# Hypersonics STEM Curriculum

## Keeping it Cool at Hypersonic Speeds

| Grade | Time | Subject Area | Key Concepts |
|---|---|---|---|
| 4 | 60 min | Physical Science | Heat<br>Temperature |

### Lesson Overview

In this lesson, students will evaluate different materials based on how well they insulate thermal energy. Students will place five different material in front of a heat lamp and take temperature measurements on both sides of the material. Students will use their data to make evaluations on what materials are good insulators of thermal energy.

### NGSS Standards

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

### Learning Objectives

By the end of this lesson, students will be able to:

- Collect data in the following formats:
  - Observations of the materials
  - Measurements of thickness of the material and temperature.
- Evaluate which materials are good insulators of thermal energy.

### Essential/Overarching Question

What materials should we use if we were to design a hypersonic rollercoaster?

### Key Vocabulary

**Speed** – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

**Speed of Sound** – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

**Mach** – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

**Sonic** – speeds equal to the speed of sound (Mach 1).

**Subsonic** – speeds smaller than the speed of sound (less than Mach 1).

**Transonic** – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

**Supersonic** – speeds greater than the speed of sound (Mach 1 and greater).

**Hypersonic** – speeds greater than five times the speed of sound (Mach 5 and greater).

**Fluid** – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

**Flow** – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

**Energy** – the ability to do work. The ability to apply a net force to move an object.

**Temperature** – the measure of the kinetic energy of the particles (atoms/molecules) in an object. A quantity to describe how hot or cold an object is.

**Thermal Energy** – heat energy. Energy possessed by an object due to the movement of the particles (atoms/molecules) within the object. As temperatures rise, particles move more, increasing thermal energy.

**Heat** – high temperatures or kinetic energy in transit between two objects or systems that have different temperatures.

**Friction** – resistance to movement. A force that opposes motion.

**Insulator -** a material or substance that does not readily allow the transfer heat, sound, electricity, or light.

## Science Concepts Overview

As aircrafts speed up from subsonic (slower than the speed of sound) to sonic (the speed of sound) to supersonic (greater than the speed of sound) and finally to hypersonic (greater than five times the speed of sound), the conditions that the aircraft experiences change and become more extreme. Additionally, the physics that describes those conditions changes as extreme speeds are reached.

There are many challenges when designing aircraft to travel at hypersonic speeds. One challenge involves finding materials that can withstand extreme conditions, particularly large

amounts of heat, generated from friction between air and the aircraft. Materials used for aircraft that travel at hypersonic speeds should be able to withstand temperatures of at least (1200 °C).

Additionally, the materials used in the vehicle need to be able to protect what is inside the vehicle – from electronics to pilots – from the extreme heat outside.

## Materials List

- ☐ Rulers (one per group)
- ☐ An assortment materials, and material thicknesses to test (cardboard, wood, metal, aluminum foil, Styrofoam, etc.)
- ☐ Heat lamps (one per group)
- ☐ Thermometers (one or two per group)
- ☐ Timer or clock (one per group or class)
- ☐ Keeping it Cool at Hypersonic Speeds handout (one per student)
- ☐ Keeping it Cool at Hypersonic Speeds Exit Ticket handout (one per student)

## Lesson Preparation

Prior to the lesson, the instructor should gather materials and make copies of the Keeping it Cool at Hypersonic Speeds handout and the Keeping it Cool at Hypersonic Speeds Exit Ticket handout. Since each group will need an outlet to plug in their heat lamp, instructors may want to map out where they want each group to work in their classroom so each group has an appropriate space.

Prior to the lesson, you may want to test your materials under the heat lamps your class will use for the lesson to ensure that they will not melt or become dangerous when heated.

## Safety

Due to the nature of this lesson, it is recommended that the class take the following safety precautions:

- Participants should wear eye protection
- Participants should be instructed in the proper use of equipment
- Participants should be reminded not to touch the light bulb and to only touch the on/off switch once the light is in use.
- Participants should be reminded to be careful when touching the hot materials

## Procedure

***Engage (15 minutes)***

1. Individually, or as a class, read the first paragraph of the Introduction of the Keeping it Cool at Hypersonic Speeds handout.
2. Watch the video clip from the Phineas and Ferb Rollercoaster episode https://www.youtube.com/watch?v=shHqnB_VAFE
3. Have students answer the two questions:
    - What are things from the video that are plausible – meaning what are things in the video that could really happen?

