XPLORLABS

PORTABLE ELECTRICAL POWER

EDUCATOR

THERMAL TEST

CASE STUDY OF SCIENCE AND ENGINEERING

SCIENTISTS ASK WHY. ENGINEERS ASK HOW.

AGE GROUP
Middle School

CATEGORY
Electrical Power

COMPLETION TIME
3 Class Periods

QUESTIONS TO XPLORE

HOW CAN WE PROTECT PEOPLE AND COMPONENTS FROM THAT HEAT?

WHAT IS THERMAL RUNAWAY AND WHAT DOES HEAT HAVE TO DO WITH IT?

As we discovered in Investigation 1, safety scientists ask why a phenomenon happens. Safety engineers ask how they can solve the problem and keep people safe. Both ask how they can design and communicate solutions.

We know that the development of any technology can lead to unintended consequences and new safety risks, particularly when these advances are fully integrated into everyday life; and battery technology is no different. Safety science research and testing is a crucial way manufacturers can develop and build batteries safely for use in emerging applications. Because lithium-ion batteries are the leading rechargeable battery for consumer electronics and electric vehicles, and are a rapidly growing source for energy storage, it is important that safety standards continue to evolve. This evolution drives safer commercial use as lithium-ion batteries power more products and are more widely used in daily devices.

THE CHALLENGE

Now that each team has done the tensile testing and constructed an enclosure, can it pass the final safety test? Students will test their hoverboard enclosure and battery pack for thermal performance to the hoverboard safety standard. They will determine whether or not the battery pack maintains normal operating temperatures and/or exceeds maximum temperature rise.

Hoverboard Part	Maximum Temperature Rise Allowed
Enclosure	May not exceed 7°F
Battery Pack Interior	May not exceed 5°F

EDUCATOR

PROBLEM TO BE SOLVED

From Investigation 2 students now have a hoverboard enclosure that will hold the required weight and has the durability to stand up to daily use. Now students will focus on thermal performance by asking does the enclosure keep the battery safe while at the same time not overheating internally or overheating the parts that are handled by the user? If not, what changes or modifications can be made to the design?

SUMMARY OF LAB

Safety Engineers follow a set of standards when evaluating products and components for safety. Standards are rigorous requirements that determine performance, may establish size or shape or capacity of a product, process, or system. As examples, standards help ensure the same size screw can be purchased anywhere in the world, that a light bulb bought at any store fits a socket in anyone's home, and plugs for electrical appliances fit outlets. With standards, our homes, workplaces, and public buildings are safer from collapse, fire, and explosion.

In this Investigation student groups will use their hoverboard enclosure with the battery pack installed as it was designed in Investigation 2 to determine if the heat transmission through the enclosure, as well as the heat generated inside the enclosure, meet safety standard requirements for thermal performance.

XPLORING THE ISSUE

BACKGROUND INFORMATION FOR EDUCATOR

A critical concern is that a small percentage of lithium-ion batteries experience internal short circuits that result in thermal runaway – the rapid buildup of heat within the battery that leads to the explosive release of energy or fire. There are three potential causes of heat generation in lithium-ion batteries:

- An improper load, one example is overcharging or over-discharging the battery.
- Heat can also be generated from inside the battery cell by an internal short circuit.
- Unsafe heat generation can also occur when the surrounding environment overheats the battery, such as motors and energy-producing components.

In all three cases when the heat generation inside the battery exceeds the battery's ability to keep the energy inside it, the result will be thermal runaway. Thermal runaway is when the separation between the positive and negative electrodes in a battery breaks down and the chemicals uncontrollably mix causing heat. That heat causes more heat and when this happens, the battery will typically catch fire, rupture, or explode.

Safety scientists and engineers examine and analyze thermal runaway causes to gain a better understanding of how these batteries react to heat conditions, which is important because all lithium-ion battery safety issues involve heat generation.

As we learned in Investigation 2, a product's enclosure provides physical protection for the battery pack and it is also very important that the enclosure does not trap too much heat, creating a situation where a person could get burned. In this Investigation we will be learning about the consequences of trapping too much heat inside the enclosure and how that heat combined with other heat-generating components can possibly lead to thermal runaway.

