Hypersonics
Mission Re-Entry

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Name:

What is "Hypersonic"?

Figure 1: Re-entry capsule exiting low earth orbit and plummeting back down to earth.

Hypersonic, or Hypersonic movement, means that something is traveling more than five times faster than the speed of sound (**343 m/s** or **767.27 mph**). Hypersonic speed is also often referred to as **Mach 5.** There are several challenges that objects must overcome to travel safely at Mach 5, the largest one being heat.

When objects speed up, friction increases, and that friction leads to an increase in thermal energy. The faster something moves, the more friction it creates and the hotter it becomes. This is an especially challenging problem for aerospace engineers developing re-entry capsules for astronauts. These re-entry capsules must travel through our atmosphere and can reach speeds up to 17,500 mph, greatly surpassing the Mach 5 indicator for hypersonic movement. All this speed develops enormous amounts of friction and the surface of the capsule itself can reach temperatures of 1,480 °C (2,700 °F).

In this activity, you will take on the job of aerospace engineer to develop a space capsule using materials that will keep the internal temperature of the spacecraft low enough for our astronauts to survive. To find the right material, we can use several indicators: Specific Heat, Thermal Conductivity, and Thermal Diffusivity. Each characteristic is unique for every material and tells us different aspects of a material's ability to withstand and exchange heat energy.

Specific Heat: How much heat energy is required to raise a material's temperature by 1°C
Thermal Conductivity: The rate at which heat energy flows through a material from one side to the other
Thermal Diffusivity: How fast a temperature change propagates through the material. This is found by dividing a material's thermal conductivity by its density and its specific heat.

Quick Check: What is the definition of heat? Why do we measure heat energy and temperature of a substance differently?

PART I – How can we use density and specific heat to identify materials?

GOAL: Identify unknown materials using material constants

MATERIALS

- 2 Small-scale calorimeters
- Scale/Balance
- 25ml Graduated Cylinder
- Cold water
- Warm water
- 2 Thermometers
- Paper Towels
- Hot Plate
- Test Tube
- Test Tube Clamp
- Pencil
- Unknown Metal Material
- Waste container

Determining an Object's Specific Heat:

When a hot material is added to a known temperature of water, the heat lost by the object is equal to the heat gained by the water. This is known as the Law of Conservation of Energy.

$$\Delta q \text{ Hot Material} = \Delta q \text{ Calorimeter} + \Delta q \text{ Water}$$

$$\Delta q = mC\Delta T$$

<u>Some important variables to note:</u>

q = heat energy (calories) | C = Specific Heat (calories/g °C) | m = Mass (g) | T = Temperature (°C) | Δ = Change (final —initial)

The rate of this heat transfer is unique for every material and can be used alongside other material properties to identify unknown materials. The purpose of this experiment is to find our object's specific heat and compare it to our table of known values to figure out the identities of our differing materials.

<u>1.) Calorimeter Constant</u>

Each calorimeter will have minor differences that need to be accounted for in our calculations. Once we determine the calorimeter constant: C, we can use it in our subsequent specific heat calculations to determine the change in energy in our calorimeter.

Table 1	**Mass No Water (g)**	**Mass With Water (g)**	**Initial Temperature**	**Final Temperature**
Cold				
Warm				

1.a. Mass each calorimeter to the nearest 0.1g and record in Table 1.

1.b. Add 8mL of cold water to the calorimeter labeled C, and 8mL of warm water to calorimeter labeled W. Record the new mass of each calorimeter in Table 1.

1.c. Insert the thermometer into each calorimeter and stir gently until the temperature is constant for 10 seconds, record temperatures in Table 1 under initial temperature.

1.d. Pour the water from the C-calorimeter into the W-calorimeter and stir until the temperature is stable for 10 seconds, record the final temperature in Table 1.

Calculations

- 1. Determine the change in energy for the cold water and the warm water.

Given Values: C_{water} = **1.00 cal/g°C**	
$\Delta q_{cold} = mC(T_f - T_i)$ $\Delta q_{cold} =$	$\Delta q_{warm} = mC(T_f - T_i)$ $\Delta q_{warm} =$
Reminder: Think back to discussion on energy, can we have negative energy? How might that impact your calculations? What should you do before continuing?	

- 2. Determine the change in termpature for the warm water.

$\Delta T_{warm} = (T_f - T_i)$
$\Delta T_{warm} =$

- 3. Determine the calorimeter constant.

