activity with your students. For each challenge, give ~3 minutes for students to construct their circuits. Encourage use of graphs and data tables created during the lab for this exercise.

1. Construct a circuit with play-doh and a light bulb and have the light bulb be as dim as possible.
2. Construct a play-doh circuit and measure a current of exactly 73mA.
3. Construct a play-doh circuit with two different lightbulbs of different brightness.

4. Construct a play-doh circuit with three lightbulbs, where if one bulb goes out, another bulb goes out, but the last bulb stays lit.
5. Construct a play-doh circuit with a play-doh switch so that a lightbulb connected could be lit on a “low,” “medium,” and “high” setting.
6. Construct a circuit using three chunks of play-doh to illustrate why equivalent resistance increases in series* (note: because it creates a “longer” resistor)
7. Construct a circuit using three chunks of play-doh to illustrate why equivalent resistance decreases in parallel* (because it creates a “wider” resistor)

*Note: 6 and 7 can be done as a demonstration to the whole class either before or after the circuit construction challenge as a culmination activity.

<u>Evaluate:</u>

To evaluate student progress, they will compete a set of analysis questions at the conclusion of the lab. This should be the main assessment of the lab to demonstrate students have achieved the learning objectives. Here is a brief discussion of each question:

[1] Common examples of pros that should be identified include decreased resistance (and therefore power loss in the household) as well as less heat generated and therefore safer to use in the household. The most important con to consider is the price of copper. 12 gauge wire is significantly more expensive then 14 gauge. For example, a Lowes.com search shows that 250’ of 12-2 Romex wire costs $72 while 250’ of 14-2 Romex wire costs $47.

[2] Students are to “discover” the equation $R=\frac{\rho L}{A}$ based upon the direct/indirect relationships observed. Make sure to mention that the temperature variable changes the resistivity, which is why the values given in the reference table are for 20 degrees Celsius. The key aspect is to derive the relationship from the graphs of the data, drawing the conclusions of direct and indirect relationships.

[3] This corresponds to a few factors, including contact resistance between the play-doh and metal leads as well as resistance in the wires in the circuit.

[4] Students will use the equation $R=\frac{\rho L}{A}$ to solve this problem. The resistivity is found from the reference table. The area is found from $A=\pi r^2$ where r=0.0010265m and the area=$3.31\times10^{-6} m^2$. Solving for resistance, the answer is 0.17Ω.

[5] The final draft should illustrate in some way that length is altered to create the dimming effect.

[6] Silver has a lower resistivity than copper and therefore would give wires lower electrical resistance. The downside of course is the price of silver, making large-scale use of it unrealistic. Silver and gold are used in select places in circuits, where the select resistivity is desired. A common example is the metal found on the

charger port stuck into IPhones. If the temperature of metals is different than room temperature, the resistivity would be different (higher if hotter and lower if colder).

[7] Students should use the equation $R=\frac{\rho L}{A}$ to solve for rho (p, resistivity) given a resistance, length, and area. The calculation is not shown here as there are far too many variables inherent in the Play-doh™ and experiment to offer an exact resistivity.
http://courseweb.stthomas.edu/apthomas/SquishyCircuits/ResistivityTesting.pdf
states that the approximate resistivity of commercial Play-doh™ is 0.4Ω-m while the approximate resistivity of insulating Play-doh™ is 0.9Ω-m.

[8] Tungsten and Nichrome have high resistivities. Because of this, large amounts of heat are generated as electricity is passed through. The heat is harnessed for light in a lightbulb and heat in a toaster. The ideal grate in a toaster contains a very long, thin wire made of a high resistance material.

[9] Typically, the difference is in the thickness of the fuse. A 15A fuse is thinner than a 20A fuse, thus it burns up and opens a circuit before a thicker 20A fuse would. The drawing should illustrate the 20A fuse as thicker than the 15A fuse. Fuses and circuit breakers prevent house fires because if you are drawing too much current through the wires in a circuit, the fuse melt or the circuit “breaks” before you risk the chance that the large amount of current drawn could create enough heat to catch your walls or outlet regions on fire.

[10] **C, E, A, D, B.** This is found by taking length/area given that all are made from the same material. For the non-constant area, assume each has an average area of 1.5.

Play-doh™ Circuits

Name: ______________________________

Partners: ____________________________

Pre-Lab:

[1] **Dimmer Switch Demo.** In the space below, write down 3 observations (not inferences!)

[2] Attempt to draw what you think the inside of a dimmer switch must look like

[3] In terms of current and resistance, how does a dimmer switch work?

[6] Why do we use large (diameter) wires for power lines but small wires for the filament of a lightbulb?

