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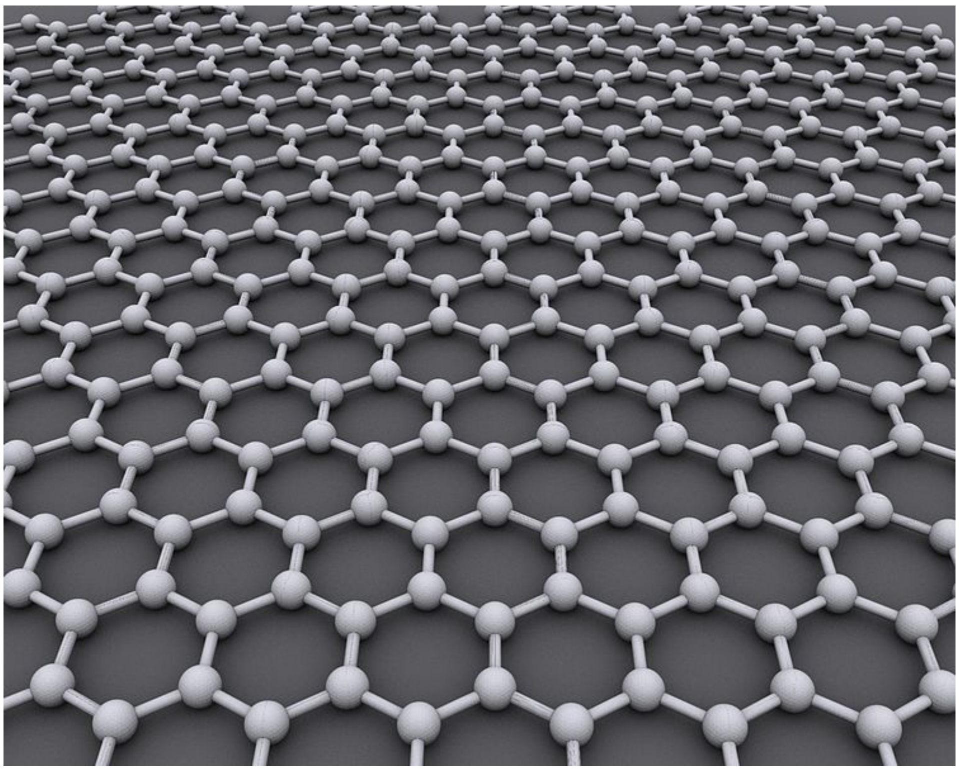
Research Experiences for Teachers (RET)



https://en.wikipedia.org/wiki/File:Graphen.jpg

Graphene-Graphite Aluminum Battery (or is it a Capacitor)

Teacher Manual

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Description:
As society moves from dependence on fossil fuels, and moves towards greener forms of energy, the demand for batteries is increasing at an enormous rate. However, most batteries that are commercially manufactured contain materials that are detrimental to the environment, explosive, made from expensive materials, and/or present a difficulty for disposal. Therefore, constructing a battery from cheap materials that are readily available, recyclable, and are less harmful to the environment is a desired. Aluminum is the third most abundant material in the Earth's crust and is exceptionally recyclable. Carbon, the only element in graphene and graphite, is the fourth most abundant element in the universe and also positively addresses the concerns of current battery materials. Recent research with these materials in a battery show a faster charge time than traditional batteries. This research module will give students exposure to current battery research. Students will construct a battery with aluminum, graphene, and graphite. Students will then be able to change some factors to try to improve the battery performance.

Learning Objectives:
- Evaluate the performance of a graphene battery by testing longevity, capability, and capacity.
- Construct a simple DC circuit with a series, parallel, and combination arrangement.
- Measure and display cell voltages and current.
- Measure the electrical energy used by an electric motor.
- Improve battery performance by testing a variety of conditions.

Prerequisite knowledge/skills:
- Basic electricity knowledge
- Wiring a series, parallel, and combination circuit
- Vernier probeware (current probe, and voltage/differential voltage probe) and Loggerpro
- Use of a saw or tin snips (a vice may be needed to straighten the cut aluminum)
- Use of a wire stripper
- Use of a rivet tool
- Use of a vacuum sealer

Duration: Two weeks (4 days for construction, 5 days for testing, 1 day to report results)

Target grade levels: 9-12

Target subjects: Freshman Physical Science, Chemistry, & Physics

Alignment with Next Generation Science Standards:

HS-PS1 Matter and Its Interactions

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

HS-PS2 Motion and Stability: Forces and Interactions

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS3 Energy

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative position of particles (objects).

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3 Earth and Human Activity

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1 Engineering Design

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Preparation time:

15-30 minutes for each day's activities. Stations may be a good idea for the first day. The instructor may want to precut the aluminum plates and drill the holes in the plates to mitigate student risk.

Preparation notes for materials and chemicals:

Tin snips may not provide the cleanest cut on aluminum, but it avoids the production of aluminum dust which can be toxic (if inhaled) and potentially explosive. Be sure to use cutting oil with the aluminum.

1.00M concentration of phosphoric acid was used for this module. If this is not readily available, dilute the concentration to the desired level.

Safety:

- Safety glasses should be worn at all times.
- Gloves should be worn when handling the graphene, graphite, polyurethane, or liquid tape.
- A fume hood is recommended for the drying of polyurethane mixtures, and liquid tape. At a minimum, a well ventilated area is required for drying processes.
- Sodium bicarbonate solution should be present to neutralize any acid spills.

