

Lesson Plan:

Designing Safe Battery Enclosures using Household Items.

Subject: BioSTEM (Science, Engineering, Technology and Mathematic)

Grade Level: High School (9-12)

Time Allotment: Two-90 minute block periods

I. Learning Objectives:

Students will be able to:

1. Define thermal runaway, explain its underlying chemical and physical processes, and articulate its dangers, particularly in the context of lithium-ion batteries.
2. Analyze common causes (e.g., internal short circuits, overcharging, external damage) and predict potential consequences of thermal runaway in various battery applications.
3. Apply engineering principles of thermal management, heat transfer (conduction, convection, radiation), and fire safety to design solutions.
4. Execute the engineering design process (Ask, Imagine, Plan, Create, Test, Improve) to develop and refine a prototype for a battery enclosure.

II. Materials:

- For the Lesson:
 - Interactive board
 - Markers/pens
 - Handouts:
 - Thermal runaway overview,
 - engineering design process steps,
 - case studies of battery incidents
 - Videos from Xplorer Lab Pathway on Thermal Runaway: Short clips demonstrating thermal runaway in batteries.
- For the Engineering Design Challenge (per group):
 - "Simulated Battery": A small, non-flammable object of similar size to a common battery (e.g., a small block of wood, a thick marker, a small plastic container). **DO NOT USE ACTUAL BATTERIES FOR THE EXPERIMENT.**
 - Heat Source (for simulated testing): A hot pack (e.g., chemical hand warmer, or a sealed bottle of hot water) to represent heat generation. **DO NOT USE OPEN FLAMES**

OR ELECTRICAL HEATERS.

- Household Items for Enclosure Construction:
 - Cardboard (cereal boxes, shipping boxes)
 - Aluminum foil
 - Cotton balls, fabric scraps
 - Sand, dirt, or baking soda (for insulation/fire suppression simulation)
 - Plastic bottles/containers
 - Duct tape, masking tape, glue
 - Scissors, craft knives (with adult supervision)
 - Popsicle sticks, straws
 - Paper, newspaper
 - Small plastic bags
- Safety Gear: Gloves, safety glasses (recommended for handling hot objects).
- Measurement Tools: Rulers, thermometers
- Stopwatches/timers.

III. Lesson Procedure:

Block Period 1: Engage, Explore, Explain (90-120 minutes)

A. Engage (15-20 minutes)

1. Hook & Prior Knowledge Activation:

- Begin with a discussion: "Beyond phones and laptops, where are high-energy batteries becoming critical in our society?" (Electric vehicles, renewable energy storage, drones, medical devices).
- "What are the inherent risks associated with storing large amounts of energy in a small space?"
- Introduce "thermal runaway" as a critical safety challenge in modern battery technology. Ask students to brainstorm what "thermal" and "runaway" imply in a scientific context.
- Show a brief, impactful video clip of a simulated battery thermal runaway event (if available and appropriate), emphasizing the controlled nature of the test. Prompt students to consider the forces at play.

B. Explore (45-60 minutes)

1. Engineering Design Challenge: Introduction & Initial Planning:

- "You are part of an engineering team tasked with designing a safety enclosure for a battery that might experience thermal runaway. Your goal is to contain the heat and potential effects, protecting the surrounding environment and users."
- Scenario: A portable electronic device's battery could potentially fail. Your enclosure

must provide a safe buffer.

