Lab Sim 06: Specific Heat Capacity

INTRODUCTION

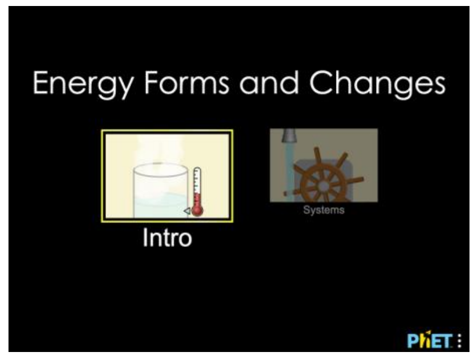
Not everything heats up the same way; if you have ever boiled water, you probably already know this. The metal saucepan gets very hot very quickly; it is soon too hot to touch. But the water in the pan takes much longer to get warm. Heat is energy, and what you are seeing is that the metal pan needs less energy to increase its temperature, and the water requires more energy.

There are two things to consider: the metal pan is a different material than the water, and there is a different amount of each material. Typically, the water will weigh more than the pan. However, in this case, we want to compare the materials themselves, not the relative amounts.

Specific heat is defined as the amount of energy, or heat, required to raise the temperature of 1 gram of a substance by 1 degree Celsius. For water, one calorie of heat is needed to raise 1 gram of water by 1°C, so by definition, its specific heat is $c_{H_2O} = 1\frac{\text{cal}}{\text{g}\cdot°\text{C}}$. The specific heat of iron is $c_{Fe} = 0.113\frac{\text{cal}}{\text{g}\cdot°\text{C}}$. This means that it takes less heat energy—only about 10%!—to raise one gram of iron by one degree, compared to the energy required for water.

OBJECTIVES

- Observe the difference between heat and temperature
- Monitor the transfer of heat from one substance to another
- Calculate the specific heat of an unknown substance
- Estimate the amount of error in an experimental value
- Examine a procedure for sources of experimental error



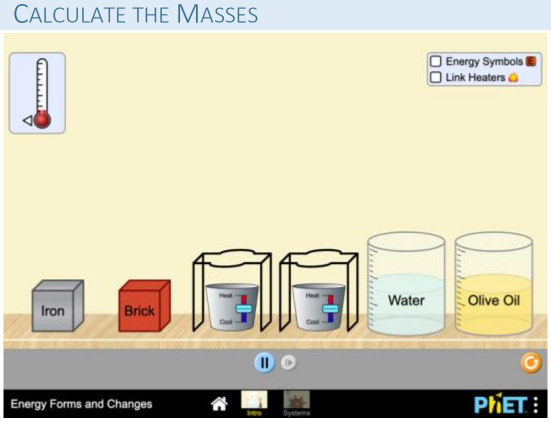
EQUIPMENT

- Internet-connected device capable of running a browser
- Paper and pen or pencil (you're always going to need these)
- Calculator

PROCEDURE

1. Read this handout completely before you try to dive in. It will save you time and frustration later. If you are able to print it, you will not have to tab between windows—you can look at this and the simulation at the same time.
2. Do you have paper and pencil handy? Don't forget your calculator.
3. In a browser window, navigate to the PhET Energy Forms and Changes simulation. Notice that we are using a different sim site this week, so it operates a little differently! Don't try to start doing the lab yet! Just verify that when you click INTRO, the simulation opens properly.

CALCULATE THE MASSES (1 POINT EACH)



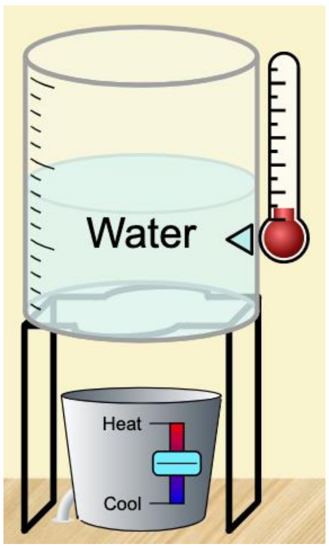
When you click the INTRO, you will see the experimental set-up shown on the left. You have four different materials, two heat sources that can be operated separately or linked together, and thermometers that can be used to measure the temperature of your materials.

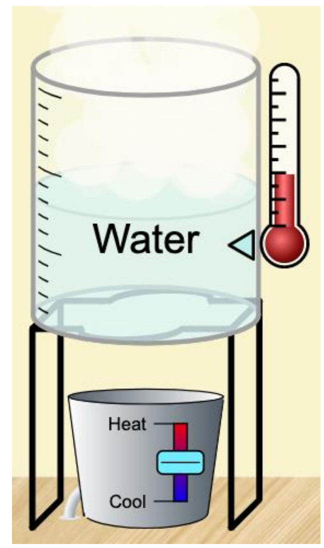
Before we start experimenting, we need to know the masses of the materials we will be testing. To find the masses (notice we don't have a balance to weigh them on!), we will need the volume for each material.