Waste disposal:

- Dispose of any excess graphene or graphite in the trash. Do not allow the flake to go down the drain as it can clog pipes.
- Follow recommended disposal procedures for the polyurethane and liquid tape.
- Only a small amount of phosphoric acid is being used. Nonetheless, phosphoric acid should be neutralized with a sodium bicarbonate solution before pouring down the drain and flushed with copious amounts of water.

Materials on-hand that were not purchased:

- Phosphoric Acid
- Transfer Pipets
- 18 gauge red and grey wire
- Aviator (Tin) snips
- Small Electric Motor
- Vernier Probes (Current & Differential Voltage) and Logger Pro
- Multimeter
- Various Glassware
- Sodium Bicarbonate solution
- Safety Glasses
- Non-latex Gloves
- Technicloth® Nonwoven Wiper (model TX 609)
- Drill with ⅛” drill bit
- Flat Faced Hammer
- Small Plastic Cups
- Stir Sticks
- 60 Grit Sandpaper
- DC Power Supply

Materials/supplies/equipment needed with example source listed/pricing/CAS # and contact information

Item Description	Item Number	Quantity	Vendor	Cost per Item	Total
3pc Artist Brush Set	5618386	1	Menards	$2.49	$2.49
Alum Sheet 12"x25" (.025")	2284141	1	Menards	$9.88	$9.88
Red Female Disc 22-16 AW	3641231	1	Menards	$1.16	$1.16
Miniwax Polyurethane Gloss	5558120	1	Menards	$4.97	$4.97
Graphene Nanopowder: A-12: 3nm-5g (shipping included in price)	A-12-5G	1	Graphene Supermarket	$100.00	$112.32
Trex 35yd Tape	4007402343	1	Walmart	$7.84	$7.84
Gorilla Tape	524763200	1	Walmart	$4.97	$4.97
Food Saver 8" Roll	5389110202	1	Walmart	$8.98	$8.98
6.5g Powdered Graphite	2614737	6	Menards	$1.29	$7.74
Silver Conductive Paint, 0.5 Tr. oz.	05001-AB	1	SPI Supplies	$47.34	$47.34
Single Layer Graphene On Copper Foil: 4"x 4"	CVD-Cu-4X4	1	Graphene Supermarket	$850.00	$850.00
Tripod	81724303762	1	Walmart	$14.88	$14.88
Liquid Electrical Tape (Black)	3642851	1	Menards	$4.99	$4.99
Liquid Electrical Tape (Red)	3642853	1	Menards	$4.99	$4.99
H-D Rivet Tool Kit	2437330	1	Menards	$9.99	$9.99
8.25" Wire Stripper/Crimp-A	3643881	1	Menards	$19.99	$19.99
Total					**$1,112.53**

Notes:

- **All other supplies used in the module, but not listed in the spreadsheet, were already present in the school's stock.**
- **The graphene foil was acquired to study the effect of a single layer deposited on copper foil vs. copper foil with graphene powder painted on. This study was entirely optional.**
- **The smallest size graphene powder was ordered and most expensive. Larger sized particles can be had from the same vendor for a decreased cost.**
- **The T-Rex tape was purchased but not used.**

Background

- **Capacitors**- store electrical energy in an electric field
  - Have no voltage until charged
  - Divided into two types:
    - Fixed capacitors- specific single value of capacitance.
      - Working voltage- largest amount voltage that can be delivered to capacitor (if exceeded, capacitor will break down)
      - Two subclasses of fixed capacitors (based on dielectric)
        - Non-electrolytic
          - less than 1 μF capacitance
          - Operating voltage can be high (500V-10,000V)
          - Has high resistance or no continuity if working correctly
        - Electrolytic
          - 1μF to several hundred thousand μF capacitance
          - Operating voltage up to hundreds of volts
          - Has less resistance than non-electrolytic and depends on the working voltage
    - Variable capacitor- can have a range of capacitance values
      - Mechanically changed
      - Electronically changed
  - Examples (named after the dielectric)
    - Mylar
      - Made of thin metal-foil plates with polyester dielectric
      - Cut into long, narrow strips and rolled together into a compact unit
      - 0.001 to 1 μF capacitance
      - Working voltage as high as 1,600 volts
      - Fixed capacitor
    - Ceramic
      - Disk-shaped or tubular dielectric
      - Alternating layers of ceramic (dielectric) and metal layers
      - 5 pF to 0.05 μF capacitance
      - Working voltage can exceed 10,000 volts
      - Fixed capacitor
    - Silvered-mica
      - Made of a thin sheet of mica (dielectric) with deposited silver metal on each side
      - 1 to 10,000 pF capacitance
      - Working voltage is around 500 volts
      - Fixed capacitor
  - Aluminum, niobium, or tantalum electrolytic (named after anode electrode)
    - Natural aluminum oxide layer acts as dielectric
    - Electrolyte can be wet, solid manganese dioxide, or solid polymer