LAB Part 1: Determination of the effect of Length on Resistance

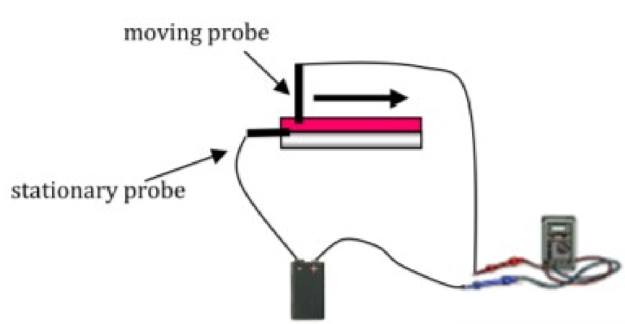
In this experiment, you will alter the length of the Play-doh™ as you measure the changes in resistance.

Note: Exposure to air and current dries out the Play-doh™, which will adversely affect your measurements. Minimize the time your Play-doh™ is out of the container to keep it moist. When taking electrical measurements, take as little time as possible between measurements and immediately disconnect the circuit when you finished taking data.

Here are a few steps to consider before collecting data:

1. Measure the diameter of the Play-doh™ and ensure that it is uniform!
2. Using a voltmeter, measure the battery voltage to ensure the battery is fully charged
3. Using any technique and materials available, design a mold to make a Play-doh™ resistor that is as uniform as possible. Don't be afraid to talk with other groups and alter your design as you try out different ideas!
4. Pack the Play-doh™ to ensure you don't have any voids
5. Make small marks with your knife in the Play-doh™ to identify 1cm intervals
6. Sand the ends of the metal rods to ensure good electrical contact (you are removing oxide or old Play-doh™)
7. Insert one rod about 1.0 cm into the end of the Play-doh™ resistor. This is the stationary probe. Make sure it is inserted in the middle and perpendicular to the cross-sectional area of the resistor. Support the other end by placing something under it so the probe maintains good contact with the Play-doh™

Use the following picture to set-up your Play-doh™ circuit. Length of Play-Doh™ is distance from stationary probe to moving probe.



Data:

Battery Voltage: V=_______volts

Diameter of Play-doh™ =__________meters

Area of Play-doh™ = ___________ meters^2

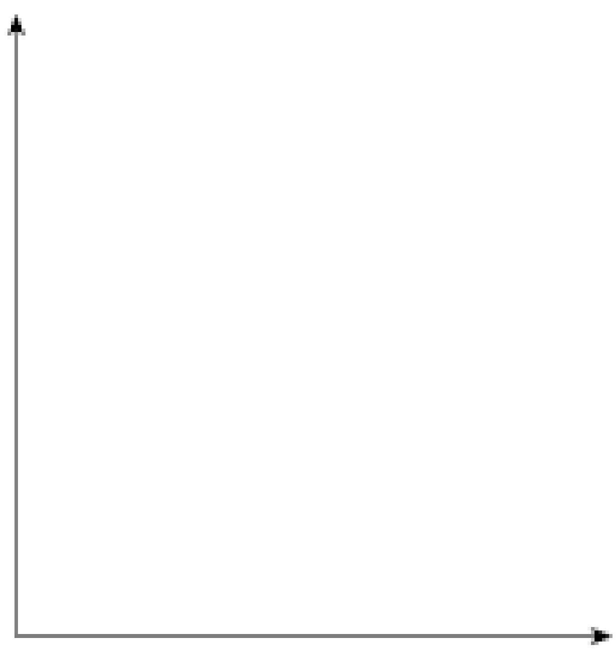
Ohm's Law: **V = IR**

V = voltage

I = current

R = resistance

Length of Play-doh™ (cm)	Current (Amps)	Resistance (Ω) Calculated



Graph: In the space to the left, create a graph of Resistance vs. Length. Make sure to properly label each axis. Draw a line or curve of best fit.

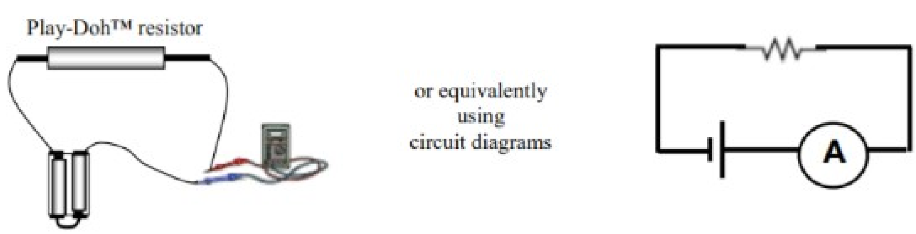
Big Question #1: How does length affect resistance? What kind of relationship is this?

Big Question #2: How does this experiment change the picture you had of the inside of the dimmer switch? Re-draw a picture below now showing what you think the inside of a dimmer looks like based upon the data you collected.

<u>LAB Part 2: Determination of the effect of Area on Resistance</u>

Since you are an old pro at this now, we will simply just offer a few words to the wise.