Calorimeter Constant = $\frac{(\Delta q_{warm} - \Delta q_{cold})}{\Delta T_{warm}}$
Calorimeter Constant =

❓ ***Quick Check: Why is it important that we each find our own calorimeter constant?***

2.) Specific Heat Calculation:

Table 2	**$Mass_{material}$ (g)**	**Mass Calorimeter (g) (No Water)**	**Mass Calorimeter (g) (With Water)**	**Initial Temp Material (°C)**	**Initial Temp Water (°C)**	**Final Temp of Mixture (°C)**

2.a Add weigh boat to scale and hit the Tare button, zeroing the initial reading.

2.b Add unknown material to the weigh boat, use the scale to record the mass to the nearest 0.1g in Table 2, then pour material from the weigh boat into a test tube.

2.c While wearing heat protective gloves and using a test tube clamp, carefully place test tube into beaker of hot water at the center of your table.

2.d While sample is heating, mass the calorimeter to the nearest 0.1g and record in Table 2.

2.e Add 15mL of water to calorimeter, record the mass and temperature to the nearest 0.1°C in Table 2.

2.f Place thermometer into test tube containing unknown material and record temperature to the nearest 0.1°C once it remains constant for 10 seconds in Table 2.

2.g When temperature of material is constant, remove from hot plate using test tube clamp and quickly but carefully pour the material into calorimeter.

2.h Stir calorimeter gently with thermometer, record temperature to the nearest 0.1°C once it remains stable for 10 seconds.

2.i Once trial is complete, remove thermometer from your calorimeter and begin calculation

Calculations:

$\Delta q_{Calorimeter}$ = calorimeter constant x ΔT_{water}	$\Delta q_{Water} = mC\Delta T$
ΔT_{water}= Final Temp Mixture — Initial Water Temp $\Delta q_{Calorimeter}$ =	m=Calorimeter with Water — Calorimeter Alone C_{water}= 1.00 cal/g°C ΔT_{water}= Final Temp Mixture — Initial Water Temp Δq_{Water} =
$\Delta q_{material} = \Delta q_{Calorimeter} + \Delta q_{Water}$ $\Delta q_{material}$=	
$C=\Delta q_{material}/m\Delta T_{material}$ m = Mass of Material $\Delta T_{material}$= Final Temp Mixture — Initial Material Temp	
C=________	

Work with your table to fill in the chart below, record each station's calculations and then find the average of all three trials:

	Specific Heat (cal/g°C)
Station 1 (Yours)	
Station 2	
Station 3	
Average:	

? Compare your table's average to the materials list provided. Using your material's density, calculated specific heats, and visual observations which material do you think you tested today?

? After group discussion, which material did your table actually have? Was your initial identification correct or incorrect? What could you have done differently to get a more accurate result?

? Looking at the materials and their listed properties. Which material do you think would be best to include in designs to prevent external heat from reaching internal spaces? Why?

PART II – Design Your Space Shuttle

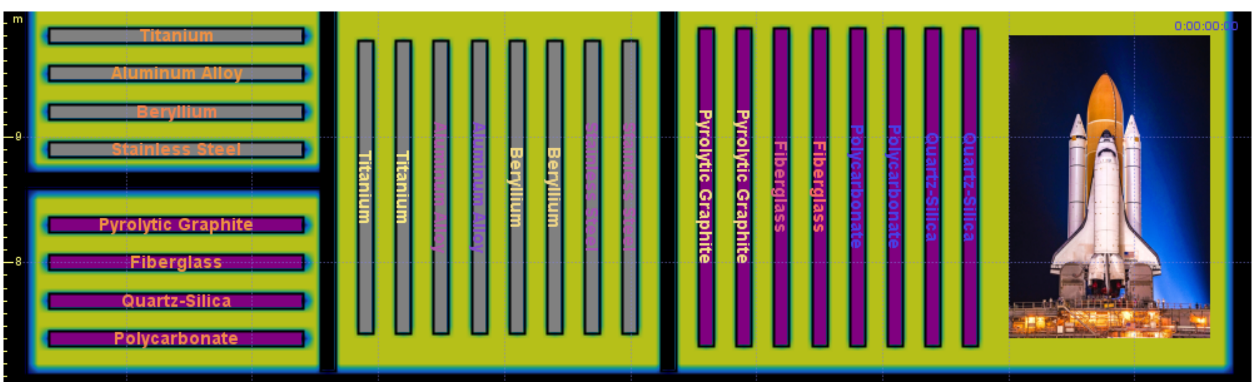
GOAL: To design a space shuttle hull that will keep the astronauts safe inside for 30 seconds (stay below 121°C).