- Supercapacitors (without traditional solid dielectric)
    - Double-layer capacitors
        - Collector made from metal foil (outside layer)
        - Activated carbon, graphene, carbon nanotubes, or carbon aerogel as electrodes (connected to collector)
        - Wet electrolyte between double layer electrodes
        - Separator- ion permeable membrane in electrolyte
    - Pseudocapacitors
        - Transition metal oxide or conducting polymer electrodes
        - Store electrical energy faradaically by electron charge transfer between electrode and electrolyte
        - High electrochemical pseudocapacitance
    - Hybrid capacitors
        - Asymmetric electrodes,
            - One electrode shows electrostatic capacitance
            - Other electrode exhibits electrochemical capacitance
- Testing the capacitors (make sure to remove or isolate it from the circuit to test)
    - Make sure to fully discharge capacitor before testing
        - Capacitance setting on a multimeter (compare value to stated value on capacitor)
        - Ohmmeter
            - If testing non-electrolyte capacitor
                - High resistance- moves from zero to almost infinite ohms when testing
                - Low resistance- leaky or shorted (should be replaced)
            - If testing an electrolytic capacitor
                - Make sure the ohmmeter uses less than the working voltage of the capacitor
                - Must be connected to the correct polarity
                - Lower resistance than non-electrolyte capacitor
        - Continuity tester (nonelectrolyte capacitor only)
            - No continuity- working correctly
            - Continuity- leaking or shorted (should be replaced)
        - Continuity tester (variable capacitor)
            - Connect an ohmmeter to its terminals
            - Slowly turn the shaft as far as it will go in both directions.
            - If the capacitor shows continuity at any point, it is shorted at that point.

- **Batteries**- store energy in chemical form
    - Basic design
        - Cathode- positively charged electrode
        - Anode- negatively charged electrode
        - Salt bridge- electrolyte separator between the cathode and anode
    - Primary- single use battery, cannot be recharged
    - Secondary- can be recharged
    - Types
        - Carbon-zinc cell
            - Oldest and most widely used
            - Primary batteries only
            - Portable energy source
            - Electrolyte is a paste of ammonium chloride and zinc chloride dissolved in water contained in the bobbin of the cell
            - Negative electrode is a zinc can
            - Positive electrode is a mixture manganese dioxide and powered carbon
            - Solid carbon rod provides a good electrical contact between the positive electrode and the positive terminal of the cell.
            - Sizes and Voltage
                - Open-circuit voltage of from 1.5 to 1.6 volts
                - Multiple cells are multiples of 1.5 volts
            - Operating efficiency is ideal when used for short periods of time at relatively low currents
        - Alkaline Cells
            - Electrolyte is potassium hydroxide
            - Negative electrode is zinc
            - Positive electrode is manganese dioxide
            - Sizes and Voltage
                - Open-circuit voltage of 1.5 volts
                - Multiple cells are multiples of 1.5 volts
            - Can be made to be primary and secondary batteries
        - Nickel-Cadmium Cell
            - Secondary battery
            - Potassium hydroxide electrolyte
            - Negative electrode is nickel hydroxide
            - Cadmium oxide positive electrode
            - Sizes and Voltage
                - Open-circuit voltage is 1.25 volts.
                - Common sizes have voltages of 6, 9.6, or 12 volts.
            - Can handle extreme conditions of shock, vibration, and temperature

        - Lithium Ion
            - Secondary battery
            - Very expensive
            - Electrolyte is a lithium salt in an organic solvent (highly flammable)
            - Graphite negative electrode
            - Positive electrode is lithium cobalt oxide, lithium iron phosphate, or lithium manganese oxide
            - Can be made in multiple shapes
            - Can operate over a wider temperature range with higher energy densities than NiCD batteries
- **Voltage (V)**
    - Electric potential energy per unit charge
    - Electromotive force
    - Measured in joules per coulomb (volts)
    - The voltage difference of an electric current between point A and point B is measured by finding the work, per unit charge, required to move the charge between the points, working against the electric field
- **Electric current (I)**
    - Rate of flow of an electric charge
    - Current moves from positive to negative, the opposite direction as the electrons
    - Measured in coulombs per second (amperes)
    - Gives energy to whatever mechanism is attached to a circuit
- **Resistance (R)**
    - Tendency to resist the movement of current through an object
    - Measured is ohms
- **Ohm's Law**
    - $V = IR$
    - The current through a conductor between two points is directly proportional to the voltage across the two points.

Preliminary Questions

1. What is voltage? How is it measured?
   Voltage is the electromotive force or potential difference. It is measured as the ratio of work done per unit charge (volts).
2. What is the difference between a battery and a capacitor?
   A battery stores energy in a chemical redox reaction, while a capacitor stores energy in an electrical field.
3. Why does a battery require an electrolyte?
   The electrolyte allows charge to flow from the positive and negative plates.
4. What are the two ways to increase the current in a circuit?
   Current can be increased by increasing voltage or decreasing resistance.

Procedure/activity: <u>Construction of the Graphene Battery (Day 1)</u>

Use protective eyewear during all steps!

Figure 1

Step 1: Cut aluminum into a 2in. x 4in. rectangle using a saw or shears. Once you cut the aluminum grind the sides to get rid of any of the sharp edges or burrs (**Figure 1**).

Step 2: Drill an ⅛” hole in the aluminum plate towards a short edge as seen in **Figure 2**. The rough edges of the hole may need to be sanded.