- What are things from the video that are not plausible – meaning what are things in the video that could not really happen?

4. Have students share their answers using either a think-pair-share format, or as an entire class discussion.
5. Individually, or as a class, read the second paragraph of the Introduction of the Keeping it Cool at Hypersonic Speeds handout.

***Explore (25 minutes)***

6. Students should work in small groups for the data collection and analysis if enough materials are available.
7. Students will pick five different materials and test the heat energy transfer through those materials using the following instructions:
    - Collect the materials that you will be testing, a heat lamp, a ruler, and a thermometer.
    - Place the material in front of the heat lamp. Allow the material to sit in front of the lamp for at least two minutes before you take your temperature measurements.
    - On the data table below, record your material name and write a description of the material.
    - Measure the thickness of your material in centimeters and record it in the data table below.
    - Record the temperature of the material on the outside ($T_{OUT}$ - the side closest to the light) in degrees Celsius and record it in the data table below.
    - Record the temperature of the material on the inside ($T_{IN}$ - the side furthest from the light) in degrees Celsius and record it in the data table below.
    - Calculate the change ($\Delta$ or delta) in temperature ($\Delta T = T_{IN} – T_{OUT}$) and record it in the data table below.

***Explain (10 minutes)***

8. Students will explain their understanding of the heat energy transfer by answering Analysis questions 1-7 on the Keeping it Cool at Hypersonic Speeds handout.

***Elaborate (5 minutes)***

9. Students will further elaborate on their understanding by answering Analysis questions 8-10 on the Keeping it Cool at Hypersonic Speeds handout.

***Evaluate (5 minutes)***

10. Students will complete the Keeping it Cool at Hypersonic Speeds Exit ticket which asks them to list:
    - Three ideas that you took away from the lesson.
    - Two wonders or questions that you have because of the lesson.
    - One thing you want to learn more about.

**STEM Career Connections**

- Aerospace engineer
- Materials scientists

- Mechanical engineer
- Systems engineer
- Pilot
- Astronaut

## Extensions

Students could further *explore* the heat and energy transfer of materials by testing other materials that they suggested in Analysis question 8 of the Keeping it Cool at Hypersonic Speeds.

Students could further *elaborate* on their understanding by researching the materials used for aircrafts, including hypersonic vehicles, using some of the National Air and Space Museum links in the References & Resources section below.

As an alternative *evaluate*, students could participate in a class discussion about their findings:

- Based on your data, what recommendations do you have for Phineas and Ferb? Explain your reasoning.
- What are materials that we did not investigate that you suggest for further testing? What makes your suggest those materials?
- What might be other uses for the research that we did? How would our research help?

## References & Resources

Disney XD. (2019, January 3). *Rollercoaster | Phineas and Ferb | Disney XD* [Video]. YouTube. https://www.youtube.com/watch?v=shHqnB_VAFE

National Air and Space Museum. (n.d.) *Ask as explainer: What kinds of materials are used to make an aircraft?*. https://howthingsfly.si.edu/ask-an-explainer/what-kinds-materials-are-used-make-aircraft

National Air and Space Museum. (n.d.) *How things fly*. https://howthingsfly.si.edu/

National Air and Space Museum. (n.d.) *Hypersonic vehicles*. https://howthingsfly.si.edu/structures-materials/hypersonic-vehicles

National Air and Space Museum. (n.d.) *Materials*. https://howthingsfly.si.edu/structures-materials/materials

National Air and Space Museum. (n.d.) *Structures & materials*. https://howthingsfly.si.edu/structures-materials/weight-and-strength-0

National Air and Space Museum. (n.d.) *Weight & strength*. https://howthingsfly.si.edu/

SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube. https://www.youtube.com/watch?v=kGefMLHJBKA

Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. https://www.youtube.com/watch?v=LBJ3tXCjzN0

TestTube 101. (2015, November 11). *Flying at hypersonic speeds* [Video]. YouTube https://www.youtube.com/watch?v=vL1qAfS0gic

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# Keeping it Cool at Hypersonic Speeds

## ✈ Introduction

In the Phineas and Ferb episode Rollercoaster, the group builds the "coolest coaster EVER!!!!" The ride experiences extreme heights, curves, and speeds before it is flung into space and catches fire while re-entering Earth's atmosphere. Watch the video below and answer the questions that follow.