Established technologies such as lithium-ion batteries are considered safe today, with a very small rate of failure, because those consequences of use were sought out, identified, and overcome. However, any technological advance will pose some risks in use, like thermal runaway.

Thermal runaway in a battery can occur when the temperature is increased (this can come from inside the battery or an outside source) inside the battery resulting in a release of energy that further increases the temperature. Imagine an avalanche.

Thermal runaway happens when the separation between the positive and negative electrodes breaks down and the chemicals mix in an uncontrolled manner, causing heat to develop. That heat causes more heat – doubling with every 10 degrees Centigrade – and causing the electrochemicals to act in a way you don't expect with catastrophic impact (burning, melting, popping, and in extreme cases, exploding!

DREAMLINER CASE STUDY

Burning and smoking lithium-ion batteries led to the decision to ground 50 Dreamliner airplanes — a dramatic step taken by the National Transportation Safety Board (NTSB) because of the uncertainty around the batteries used as primary backup source for the aircraft.
In this case, the NTSB chose UL to conduct a comprehensive investigation led by UL's safety scientists and engineers. Many other safety scientists and engineers worked with UL to complete a comprehensive forensic analysis on the Boeing 787's battery and cells. Their findings were:

"The NTSB determines that the probable cause of this incident was an internal short circuit within a cell of the APU [Auxiliary Power Unit] lithium-ion battery, which led to thermal runaway that cascaded to adjacent cells, resulting in the release of smoke and fire. The incident resulted from Boeing's failure to incorporate design requirements to mitigate the most severe effects of an internal short circuit within an APU battery cell and the FAA's failure to identify this design deficiency during the type design certification process." (NTSB's Incident Report, (2013) Probable Cause).

MATERIALS

- From Investigation 2 – hoverboard enclosure designed/built/tested by group
- Bundle of 4 handwarmers, activated 30-45 minutes prior to use* – use a rubber band to bundle the handwarmers
- Meat thermometer
- Infrared thermometer or other surface thermometer that reads over 140°F
- One can of soup weighing 16-18 oz**
- Or student XplorLab pages

NOTES

*The handwarmers will reach peak temperature in approximately 30-45 minutes after being activated (taken out of packaging). Each group will need 4 handwarmers. Make sure to activate them prior (30-45 minutes) to the thermal testing, but no sooner as they will begin to drop in temperature after approximately 60-90 minutes.

For battery placement phase within the hoverboard enclosure, the handwarmers can be handled in the packaging without activating them.

Once handwarmers are activated (taken out of packaging), limit handling because the more the handwarmer is handled the faster the heat dissipates.

When bundling the battery pack (handwarmers) with the rubber band, be sure not to wrap them too tightly.

It is acceptable to place the handwarmers individually inside the enclosure, but see where the students take this and if they bring it up in their design.

**A can of soup weighing 16-18 oz. was selected to represent the shape and weight distribution of a person standing on a hoverboard. The weight of 16-18 oz. was selected to be relative to the size of the hoverboard enclosure. If you have access to weights or other materials, feel free to substitute.

The digital thermometers are recommended because they measure over 100°F, unlike many non-digital thermometers

MATERIALS

SAFETY CONSIDERATIONS

Handwarmers peak around 140°F

Do not puncture or open the handwarmers

HELPFUL TIPS

When handwarmers are handled, for instance held in closed hands, they lose their heat. In order to get the best thermal test, it is best not to handle the handwarmers more than necessary.

When creating a battery pack bundle, it is best to loosely rubber band them together, if the rubber band is too tight the meat thermometer cannot be inserted in the middle of the battery pack (handwarmers) without damaging the handwarmers.

The meat thermometer is the best instrument when measuring the internal heat of the "battery pack" (handwarmer bundle).

The infrared thermometer and meat thermometer are the only tools found that measure above 100°F. While not necessary, it is the most effective way to measure the external heat.