MATERIALS

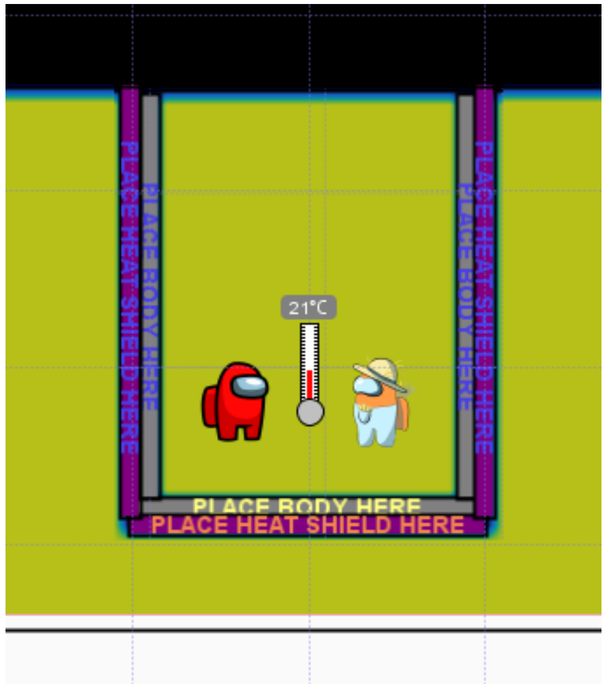
- Computer with Energy2D installed (PC, Linux, Mac)
- Pen/Pencil
- Stopwatch/Cellphone

☐ 1. Open the “design” file. You will see various thin bars of materials. You will be designing a cross-section of a space shuttle (real space shuttles are less than an inch thick!). Your task is to design a space shuttle hull that will keep the astronauts safe inside for at least 30 seconds. Ambient temperature inside the space shuttle is roughly 70-75°F, or around 21°C, and space suits are meant to withstand up to 250°F, or 121°C. You may test as many times as you want. Record the results of at least three of your designs. You will write down the materials you used for each layer and how long it took for the interior of your space shuttle to go above 121°C.

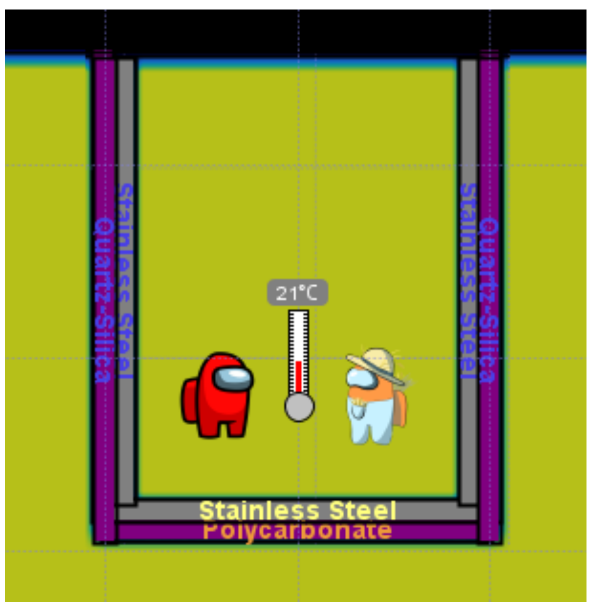
☐ 2. Look at our layout for the space shuttle design simulation. At the top, you will see different sets of bars. Grey bars represent the body of the space shuttle, the purple bars represent the tiles that serve as a heat shield for the space shuttle.



☐ 3. At the bottom of our model, we have out cross-section layout. Pay attention to how the grey bars are on the inner layer of the cross section and the purple bars are on the outer layer of the cross section. You will be placing your materials on top of the grey and purple bars already put there for you.



☐ 4. Here is an example of what it will look like after you drag your bars over the design platform. You do NOT need to use the same material for all parts of the cross-section. The only rule is that hull materials (grey bars) must be on the inner layer and the tile materials (purple bars) must be on the outer layer.



☐ 5. Once you have placed your materials for your space shuttle, write down your materials on the table. Now grab a stopwatch or use your phone. Start the timer when you click run. After 30 seconds, hit stop and record the observed temperature on the thermometer. You have about 25 minutes to design and test your space shuttle.

Design #	Left Layer Combination (Outer/Inner)	Cone Layer Combination (Outer/Inner)	Right Layer Combination (Outer/Inner)	Temperature after 30 seconds (C°)
1				
2				
3				

Conclusions

Which combination of materials worked best for your design? What was the lowest temperature you were able to record after 30 seconds?

Did the thermal properties of any the materials stand out? If so, which ones and why?