Figure 2

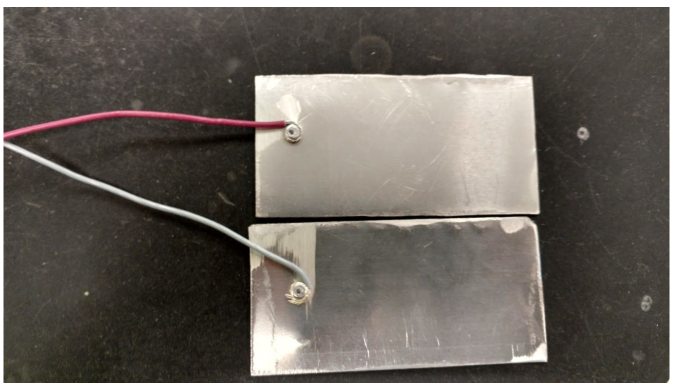


Figure 3

Step 3: Strip two wires, one red (positive) and one grey (negative) about ¾” to 1”. Twist the red wire and the stripped wire around a 1/8” x 3/16” rivet. Use a rivet tool and rivet the wire to the plate (**Figure 3**). Repeat for the grey wire. Note: Black is customarily used for the negative wire.

Step 4: Flip the plates over to expose the other side of the rivet. Using any flat faced hammer, pound the opposite side of the rivet flat into the aluminum plate as in **Figure 4.**

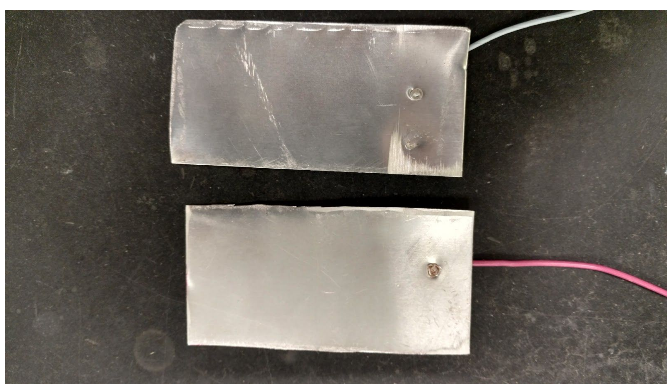


Figure 4

Step 5: Using a piece of 60 to 80 grit sandpaper, sand the aluminum plate on the side opposite of the wires. Sand the aluminum in a circular motion (**Figure 5**). Make sure that the surface is rough. The surface has to be rough to increase adhesion so the polyurethane will stick to the aluminum.

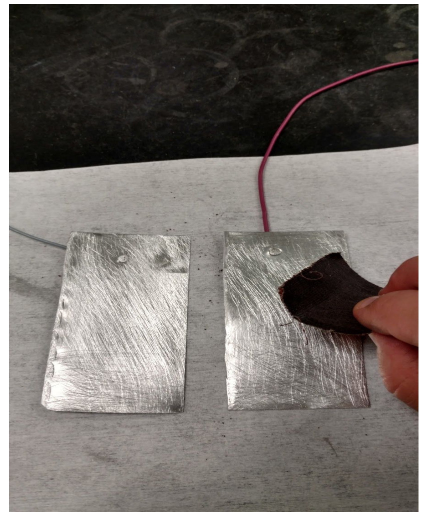


Figure 5

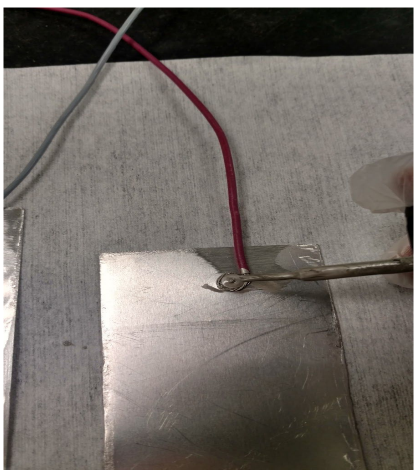


Figure 6

Step 6: (optional, but highly recommended): Use silver conductive paint around the rivet and plate to ensure a good electrical connection between the rivet, aluminum plate, and electrical wire (**Figure 6**). Note: If this step is used, the paint must dry before going onto the next step, so this will be the stopping point for Day 1.

Figure 7

Step 7: It is important make sure there is not any exposed aluminum if an acid based electrolyte is used. **Put on gloves for this step.** Liquid tape is used on the side of the plate connected to the wire. Red liquid tape is used for the positive plate and black liquid tape is used for the negative plate. Cover the plates completely as in **Figure 7** and **Figure 8**. Note: Multiple coats may be needed to ensure entire coverage.

Figure 8

Construction of the Graphene Battery (Day 2):

Use gloves and protective eyewear during all steps!

Figure 9

Step 8: Scoop out a small amount (less than 0.5 g) of graphene flake into a mixing dish (**Figure 9**). Add polyurethane sparingly to coat the graphene flake. Mix the graphene and polyurethane until you get a uniform mixture that when painted on the plate will give a uniform distribution (**Figure 10**). (Put on gloves to perform this step, polyurethane should not get on your skin. In the event it does wash your skin with soap and water as soon as possible.)