ROLES

THE STUFF SUPERVISOR

Gathers and cleans up materials

THE EXPERIMENT EXEC

Runs the experiment

THE DIRECTOR OF DOCUMENTS

Reads the procedure to the group and helps the group members with data collection

THE PRINCIPAL PRESENTER

Shares the group's work with the rest of the class

PROCEDURE - EDUCATOR

ENGAGE

WHAT EDUCATOR DOES

Remind students that a hoverboard enclosure has to hold the required weight and has the durability to stand up to daily use. The focus on thermal performance asks: Does the enclosure keep the battery safe AND not overheat the internal parts or parts that are handled by the user?

Discuss what thermal runaway is and why heat is a critical element to designing a product that uses lithium-ion batteries. Share what an internal short circuit is in a battery and how that can result in thermal runaway highlighting the three potential causes of heat generation in lithium-ion batteries.

Introduce the thermal performance test. Explain that this test is conducted to determine whether or not the battery pack maintains normal operating temperatures and/or does not exceed maximum temperature rise as indicated in the chart below.

Hoverboard Part	Maximum Temperature Rise Allowed
Enclosure	May not exceed 7°F
Battery Pack Interior	May not exceed 5°F

Review how the students will collect data (data table or have students design data table) and model proper set-up for the thermal test.

WHAT STUDENTS DO

Discuss concerns and considerations regarding heat generation in product design. How do they think their design is going to do during testing?

Review how to collect the data and set up for the thermal test.

PROCEDURE - EDUCATOR

XPLORE

WHAT EDUCATOR DOES

Move around the room asking questions and checking for understandings about data and findings.

WHAT STUDENTS DO

- Use the thermometer to RECORD the temperature (°F) of the enclosure surface over the location of where the battery pack will be. Hint: place a mark on the surface for ease in identifying location.
- Use the meat thermometer to RECORD the internal temperature (°F) of the battery pack. For the best results, make sure to insert the thermometer in between, the middle of, the bundled handwarmers (do not bundle too tight).
- Arrange the activated (hot) battery pack in the enclosure. Place the soup can on the enclosure (representing the person standing on the hoverboard).
- Wait 5 minutes. (Good time to check your data tables and make sure your observations are complete!)
- Use the thermometer to RECORD the external temperature (°F) of the enclosure surface over the location of the battery pack; use the spot you marked.
- Take the battery pack out and immediately measure the internal temperature (^{o}F) of the battery pack using the meat thermometer. RECORD the internal temperature of the battery pack.
- Did the external temperature of the enclosure increase by more than 7°F? If yes, redesign the placement of the battery pack inside your enclosure and repeat the test.

PROCEDURE - EDUCATOR

XPLORE CONT.

WHAT STUDENTS DO CONT.

- Did the internal temperature of the battery pack increase by more than 5°F? If yes, redesign the placement of the battery pack inside your enclosure and repeat the test.
- If the answers to both questions in steps 7 and 8 are no, your design has passed the thermal performance test as required in the safety standard.

XPLAIN

WHAT EDUCATOR DOES

Elicit student explanations about what design features were most effective to pass the thermal performance test.

WHAT STUDENTS DO

Draw/write/discuss the successful and unsuccessful design features that passed the thermal performance test. What was a common factor that caused heat to be trapped inside the enclosure? How can you mitigate (lessen) for that factor in your design? Did the materials you used in your enclosure design contribute to heat generation? How? What surprised you? What did you predict correctly?

ELABORATE

WHAT EDUCATOR DOES

Ask students to predict the thermal performance of their design.

WHAT STUDENTS DO

Discuss or write about other products on the market that use lithium-ion batteries. Pick out your favorite product and think about the design of the product. Why is it important in the design phase to determine where the placement of the battery pack is and what might cause heat generation within that product?

PROCEDURE - EDUCATOR

EVALUATE

WHAT EDUCATOR DOES

Have students explain why they would choose to be either a safety scientist or a safety engineer if they had the opportunity to work on the Boeing 787 Investigation. Elicit responses to final reflection.