1. Check to make sure the battery voltage hasn't changed. If it has, write it down
2. Sand the metal probes again as they corrode quite quickly
3. Connect the circuit as shown below:



4. Push the metal rods about 1 cm into the center of each end of your Play-doh™ resistor, read the current, and disconnect the circuit immediately.
5. Be extremely careful to ensure that you are maintaining a constant length throughout the experiment. Somewhere around a constant 10cm length should be fine

Data:

Battery Voltage: V=_______volts

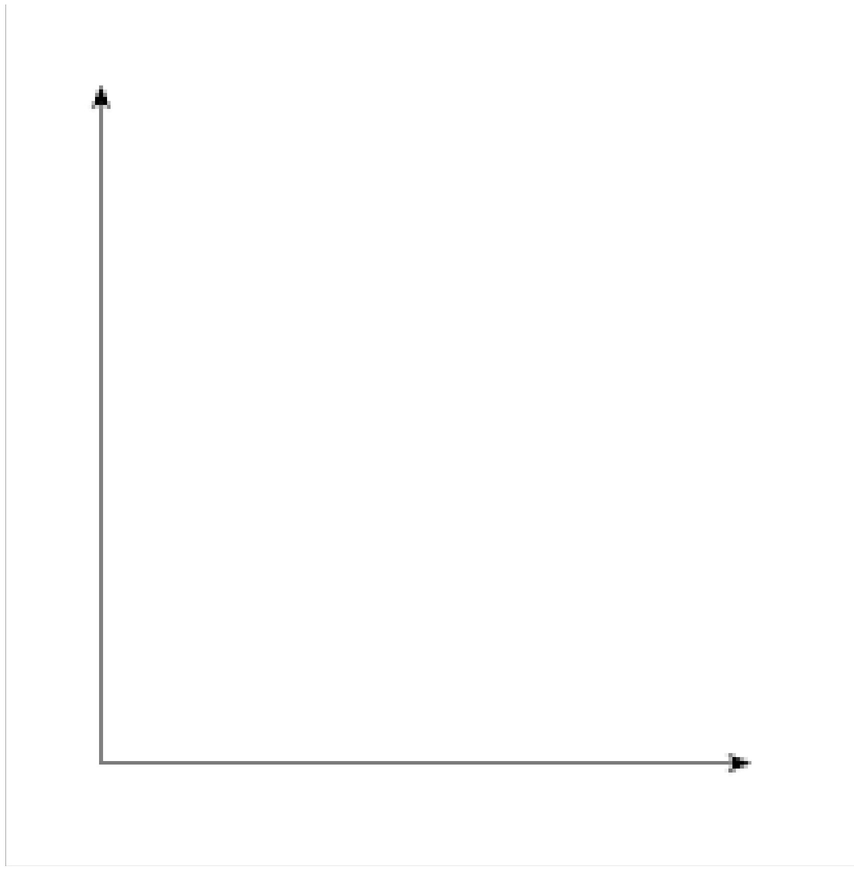
Length of Play-doh™=___________m

Cross-sectional Area of Cylinder: **$\pi \times r^2$**

Diameter = Circumference/ pi **(D = C/ π)**

Radius of one side of Play-doh™ (m)	Cross-Sectional Area (m^2)	Current (Amps)	Resistance (Ω) Calculated

Graph: In the space below, create a graph of Resistance vs. Area. Make sure to properly label each axis. Draw a line or curve of best fit.



Big
Question #1: How does area affect resistance? What kind of relationship is this?

Big Question #2: Go back to pre-lab question #6. How does this experiment alter how you answered that question? Try to improve your answer in the space below.

Part 3: Resistivity

Different Play-Doh

Using any techniques desired, conduct an experiment with the homemade Play-doh™ to determine the resistance of the Play-doh™. You should collect data that will allow you to compare it to the Play-doh™ data already collected as well as allow you to answer the questions following. Use the space below to organize your data and write down an experimental procedure.

Questions for part 3:

1. Provided each material had the same length and area, which one had a greater resistance? How can you justify this claim?

Here are the recipes for each batch of Play-doh™ used:

Play-doh™ (experiments #1 and 2)

- 1C Tap Water
- 1.5C flour
- 0.25C Salt
- 1 T Vegetable Oil

Play-doh™ (experiment #3)

- 1.5C flour
- 0.5C sugar
- 3 T vegetable oil
- 0.5C deionized or purified water

2. Based upon the ingredients, why do you suppose that experiment #3 Play-doh™ has a different resistance?

3. Draw a picture of each Play-doh™ resistor, showing an individual electron traveling through it. In your model, be sure to show the electrons as well as the molecules of play-doh. Your model should demonstrate in some way the **difference in resistance** in the two types of Play-doh™.

Part 4: TEACHER DEMONSTRATION: Effect of Temperature on Resistance

Take out the bare filament set-up. Hook up the 9V battery and turn on, checking to make sure the small light-bulb lights up. Note: The bare filament light bulb will not emit light as it requires 120V to turn on, but electricity will be flowing through it because it is connected in series to the small light. Go to a dark area in the class or turn off the lights in the room.