- Goal: Design an enclosure using household items that can effectively contain the heat from a "simulated battery" for a specified duration (e.g., 5-10 minutes), preventing significant heat transfer to the exterior.
- Key Performance Indicators (KPIs): How hot does the outside get? How long does it contain the heat? How strong is the structure?
- Engineering Design Process Overview: Review the iterative nature of the engineering design process:
 - **Ask: Define the problem, identify constraints (materials, time, safety), and criteria for success (KPIs).**
 - **Imagine: Brainstorm diverse solutions individually, then as a group. Encourage sketching and labeling, design model. (Use your home design models)**
 - **Plan: Create detailed blueprints, specify materials, and outline construction steps. Consider material properties (insulators vs. conductors).**
 - **Create: (This will continue into Block Period 2) Build the prototype.**
 - **Test: (This will continue into Block Period 2) Systematically evaluate performance against criteria.**
 - **Improve: (This will continue into Block Period 2) Analyze test data, identify weaknesses, and propose design modifications.**
- Brainstorm & Plan (Group Activity):
 - Divide students into small groups (3-4 students).
 - Provide each group with the list of available household items, their "simulated battery," and heat source.
 - Brainstorming: Encourage students to consider: (STUDENT MUST PICK ONE FROM THE FOLLOWING LIST:)
 - Thermal Insulation: How to create layers of trapped air, use low-conductivity materials.
 - Heat Dissipation/Absorption: Can any materials absorb heat or conduct it away safely? (e.g., aluminum foil as a heat spreader, sand as a heat sink).
 - Gas/Smoke Containment: How to create a relatively sealed environment or formation of air borne precipitate.
 - Structural Integrity: How to ensure the enclosure remains intact under stress.
 - Ventilation (Controlled): Could controlled venting be part of a strategy, or is full containment preferred for this challenge?
 - Planning: Each group must produce a detailed sketch or diagram of their design, clearly labeling all materials and their intended function. They should also outline the construction steps. Emphasize that the "simulated battery" must fit securely inside.

C. Explain (30-40 minutes)

1. Deep Dive: The Science of Thermal Runaway:

- Explain thermal runaway as a positive feedback loop involving exothermic chemical reactions.
- Focus on Lithium-ion Batteries:
 - Discuss the basic components:
 - anode (typically graphite),
 - cathode
 - electrolyte (lithium salt dissolved in organic solvents),
 - separator (a porous polymer film).

Explain how an initial trigger (e.g., internal short circuit due to physical damage, dendrite formation from overcharging, or manufacturing defect) leads to localized heating.

- The Chain Reaction - Chemical & Physical Processes:
 - Stage 1: Initial Heating & Electrolyte Decomposition: As temperature rises the solid electrolyte interphase (SEI) layer on the anode begins to decompose exothermically, releasing heat.
 - Stage 2: Separator Melting & Internal Shorting: Further temperature increase causes the polymer separator to melt and shrink, leading to widespread internal short circuits between the anode and cathode.
 - Stage 3: Cathode Decomposition & Oxygen Release: At even higher temperatures, the cathode material begins to decompose, releasing oxygen gas. This oxygen is highly reactive and fuels the combustion of the organic electrolyte.
 - Stage 4: Electrolyte Combustion & Gas Venting: The organic electrolyte, now exposed to oxygen and high temperatures, ignites, leading to rapid combustion. This process also generates large volumes of flammable and toxic gases (e.g., hydrogen, carbon monoxide, methane, and highly corrosive hydrogen fluoride). The rapid gas generation causes significant internal pressure buildup, often leading to venting or even explosion.

- Energy Transfer: This entire process is driven by the rapid conversion of stored chemical energy into thermal energy, which then propagates through the battery cell and potentially to adjacent cells (thermal propagation).
- Use the snowball analogy, but also introduce the concept of a "chain reaction" or "domino effect" where each step exacerbates the next.

- Dangers: Emphasize the severity: violent combustion, explosion, release of highly toxic and corrosive gases. Discuss the importance of understanding these dangers for public safety and engineering design.

Causes & Mitigation Strategies:

- **Causes: Elaborate on:**
 - Overcharging/Over-discharging: Discuss the electrochemical stress, lithium plating (dendrite formation) on the anode that can puncture the separator.
 - Physical Damage: Punctures, crushing, impact – how these compromise internal structures and create direct short circuits.
 - Manufacturing Defects: Briefly touch upon impurities, uneven coating, or misaligned components that can lead to localized hot spots or internal shorts.
 - External Heat Sources: The importance of environmental factors like high ambient temperatures affecting the battery's operating range.