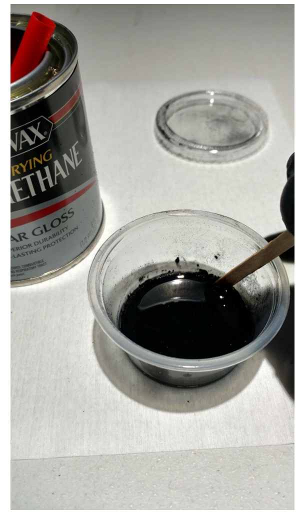


Figure 10

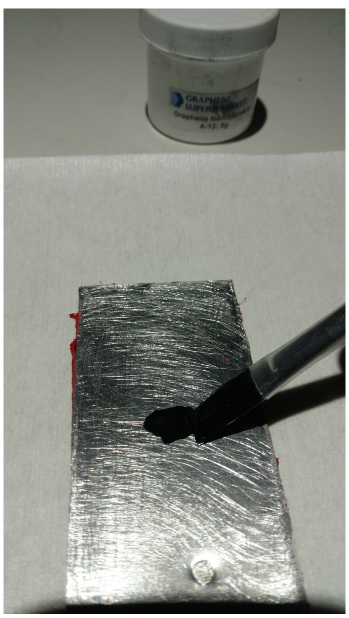


Figure 11

Step 9: Paint the graphene mixture on the sanded-side of the aluminum plates (**Figure 11**). Ensure that there is complete coverage of the paint over the plate (**Figure 12**). Let dry for four hours. Recoat if bare spots exist.

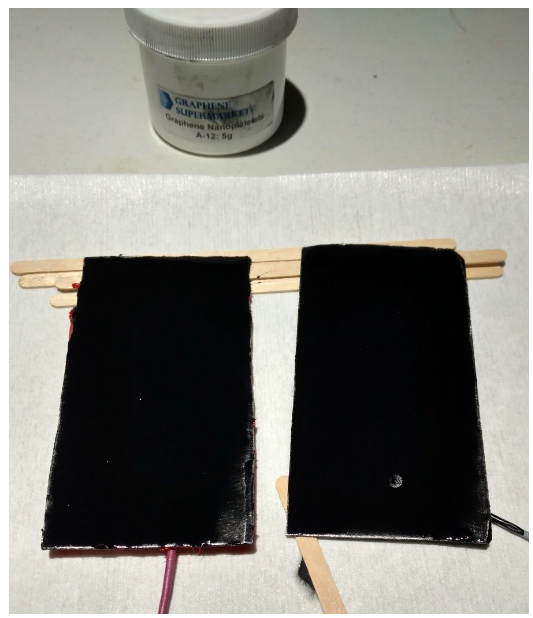


Figure 12

NOTE: These plates may be carefully transferred to a fume hood for drying.

Go to the Battery simulation link and complete the simulation:
https://interactives.ck12.org/simulations/chemistry/redox-reaction/app/index.html?lang=en&referrer=ck12Launcher&backUrl=https://interactives.ck12.org/simulations/chemistry.html

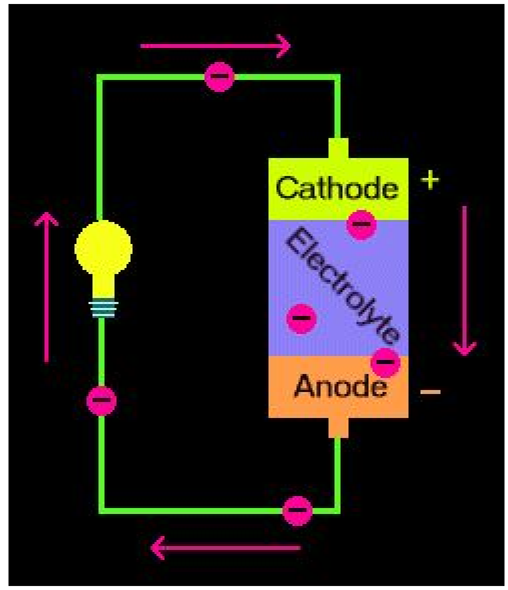
Answer the following questions on the next page.

<u>Simulation Questions</u>

Answer these in your own words:

1.) Describe how a battery works. Include a diagram and label it.

The battery consists of a cathode, anode, and an electrolyte. The cathode loses electrons to the anode. The electrolyte allows for the transfer of charge between the cathode and anode. When a battery is connected to a circuit, the electrons move the from the anode to the cathode to make both electrically neutral.



http://www.qrg.northwestern.edu/projects/vss/docs/media/Power/battery.gif

2.) Why are some batteries rechargeable?

The redox reaction which provides energy to the battery is reversible. Batteries that are not rechargeable only experience a single direction reaction.

3.) Describe how current flows from a battery through a completed circuit.

Current is traditionally thought to move from positive charge to negative charge. This is opposite of the flow of electrons which is from anode to cathode.

4.) Draw a diagram of a battery connected to a light. Be sure to label all parts and show the flow of the current.

See answer to #1

5.) Describe how to connect an ammeter (measures current) and a voltmeter (measures potential difference) to the circuit above.

A voltmeter is connected in parallel to what is being measured, while a ammeter is connected in series to the circuit.

<u>Construction of the Graphene Battery (Day 3):</u>

Use gloves and protective eyewear during all steps!

Figure 13

Step 10: Repeat the process in steps 8 & 9 replacing the graphene flake with powdered graphite. Add a small amount (less than 0.5 g) of graphite powder into a mixing dish (**Figure 13**). Add polyurethane and mix until it is uniform (**Figure 14**).
<u>Remember:</u> Add polyurethane sparingly to coat the graphite. Mix the graphite and polyurethane until you get a uniform mixture that when painted on the plate will give a uniform distribution.