Disney XD. (2019, January 3). *Rollercoaster | Phineas and Ferb | Disney XD* [Video]. YouTube. https://www.youtube.com/watch?v=shHqnB_VAFE

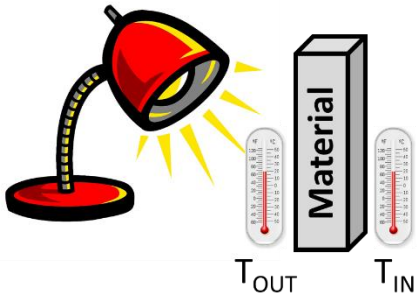
1. What are things from the video that are plausible – meaning what are things in the video that could really happen?

2. What are things from the video that are not plausible – meaning what are things in the video that could not really happen?

If a roller coaster did fall back to Earth from space, there is a high probability that the roller coaster would reach supersonic and possibly hypersonic speeds. ***Supersonic*** refers to objects moving at faster than the speed of sound (343 m/s = 767 mph). ***Hypersonic*** refers to objects moving faster than five times the speed of sound (1715 m/s = 3836 mph). When objects are moving that fast they experience a lot of ***heat*** (high temperatures) and ***friction*** (resistance). So, the fact that the roller coaster in the video burned up is plausible. Investigating the heat and energy transfer properties of materials is a very important area of study within hypersonics. In this lesson, you will study the heat and energy transfer properties of common materials.

## Data Collection

- ☐ Collect the five materials that you will be testing, along with a heat lamp, a ruler, and two thermometers.
- ☐ Place your materials in front of the heat lamp, one material at a time. Allow each material to sit in front of the lamp for at least two minutes before you take your temperature measurements (see diagram).
- ☐ On the data table below, record your material name and write a description of the material.
- ☐ Measure the thickness of your material in centimeters and record it in the data table below.
- ☐ Record the temperature (T) of the material on the inside (IN), or the side furthest from the light, in degrees Celsius and record it in the data table below ($T_{IN}$ = the side furthest from the light).
- ☐ Record the temperature (T) of the material on the outside (OUT), or the side closest to the light, in degrees Celsius and record it in the data table below ($T_{OUT}$ = the side closest to the light).
- ☐ Calculate the change ($\Delta$ or delta) in temperature ($\Delta T = T_{IN} - T_{OUT}$) and record it in the data table below.




| Material | Description | Thickness (cm) | $T_{IN}$ (°C) | $T_{OUT}$ (°C) | $\Delta T$ (°C) |
|---|---|---|---|---|---|
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## ✈ Analysis

1. What does the negative sign mean on your $\Delta T$ calculations?

2. Is all of the thermal (heat) energy transferred through the materials? What evidence supports your claim?

3. Do you think the thickness of the material effects the amount of thermal (heat) energy transferred through the material? What evidence supports your claim?

4. Do you think the type of material effects the amount of energy transferred through the material? What evidence supports your claim?

5. Do you think there are other properties or characteristics of the material that effects the amount of energy transferred through the material? What evidence supports your claim?

6. A material that does not allow energy to move easily through it is called an insulator. What material was the best insulator? What evidence supports your claim?

7. What material was the worst insulator? What evidence supports your claim?

8. What other materials do you think would be interesting to test?

9. If you were to use the materials that we tested to improve the safety of Phineas and Ferb's roller coaster, what would you use and how would you use them? Explain your reasoning.

10. What other things, beyond what we measured in this investigation, might we consider when looking at materials for a hypersonic aircraft such as a spaceship or a sounding rocket?

Name: _____

## Keeping it Cool at Hypersonic Speeds Exit Ticket

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|---|---|
| 3 | Three ideas that you took away from the lesson. |
| 2 | Two wonders or questions that you have because of the lesson. |
| 1 | One thing you want to learn more about. |

Name: _____

## Keeping it Cool at Hypersonic Speeds Exit Ticket

| | |
|---|---|
| 3 | Three ideas that you took away from the lesson. |
| 2 | Two wonders or questions that you have because of the lesson. |
| 1 | One thing you want to learn more about. |