WHAT STUDENTS DO

Define internal short circuits and thermal runaway. Read the short narrative about the Boeing 787 Investigation. Watch the Nail Penetration test, and two Internal Short Circuit tests. Read the article "Powering Up: From Dreamliners to Hoverboards". Answer the question if you were asked to help with the Boeing 787 Investigation which role would you rather be in – a safety scientist who asks why a phenomenon happens or the safety engineer who asks how they can solve the problem? Why?

https://drive.google.com/open?id=0B2KJktL0zDO5YU9WVkN6c2htNmc

https://drive.google.com/open?id=0B2KJktL0zDO5dnBZTXk1azJ5Z2s

https://drive.google.com/open?id=0B2KJktL0zDO5a3FQUXFoVmM5OEU

http://www.ul.com/inside-ul/powering-up-from-dreamliners-to-hoverboards-ul-researcher-alvin-wu-leads-efforts-to-make-batteries-safer-2/

XTEND

XTENSION

Activate another 4 handwarmers to represent the other heat-generating components in a hoverboard and install them in the enclosure. Conduct another round of thermal testing. What is the comparison? Do the same designs pass when more heat is added? What are the most successful designs? What do they have in common?

NRC FRAMEWORK

PRACTICE 3: PLANNING AND CARRYING OUT INVESTIGATIONS

PRACTICE 4: ANALYZING AND INTERPRETING DATA

PRACTICE 5: USING MATHEMATICS AND COMPUTATIONAL THINKING

PRACTICE 6: CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

MS-ETS1 ENGINEERING DESIGN

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

SCIENCE AND ENGINEERING PRACTICES

Asking Questions and Defining Problems

- Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1)

Developing and Using Models

- Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4)

NRC FRAMEWORK

SCIENCE AND ENGINEERING PRACTICES CONT.

Analyzing and Interpreting Data

- Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3)

Engaging in Argument from Evidence

- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)

DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimited Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)

ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

(MS-ETS1-2), (MS-ETS1-3)

- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)
- Models of all kinds are important for testing solutions. (MS-ETS1-4)

ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS- ETS1-4)

NRC FRAMEWORK

CROSSCUTTING CONCEPTS

Influence of Science, Engineering and Technology on Society and the Natural World

- All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ETS1-1)
- The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-ETS1-1)

MS-PS3 ENERGY

MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*

MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

SCIENCE AND ENGINEERING PRACTICES

Analyzing and Interpreting Data

- Construct and interpret graphical displays of data to identify linear and nonlinear relationships. (MS-PS3-1)

Constructing Explanations and Designing Solutions

- Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3)

Engaging in Argument from Evidence

- Construct, use, and present oral and written arguments supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon. (MS-PS3-5)

NRC FRAMEWORK

DISCIPLINARY CORE IDEAS

PS3.B: Conservation of Energy and Energy Transfer

- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS-PS3-4)
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)

PS3.C: Relationship Between Energy and Forces
When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)

ETS1.A: Defining and Delimiting an Engineering Problem
The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (secondary to MS-PS3-3)

ETS1.B: Developing Possible Solutions
A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. (secondary to MS-PS3-3)

CROSSCUTTING CONCEPTS

Energy and Matter

- Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion). (MS-PS3- 5)
- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS- PS3-3)

COMMON CORE STATE STANDARDS CONNECTIONS

RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks (MS-PS3-3), (MS-PS3-4)

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-PS3-1).

WHST.6-8.1 Write arguments focused on discipline content. (MS-PS3-5)

NRC FRAMEWORK

COMMON CORE STATE STANDARDS CONNECTIONS

WHST.6-8.7 Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-PS3-3), (MS-PS3-4)

RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-2),(MS-ETS1-3)

MP.2 Reason abstractly and quantitatively. (MS-PS3-1),(MS-PS3-4),(MS-PS3-5)

XPLORING FOUNDATIONAL RISK ASSESSMENT

Start with a discussion that will get the students thinking about safety engineering. Safety Engineers use a Hazard-Based Safety Engineering process where they:

- Identify the energy source.
- Is the energy source hazardous.
- Identify means by which energy can be transferred to a body part.
- Identify safeguards that will prevent energy transfer to a body part (think about eliminating the energy transfer, warning about the energy transfer, and/or guarding against the energy transfer).