Figure 14

Step 11: Add a coat of the graphite mixture to the same side as the graphene painted side. Ensure that there is complete coverage of the paint over the plate Let dry for four hours. Recoat if bare spots exist. NOTE: These plates may be carefully transferred to a fume hood for drying.

Step 12: Let dry overnight. NOTE: These plates may be carefully transferred to a fume hood for drying.

Complete the webquest on the next page for homework.

<u>Webquest</u>

<u>Use an internet search to obtain the answers to the following questions (in your own words):</u>

1) What is a capacitor?

A passive two-terminal electrical component used to store electrical energy temporarily in an electric field.

2) What does an ohmmeter test?

An ohmmeter tests electrical resistance.

3) What is voltage?

Electrical potential energy per unit charge. It is Measured in Joules.

4) How is voltage calculated (Hint: Ohm's Law)?

Voltage(V)=Current(I) x Resistance(R)

5) What is a battery?

Batteries store an electrical charge that can be discharged to power an electrical device.

6) What are the three types of capacitors, and what is the capacity and voltage ratings?

   a) **Mylar capacitors, capacity->0.001 to 1 microfarad, up to 1,600 volts**

   b) **Ceramic Capacitors, capacity->5 picofarads to 0.05 microfarad, exceeds 10,000 volts**

   c) **Silvered-Mica Capacitors, capacity->1 to 10,000 picofarads, up to 500 volts**

For questions 7-9, go to http://www.batteryeducation.com/2006/04/battery_degrada.html

7) What is cell oxidation?

When the cells of a battery lose their electrons.

8) What are the main causes of declining capacity?

The main causes are ageing, usage, and lack of maintenance.

9) What is internal resistance?

It is a measure of opposition to a sinusoidal electric current.

<u>Construction of the Graphene Battery (Day 4):</u>

Use gloves and protective eyewear during all steps!

Step 13: Cut a Technicloth® Nonwoven Wiper (model TX 609), to a piece that is 2 ¼” x 8 ¼”. Fold the cut piece in half (**Figure 15)**. Note: A thicker paper towel or cardboard may be used to hold the electrolyte. The wiper should be cut slightly larger than the aluminum plates.

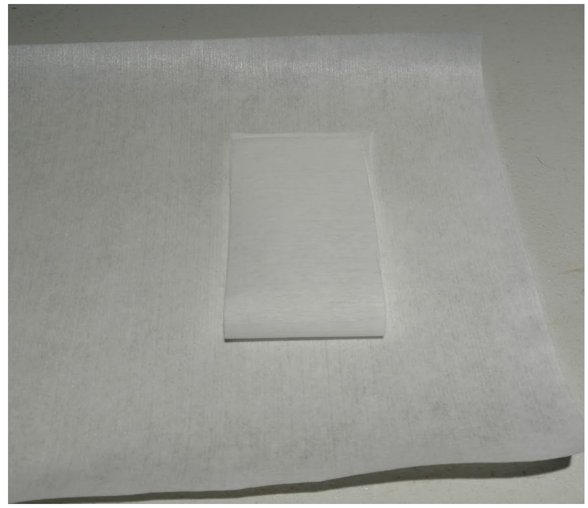


Figure 15

Note: The wiper holds the electrolyte but also prevents the plates from touching directly. If the two plates touch directly, your battery will deplete very quickly.

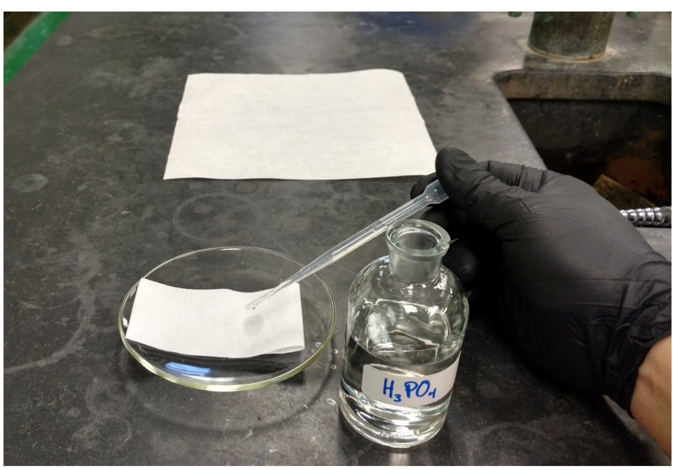


Figure 16

Step 14: Use a transfer pipet to add phosphoric acid to the cut wiper (**Figure 16**). Wet the wiper completely, but do not oversaturate the wiper so that it drips out. It may be a good idea to practice this step with water first to get an idea how much the wiper will hold.

Note: If any of the phosphoric acid solution spills, neutralize it immediately with sodium bicarbonate (baking soda). If any get on your hand, run your hands under a continuous stream of water for 15 minutes.

Step 15: Center the electrolyte infused wiper between the aluminum plates (**Figure 17**).