1. In the space below, write down your observations.

2. Now, take a straw and blow on your hand through the straw. What do you feel (hot, cold?)

3. Take the straw and gently blow on the filament. While blowing on the filament, observe the small bulb. Write down your observations here.

4. Take a lighter provided by your instructor and carefully place the tip of the flame on the filament for a second or two, so that they filament becomes orange-red. Observe the small light-bulb. Write down your observations here.

5. Make a claim (a single sentence) about the relationship between resistance and temperature.

6. Provide evidence (your observations!) from 1-4 to support your claim

7. Using your model of resistance created from the previous parts, provide reasoning to support your claim. In other words, **why** does your claim make sense from what you know about physics and what you've learned from this lab?

Part 5: Play-doh™ Dimmer Switch

Using Play-doh™, alligator clips, wire, a 9V battery, and a lightbulb, design a working dimmer switch. Your dimmer should be able to **smoothly** change the brightness of the bulb. Have your instructor approve the working design and sketch a diagram of it below, showing the physical characteristics of the circuit.

Part 6: The Ultimate Circuit Construction Challenge!

In your groups, you will be given three minutes to construct special circuits determined by your instructor. Use the space below to jot down any notes, perform any calculations, or to sketch out ideas!

Analysis Questions:

[1] There are two common gauge wires used in houses. 12 gauge wire has a diameter of 2.053mm and 14 gauge wire has a diameter of 1.628mm. Wires in houses are commonly copper. What are the advantages and disadvantages of using 12 gauge wire in your house?

[2] Based upon your experiments, create an equation for resistance which includes the resistivity, length, and area. Defend each variable using data from your experiment. When coming up with your equation, you should be using the graphs to determine direct/indirect relationships and the shapes of the graphs to determine (roughly) the power of the relationship (e.g. linear, quadratic, square root, etc.) When done, research the equation for resistance to compare. If there are any differences, state them in the space below.

[3] Examine your graph of resistance vs. length. When drawing your line of best fit, you will have noticed that the line seems to intersect with the y-axis. In other words, for a resistor of length=0, there is still some value of resistance. In terms of your circuits created, explain why this occurs.

[4] Calculate the resistance of 100m of 12 gauge wire in your house and compare it to the same amount of 14 gauge copper wire.

[5] Come up with a final draft of what the inside of the dimmer switch looks like. Think like an engineer here. Although many things can change resistance, from a [a] money, [b] practicality, [c] ease of construction, and [d] ability to accomplish the task in a small space, one choice stands out. Your dimmer switch should illustrate that you've thought about [a]-[d].

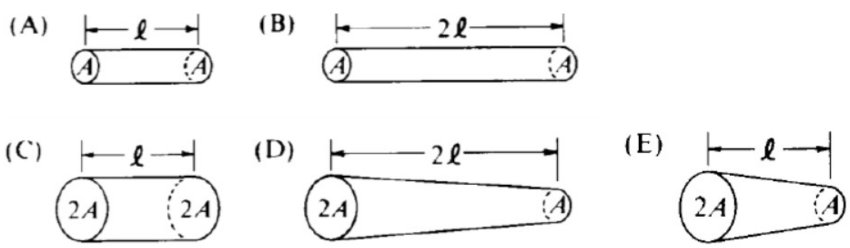
[6] Look up values for resistivity in the reference table. What materials would possibly work better in household circuits and why don't we use them? Also, why are the values given for 20 degrees Celsius? What would be different if, for example, your wires were hotter?

[7] Using the data from your lab, determine the average resistivity of your Play-doh™ (both store-bought and home-made versions).

[8] Why is tungsten the common material in the filament of a lightbulb and Nichrome the material inside the grates of a toaster? Draw what an "ideal" (the best possible design) of a super-powerful toaster (the heating element) would look like.

[9] Old fashion houses used to have fuses which would “burn up” if too much current was being drawn through a circuit in a house. Common fuses are 15 Amp and 20 Amp. Draw what the two could look like, highlighting their differences. What do fuses and circuit breakers do to prevent house fires?

[10] Rank the following from least resistance to greatest resistance:



Play-doh™ Circuits-KEY

Name: ______________________________

Partners: ____________________________

Pre-Lab:

[1] **Dimmer Switch Demo.** In the space below, write down 3 observations (not inferences!)

Observations should focus on brightness as well as the teacher turning the knob of the dimmer

[2] Attempt to draw what you think the inside of a dimmer switch must look like

Student opinion. Pay attention to these to reference later.

[3] In terms of current and resistance, how does a dimmer switch work?

When a dimmer switch makes a bulb dimmer, it is "somehow" increasing resistance and decreasing current drawn. Voltage is staying constant as it is supplied by the battery/outlet.

[4] Why do we use large (diameter) wires for power lines but small wires for the filament of a lightbulb?