Block Period 2: Elaborate, Evaluate (90-120 minutes)

D. Elaborate (60-75 minutes)

1. Create (Construction Phase):

- Students build their prototypes based on their detailed plans from Block Period 1.
- Circulate, providing guidance, troubleshooting construction issues, and ensuring safe use of tools (scissors/craft knives).
- Encourage precision and adherence to their plans, but also allow for minor on-the-fly adjustments if a design flaw becomes apparent during construction. Document these changes.

2. Test & Improve:

- Safety Briefing & Setup (10-15 min):
 - Reiterate Safety First: Designate a clear, supervised testing area. Ensure all students wear safety glasses and gloves when handling the hot pack. Have a bucket of sand or water nearby for extreme caution (though not expected to be needed with simulated heat).
 - Review the testing procedure:
 - Place the "simulated battery" inside the enclosure.
 - Activate the hot pack and place it immediately adjacent to the "simulated battery" inside the enclosure.
 - Seal the enclosure as per design.
 - Start a timer.
 - Observation & Data Collection:

- Regularly (e.g., every minute) touch the *outside* of the enclosure (carefully, with gloves) to assess heat transfer.
 - If using thermometers/IR thermometers, record temperature readings on the exterior at set intervals.
 - Note any structural changes, material degradation, or signs of heat escaping.
 - Crucial: If any part of the enclosure becomes too hot to safely touch, or if the heat pack significantly cools, the test is concluded. Record the time.
- Testing & Evaluation (20-25 min):
 - Groups conduct their simulated thermal runaway tests.
 - Facilitate observation and data recording.
 - Evaluation Discussion: After testing, each group analyzes their results:
 - How effectively did the enclosure contain the heat? (Refer to temperature readings and observations).
 - What was the duration of effective containment?
 - What materials/design choices worked well? Why?
 - What materials/design choices failed or were ineffective? Why?
 - What unexpected challenges arose during testing?
- Improve (15-20 min):
 - Based on their evaluation, groups brainstorm and sketch specific improvements to their designs.
 - Encourage them to think about how they could address weaknesses observed during testing. This reinforces the iterative nature of engineering.
 - If time permits, allow for quick modifications and a brief re-test.

E. Evaluate (15-20 minutes)

1. Group Presentations & Peer Review:

- Each group briefly presents their initial design, their test results (including any data), and their proposed improvements.
- Encourage constructive peer feedback and questions.
- Discuss the variety of solutions and the different engineering principles applied. Highlight successful strategies (e.g., multi-layered insulation, specific material choices for heat management).

2. Debrief & Connection to Real World:

- Reiterate the critical importance of thermal management and safety engineering in real-world battery applications (e.g., electric vehicles, grid-scale energy storage, consumer electronics).
- Discuss how professional engineers use advanced materials, active cooling systems,

and sophisticated simulations to prevent and mitigate thermal runaway.

- Emphasize the value of failure in the design process – it provides crucial data for improvement.
- "How does this challenge relate to the broader field of materials science or mechanical engineering?"
- "Why is it essential for engineers to consider worst-case scenarios and design for safety?"

IV. Assessment:

- Formative:
 - Active participation in discussions and group work.
 - Quality and completeness of brainstormed ideas and detailed design plans/sketches.
 - Effective teamwork during construction and testing.
 - Observational notes and data collected during testing.
- Summative (Optional):
 - A formal engineering design report from each group, detailing:
 - Problem statement and design criteria.
 - Initial design (with diagrams/sketches).
 - Materials used and their rationale.
 - Testing procedure and results (including quantitative data if collected).
 - Analysis of results (what worked, what didn't, why).
 - Proposed improvements for a next iteration.

V. Extensions (Optional):

- Research: Students research specific battery chemistries (e.g., LFP vs. NMC) and their thermal stability characteristics. Investigate real-world battery fire incidents and their root causes.
- Detection Systems: Design a conceptual system for early detection of thermal runaway (e.g., using smoke, gas, or advanced temperature sensors).
- Material Science: Research advanced thermal management materials (e.g., phase change materials, aerogels) used in commercial battery packs.
- Career Connections: Invite a guest speaker (engineer, firefighter, materials scientist) to discuss battery safety or related fields.