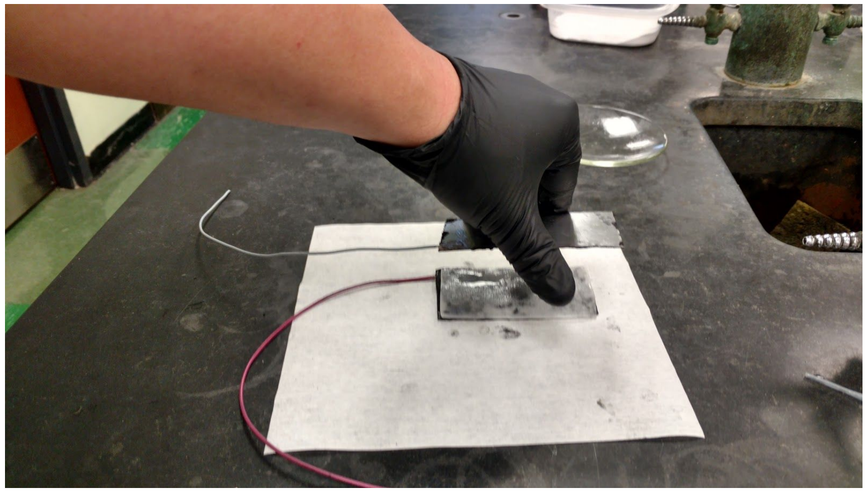


Figure 17

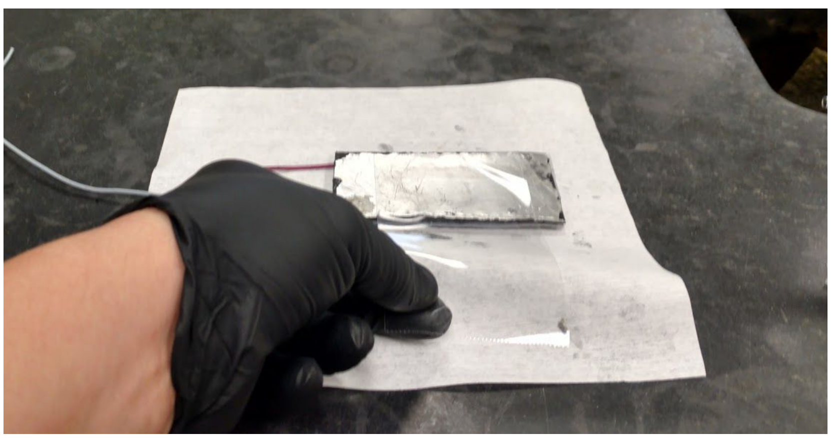


Figure 18

Step 16: Use a few pieces of packing tape to hold everything together so the next step is easier (**Figure 18**).

Figure 19

Step 17: Place the apparatus into a vacuum sealing bag, and vacuum seal shut the battery (**Figure 19**). When sealing the battery allow a the positive and negative wires hangout of the vacuum seal. You will need these wires to connect to your motor. Be sure to vacuum seal both sides of the battery. Strip the wires that protrude from the vacuum bag.

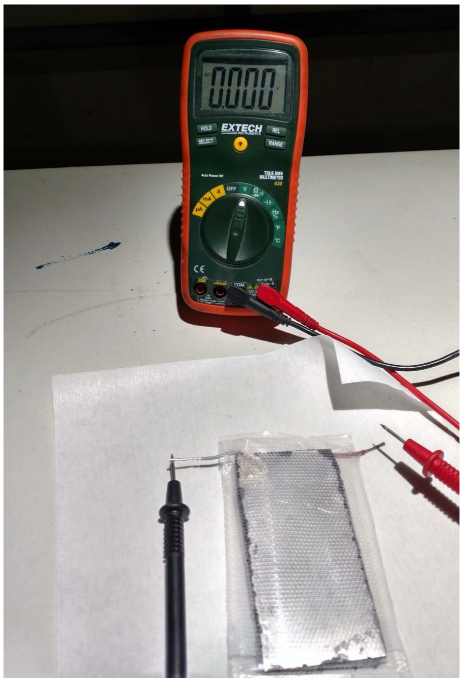


Figure 20

Step 18 (optional): Connect to a voltmeter to see if there is any initial voltage (**Figure 20**).

<u>Independent Research Opportunity</u>

The following experimental conditions can be changed from the original setup and studied for efficacy:

Electrolytes:

1. Sodium chloride solution
2. Potassium hydroxide solution
3. Acetic acid solution
4. Other acid solution
5. Dry electrolyte

Plates:

1. Copper plate (wires can be soldered)
2. Stainless steel plate (wires can be soldered)
3. Copper foil with graphene deposited

Polyurethane mixed with:

1. Graphene flake only
2. Graphite powder only
3. 50%-50% graphene flake & graphite powder

Binding Agent: use paraffin wax instead of polyurethane

Concentration of the electrolyte: (initial concentration is 1.00M H_3PO_4)

1. Weaker concentration than initially used (diluted with water)
2. Stronger concentration than initially used

Thickness of electrolyte medium (initial condition was two layers)

1. Single layer of Technicloth® nonwoven wiper (cut the piece in half)
2. Four layers of Technicloth® nonwoven wipers (cut the piece twice as large and fold twice)

Testing of the battery procedure:

Step 1: Connect the battery to a DC power supply. Charge the battery for 10 sec with at 1.5 volts. Record the charge time in the table.

Step 2: Hook it up to a small motor and single switch (start: open) in series to the battery.

Step 3: Attach a Vernier voltage probe or potential difference probe across the battery.

Step 4: Attach a Vernier current probe to the circuit.

Step 5: Close the switch and start the data collection for current and potential difference. Make sure the data collection time is fairly long to measure full battery depletion time. Save the data and graphs.