Reference this question and student answers towards the end of the lab (area dependence)

LAB Part 1: Determination of the effect of Length on Resistance

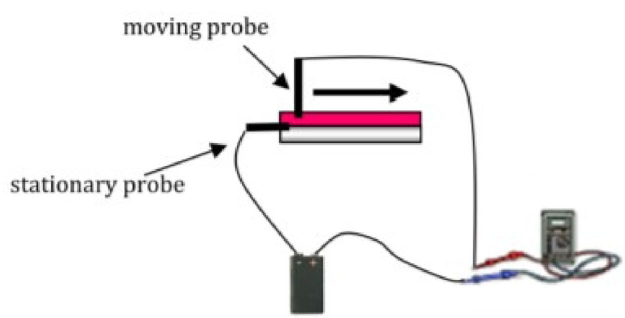
In this experiment you will alter the length of the Play-doh™ as you measure the changes in resistance.

Note: Exposure to air and current dries out the Play-doh™, which will adversely affect your measurements. Minimize the time your Play-doh™ is out of the container to keep it moist. When taking electrical measurements, take as little time as possible between measurements and immediately disconnect the circuit when you finished taking data.

Here are a few steps to consider before collecting data:

8. Measure the diameter of the Play-doh™ and ensure that it is uniform!
9. Using the a voltmeter, measure the battery voltage to ensure the battery is fully charged
10. Using any technique and materials available, design a mold to make a Play-doh™ resistor that is as uniform as possible. Don't be afraid to talk with other groups and alter your design as you try out different ideas!
11. Pack the Play-doh™ to ensure you don't have any voids
12. Make small marks with your knife in the Play-doh™ to identify 1cm intervals
13. Sand the ends of the metal rods to ensure good electrical contact (you are removing oxide or old Play-doh™)
14. Insert one rod about 1.0 cm into the end of the Play-doh™ resistor. This is the stationary probe. Make sure it is inserted in the middle and perpendicular to the cross-sectional area of the resistor. Support the other end by placing something under it so the probe maintains good contact with the Play-doh™

Use the following picture to set-up your Play-doh™ circuit



Data:

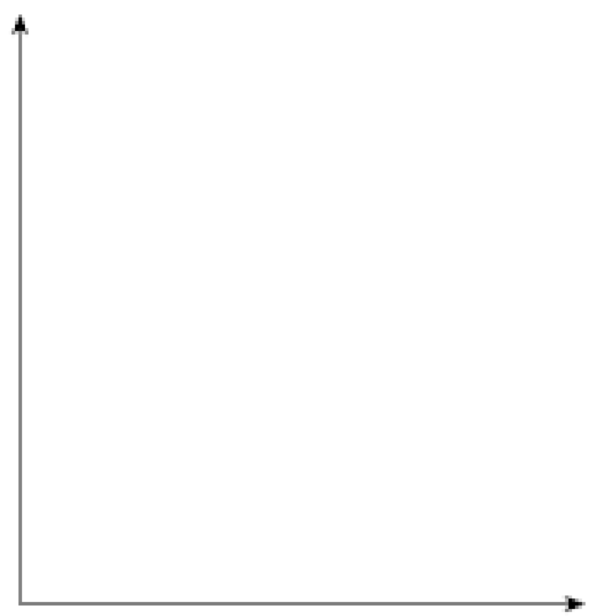
Battery Voltage: V=__3-9___volts

Diameter of Play-doh™ =____0.02-0.20_____meters

Area of Play-doh™ = _____square or circle works!____ meters^2

Length of Play-doh™ (cm)	Current (Amps)	Resistance (Ω) Calculated

Graph: In the space below, create a graph of Resistance vs. Length. Make sure to properly label axis.



Big Question #1: How does length affect resistance? What kind of relationship is this?

Direct Linear Relationship. Graph should be scatterplot of points showing direct relationship with a straight line of best fit. Line **should** intersect y-axis due to [1] contact resistance where play-doh meets metal bars and [2] resistance in wires/connections throughout circuit. This value usually ends up somewhere between 20-50Ω but can vary.

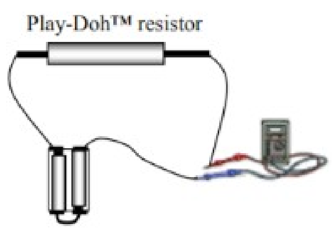
Big Question #2: How does this experiment change the picture you had of the inside of the dimmer switch. Re-draw a picture below now showing what you think the inside of a dimmer looks like.

Picture should now include some mention of length

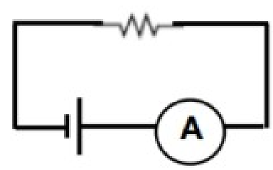
LAB Part 2: Determination of the effect of Area on Resistance

Since you are an old pro at this now, we will simply just offer a few words to the wise.