Step 6: Record the data in a data table. See the sample chart below.

Step 7: Repeat steps 1-6 for a minimum of 30 times and record the data.

Step 8: Change the battery charge time to 20 seconds, 30 seconds. Complete 30 trials for each new condition.

Step 9: Change the charge voltage to 3.0 volts for 10 seconds, 20 seconds, and 30 seconds. Complete 30 trials for each new condition.

Date:

Voltage	Charge Time	Battery Depletion Time

Independent Research Opportunity: Come up with a new condition, including multiple batteries, to test and conduct the research. Indicate the conditions below and record the findings in a data table.

Post Research Assessment:

1. Report the average and standard deviation of the depletion time for each condition tested.
   Answers will vary.

2. What do you think are the advantages of making a battery out of aluminum, graphene, and graphite?
   The materials are recyclable, materials are readily available, less charge time, and less hazardous than current materials.

3. What do you think are the disadvantages of making a battery out of aluminum, graphene, and graphite?
   The voltage may be lower than current battery materials. Graphene is very expensive since it is not a commonly manufactured material.

4. What were some of the challenges in the construction and testing of the battery?
   Answers will vary.

5. What would do you suggest to mitigate the challenges in the construction and testing of the battery?
   Answers will vary.

6. Did you make a battery or a capacitor? Justify your response with evidence.
   Answers will vary.

7. Attach a representative graph and data table for each test condition.
   Answers will vary.

Post Research Questions (Part B):

1. What is the highest voltage for the battery?
   Answers will vary.

2. What conditions provided the highest voltage?
   Answers will vary depending on conditions tested.

3. How does the graphene battery compare to these other batteries?
   Answers will vary depending on conditions tested.

Type	**Zinc–Carbon**	**Alkaline**	**RAM**	**Li-FeS_2**	**Li-ion**	**NiCd**	**NiMH**	**NiZn**
IEC name	R6	LR6	LR6	FR6	?	KR6	HR6	ZR6
ANSI/NEDA name	15D	15A	15A	15LF	14500	1.2K2	1.2H2	?
Capacity under 50 mA constant drain	400–1700 mAh	1800–2600 mAh	1800–2600 mAh	2700–3400 mAh	600-840 mAh	600–1000 mAh	600–2850 mAh	1500–1800 mAh
Nominal voltage	1.5 V	1.5 V	1.5 V	1.5 V	3.6-3.7 V	1.2 V	1.2 V	1.6-1.65 V
Max. energy at nominal voltage and 50 mA drain	2.55 Wh	3.90 Wh	3.90 Wh	5.10 Wh	2.88-2.96 Wh	1.20 Wh	3.42 Wh	2.97 Wh
Rechargeable	No	Some	Yes	No[8]	Yes	Yes	Yes	Yes

Chart source: https://en.wikipedia.org/wiki/Comparison_of_commercial_battery_types

4. What is the current output (in milliamps) of the aluminum-graphene-graphite battery?
   Answers will vary depending on conditions tested.

Links to the research articles and other resources:

Aluminum battery from Stanford offers safe alternative to conventional batteries:
https://news.stanford.edu/2015/04/06/aluminum-ion-battery-033115/

Stanford engineers create a low-cost battery for storing renewable energy:
https://news.stanford.edu/press-releases/2017/02/07/stanford-engineerenewable-energy/

A step towards new, faster-charging, and safer batteries:
https://www.sciencedaily.com/releases/2016/04/160405175659.htm

Stanford Aluminum-Ion Battery:
https://www.youtube.com/watch?v=ZKIcYk7E9lU

Aluminum Ion Battery:
https://en.wikipedia.org/wiki/Aluminium-ion_battery

Graphene and Batteries:
https://www.graphene-info.com/graphene-batteries

Graphene-Based Supercapacitors Could Lead To Battery-Free Electric Cars Within 5 Years:
http://www.iflscience.com/technology/graphene-based-supercapacitors-could-eliminate-batteries-electric-cars-within-5-years/

Samsung's 'graphene ball' battery could lead to fast-charging EVs:
https://www.engadget.com/2017/11/29/samsung-graphene-ball-battery-fast-charging/

Measurement of the quantum capacitance of graphene
https://www.nature.com/articles/nnano.2009.177

Capacitance of carbon-based electrical double-layer capacitors
https://www.nature.com/articles/ncomms4317

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The *nano@illinois* Research Experience for Teachers (RET) at the University of Illinois at Urbana-Champaign (from 2014-2017) exposes a diverse set of in-service and pre-service science, technology, engineering, and mathematics (STEM) teachers and community college faculty from across the nation to cutting-edge research in nanotechnology. The RET focuses on recruiting underrepresented minority populations (focused on ethnicity, geography, disability, and veteran status) including women and will target teachers from high-need areas, including inner city, rural, low-income, and those with significant URM students. Participants conduct research over 6 weeks in world-class labs with 4 follow-up sessions during the school year.

Teacher professional development opportunities includes teacher-focused lectures, mentoring, networking, poster sessions, ethics seminars, hands-on modules, STEM education issues, career choices, and resources for implementing a nano lab and curriculum. Teachers will develop modules to be disseminated widely and present their results. High-quality follow-up sessions and evaluation will be infused.

The nano@illinois Research Experiences for Teachers (RET) is managed by the University of Illinois Center for Nanoscale Science Technology.

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