6. Check to make sure the battery voltage hasn't changed. If it has, write it down
7. Sand the metal probes again as they corrode quite quickly
8. Connect the circuit as shown below:



or equivalently using circuit diagrams



9. Push the metal rods about 1 cm into the center of each end of your Play-doh™ resistor, read the current, and disconnect the circuit immediately.
10. Be extremely careful to ensure that you are maintaining a constant length throughout the experiment. Somewhere around a constant 10cm length should be fine

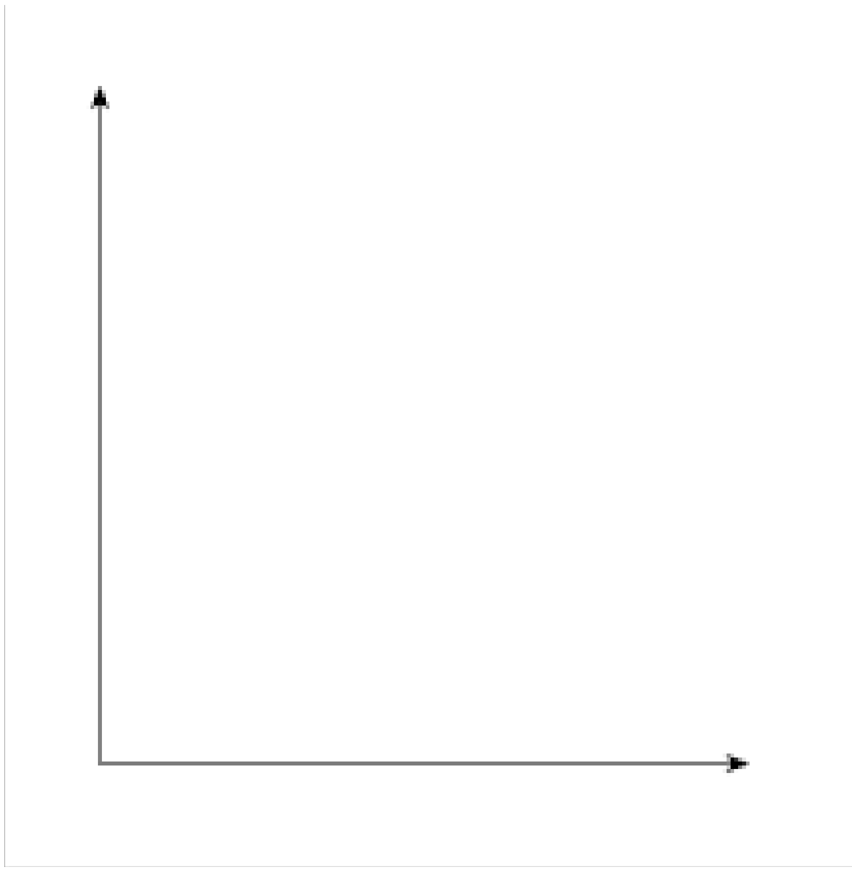
Data:

Battery Voltage: V=___Re-check to make sure V hasn't changed____volts

Length of Play-doh™=____0.05-0.20_____m

Radius of one side of Play-doh™ (m)	Cross-Sectional Area (m^2)	Current (Amps)	Resistance (Ω) Calculated

Graph: In the space below, create a graph of Resistance vs. Area. Make sure to properly label axis. Draw a line or curve of best fit.



Big Question #1: How does area affect resistance? What kind of relationship is this?

Graph should be an indirect relationship similar to graph of y=1/x. For linear looking graphs, check to make sure length has not changed and have students take a few more data points for very large and very small areas because if they only take middle data points the graph can look slightly linear (e.g. graph y=1/x and you can note that between x=.5 and x=1.0, the graph looks “relatively” linear.

Big Question #2: Go back to pre-lab question #6. How does this experiment alter how you answered that question? Try to improve your answer in the space below.

Larger Area=Less Resistance. For power lines, the less resistance, the less energy lost. For a lightbulb, we want resistance to create heat from friction effects.

Part 3: Resistivity

Using any techniques desired, conduct an experiment with the homemade Play-doh™ to determine the resistance of the Play-doh™. You should collect data that will allow you to compare it to the Play-doh™ data already collected as well as allow you to answer the questions following. Use the space below to organize your data and write down an experimental procedure.

Keep Area constant, alter length using homemade play-doh. Compare multiple data points. Graph produced should be linear as well, but steeper slope as the homemade play-doh has significantly higher resistance.

Questions for part 3:

4. Provided each material had the same length and area, which one had a greater resistance? How can you justify this claim?

MUST be based upon data here!

Here are the recipes for each batch of Play-doh™ used:

Play-doh™ (experiments #1 and 2)

- 1C Tap Water
- 1.5C flour
- 0.25C Salt
- 1 T Vegetable Oil

Play-doh™ (experiment #3)

- 1.5C flour
- 0.5C sugar
- 3 T vegetable oil
- 0.5C deionized or purified water

5. Based upon the ingredients, why do you suppose that experiment #3 Play-doh™ has a different resistance?

The salt ionizes allowing free electrons to move and electricity to be conducted easily throughout the play-doh. See http://masterconceptsinchemistry.com/index.php/2017/10/28/salt-solution-conduct-electricity-sugar-solution-doesnt/ for a resource about the chemistry of why sugar does not conduct electricity.

6. Draw a picture of each Play-doh™ resistor, showing an individual electron traveling through it. Your picture should demonstrate in some way the difference in resistance in the two types of Play-doh™.

Picture should be similar to “Plinko” idea discussed.

Part 4: Effect of Temperature on Resistance

Take out the bare filament set-up. Hook up the 9V battery and turn on, checking to make sure the small light-bulb lights up. Note: The bare filament light bulb will not emit light as it requires 120V to turn on, but electricity will be flowing through it because it is connected in series to the small light. Go to a dark area in the class or turn off the lights in the room.

1. In the space below, write down your observations.

Bare filament doesn’t light, bulb turns on, etc.

2. Now, take a straw and blow on your hand through the straw. What do you feel (hot, cold?)

3. Take the straw and gently blow on the filament. While blowing on the filament, observe the small bulb. Write down your observations here.

Small bulb gets brighter!

4. Take a lighter provided by your instructor and carefully place the tip of the flame on the filament for a second or two, so that they filament becomes orange-red. Observe the small light-bulb. Write down your observations here.

Small bulb gets dimmer

5. Make a claim (a single sentence) about the relationship between resistance and temperature.

Temperature is directly related to resistance.

6. Provide evidence (your observations!) from 1-4 to support your claim

Cold air caused the bulb to get brighter.

Hot air caused the bulb to get dimmer.

7. Using your model of resistance created from the previous parts, provide reasoning to support your claim. In other words, **why** does your claim make sense from what you know about physics and what you've learned from this lab?

Based upon the model we have developed about resistance being collisions of electrons in a material, a hotter object would have a greater resistance as the molecules of hotter objects jiggle around faster than the molecules of colder objects, thus an electron traveling through a hotter object would encounter more collisions and therefore would have a larger resistance.

Part 5: Play-doh Dimmer Switch

Using play-doh, alligator clips, a 9V battery, and a lightbulb, design a working dimmer switch. Have your instructor approve the working design and sketch a diagram of it below, showing the physical characteristics of the circuit.

Students should alter either area or length. Discuss what is easier to do. Ask students to consider what a company like GE would choose to do to have the best/cheapest solution.

Analysis Questions: (See also Lesson plan for discussion of solutions)

[1] There are two common gauge wires used in houses. 12 gauge wire has a diameter of 2.053mm and 14 gauge wire has a diameter of 1.628mm. Wires in houses are commonly copper. What are the advantages and disadvantages of using 12 gauge wire in your house?

Common examples of pros that should be identified include decreased resistance (and therefore power loss in the household) as well as less heat generated and therefore safer to use in the household. The most important con to consider is the price of copper. 12 gauge wire is significantly more expensive then 14 gauge. For example, a Lowes.com search shows that 250' of 12-2 Romex wire costs $72 while 250' of 14-2 Romex wire costs $47.

[2] Based upon your experiments, create an equation for resistance which includes the resistivity, length, and area. Defend each variable using data from your experiment. When coming up with your equation, you should be using the graphs to determine direct/indirect relationships and the shapes of the graphs to determine (roughly) the power of the relationship (e.g. linear, quadratic, square root, etc.) When done, research the equation for resistance to compare. If there are any differences, state them in the space below.

Students are to "discover" the equation $R=\frac{\rho L}{A}$ based upon the direct/indirect relationships observed. Make sure to mention that the temperature variable changes the resistivity, which is why the values given in the reference table are for 20 degrees Celsius. The key aspect is to derive the relationship from the graphs of the data, drawing the conclusions of direct and indirect relationships.

[3] Examine your graph of resistance vs. length. When drawing your line of best fit, you will have noticed that the line seems to intersect with the y-axis. In other words, for a resistor of length=0, there is still some value of resistance. In terms of your circuits created, explain why this occurs.

This corresponds to a few factors, including contact resistance between the Play-doh™ and metal leads as well as resistance in the wires in the circuit.

[4] Calculate the resistance of 100m of 12 gauge wire in your house and compare it to the same amount of 14 gauge copper wire.

Students will use the equation $R=\frac{\rho L}{A}$ to solve this problem. The resistivity is found from the reference table. The area is found from $A=\pi r^2$ where r=0.0010265m and the area=$3.31 \times 10^{-6} m^2$. Solving for resistance, the answer is 0.17Ω.

[5] Come up with a final draft of what the inside of the dimmer switch looks like.

The final draft should illustrate in some way that length is altered to create the dimming effect.

[6] Look up values for resistivity in the reference table. What materials would possibly work better in household circuits and why don't we use them?

Silver has a lower resistivity than copper and therefore would give wires lower electrical resistance. The downside of course is the price of silver, making large-scale use of it unrealistic. Silver and gold are used in select places in circuits, where the select resistivity is desired. A common example is the metal found on the charger port stuck into IPhones. If the temperature of metals is different than room temperature, the resistivity would be different (higher if hotter and lower if colder).

[7] Using the data from your lab, determine the resistivity of your Play-doh™ (both store-bought and home-made).

Students should use the equation $R = \frac{\rho L}{A}$ to solve for rho (p, resistivity) given a resistance, length, and area. The calculation is not shown here as there are far too many variables inherent in the Play-doh™ and experiment to offer an exact resistivity.
http://courseweb.stthomas.edu/apthomas/SquishyCircuits/ResistivityTesting.pdf states that the approximate resistivity of commercial Play-doh™ is 0.4Ω-m while the approximate resistivity of insulating Play-doh™ is 0.9Ω-m.

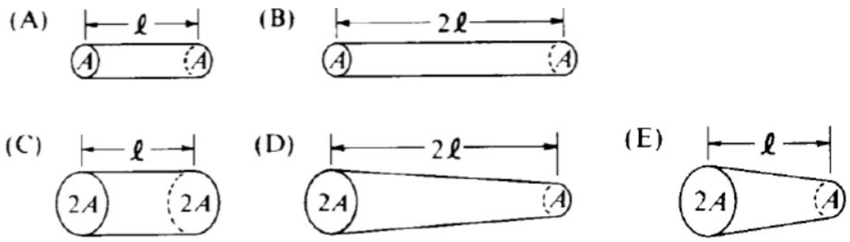
[8] Why is tungsten the common material in the filament of a lightbulb and Nichrome the material inside the grates of a toaster? Draw what an "ideal" (the best possible design) of a super-powerful toaster (the heating element) would look like.

Tungsten and Nichrome have high resistivities. Because of this, large amounts of heat are generated as electricity is passed through. The heat is harnessed for light in a lightbulb and heat in a toaster. The ideal grate in a toaster contains a very long, thin wire made of a high resistance material.

[8] Old fashion houses used to have fuses which would "burn up" if too much current was being drawn through a circuit in a house. Common fuses are 15 Amp and 20 Amp. Draw what the two could look like, highlighting their differences. What do fuses and circuit breakers do to prevent house fires?

Typically, the difference is in the thickness of the fuse. A 15A fuse is thinner than a 20A fuse, thus it burns up and opens a circuit before a thicker 20A fuse would. The drawing should illustrate the 20A fuse as thicker than the 15A fuse. Fuses and circuit breakers prevent house fires because if you are drawing too much current through the wires in a circuit, the fuse melt or the circuit "breaks" before you risk the chance that the large amount of current drawn could create enough heat to catch your walls or outlet regions on fire.

[9] Rank the following from least resistance to greatest resistance:

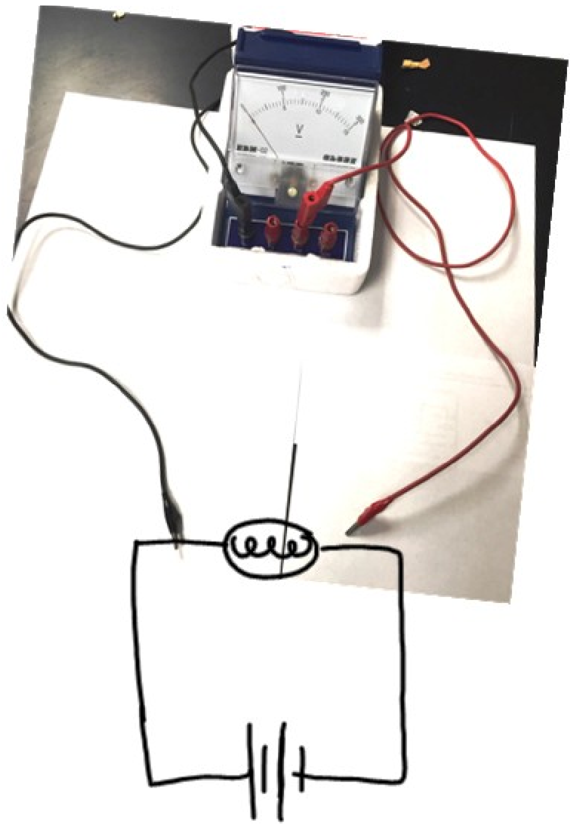


[10] **C, E, A, D, B.** This is found by taking length/area given that all are made from the same material. For the non-constant area, assume each has an average area of 1.5.

Appendix:

Connecting a Voltmeter and Ammeter Worksheet to Give to Students (optional)

Voltmeter connected in parallel



Ammeter connected in series