1. The cube of iron and the cube of brick have the same dimensions. Each cube has sides of length $l = 10\text{cm}$. What is the volume of each cube?
   A) $V = 0.01\text{cm}^3$
   B) $V = 0.1\text{cm}^3$
   C) $V = 1\text{cm}^3$
   D) $V = 10\text{cm}^3$
   E) $V = 100\text{cm}^3$
   F) $V = 1000\text{cm}^3$
2. The density of iron is $\rho_{Fe} = 7.87\frac{\text{g}}{\text{cm}^3}$. Calculate the mass of the iron cube using the definition of density: $\rho = \frac{m}{V}$.
   A) $m_{Fe} = 7870\text{g}$
   B) $m_{Fe} = 787\text{g}$
   C) $m_{Fe} = 78.7\text{g}$
   D) $m_{Fe} = 7.87\text{g}$
   E) $m_{Fe} = 0.787\text{g}$
   F) $m_{Fe} = 0.0787\text{g}$
3. The density of brick is $\rho_{br} = 1.92\frac{\text{g}}{\text{cm}^3}$. Calculate the mass of the brick cube using the definition of density: $\rho = \frac{m}{V}$.
   A) $m_{br} = 1920\text{g}$
   B) $m_{br} = 192\text{g}$
   C) $m_{br} = 19.2\text{g}$
   D) $m_{br} = 1.92\text{g}$
   E) $m_{br} = 0.192\text{g}$
   F) $m_{br} = 0.0192\text{g}$

4. The water and the oil are both in beakers with a 3-liter capacity. Each of the major tick marks on the beaker is 1 liter, and each minor tick mark is 0.2 liters. Examine the beakers and determine the volume of liquid in each.
   A) $V = 1.0\text{l} = 1000\text{ml} = 1000\text{cm}^3$
   B) $V = 1.2\text{l} = 1200\text{ml} = 1200\text{cm}^3$
   C) $V = 1.4\text{l} = 1400\text{ml} = 1400\text{cm}^3$
   D) $V = 1.6\text{l} = 1600\text{ml} = 1600\text{cm}^3$
   E) $V = 1.8\text{l} = 1800\text{ml} = 1800\text{cm}^3$
   F) $V = 2.0\text{l} = 2000\text{ml} = 2000\text{cm}^3$
   G) $V = 2.2\text{l} = 2200\text{ml} = 2200\text{cm}^3$
   H) $V = 2.4\text{l} = 2400\text{ml} = 2400\text{cm}^3$
   I) $V = 2.6\text{l} = 2600\text{ml} = 2600\text{cm}^3$
   J) $V = 2.8\text{l} = 2800\text{ml} = 2800\text{cm}^3$
   K) $V = 3.0\text{l} = 3000\text{ml} = 3000\text{cm}^3$
5. The density of water is $\rho_{H_2O} = 1\frac{\text{g}}{\text{cm}^3}$. Calculate the mass of the water using the definition of density: $\rho = \frac{m}{V}$.
   A) $m_{H_2O} = 1200\text{g}$
   B) $m_{H_2O} = 1400\text{g}$
   C) $m_{H_2O} = 1600\text{g}$
   D) $m_{H_2O} = 1800\text{g}$
   E) $m_{H_2O} = 2000\text{g}$
   F) $m_{H_2O} = 2200\text{g}$
6. The density of olive oil is $\rho_{oil} = 0.917\frac{\text{g}}{\text{cm}^3}$. Calculate the mass of the oil using the definition of density: $\rho = \frac{m}{V}$.
   A) $m_{oil} = 1267\text{g}$
   B) $m_{oil} = 1467\text{g}$
   C) $m_{oil} = 1667\text{g}$
   D) $m_{oil} = 1867\text{g}$
   E) $m_{oil} = 2067\text{g}$
   F) $m_{oil} = 2267\text{g}$

CALIBRATE THE THERMOMETER (2 POINTS EACH)





Return to your browser window and place the beaker of water on the stand (click and drag). Now grab a thermometer and drag it next to the beaker. As shown on the left, when the triangle indicator turns blue, the thermometer measures the water's temperature.

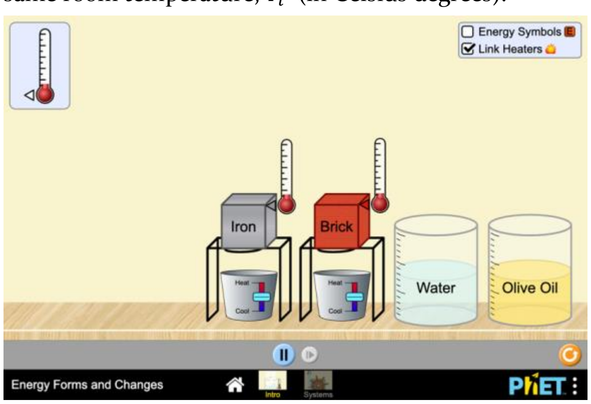
Because the thermometer has no scale, how do we know what the temperature is? We'll have to make an assumption, then perform a calibration. First, let's assume that the experiment is happening at room temperature. What would be a reasonable room temperature?

7. We will assume that the room is at $T_i = 77°\text{F}$. Convert this temperature from Fahrenheit to Celsius degrees.
   A) $T_i = 21°\text{C}$
   B) $T_i = 22°\text{C}$
   C) $T_i = 23°\text{C}$
   D) $T_i = 24°\text{C}$
   E) $T_i = 25°\text{C}$
   F) $T_i = 26°\text{C}$

Now drag the slider on the bucket to maximum heat and apply the heat until the water reaches the boiling point, $T = 100°\text{C}$. Notice that the temperature stops increasing once the water reaches the boiling point! Also, you can hit the PAUSE button on the sim so that you can see the thermometer clearly.

8. The second tick mark on the thermometer corresponds to the initial room temperature, T_i. Which tick corresponds to $T = 100°C$?
   A) The second tick.
   B) Third tick mark.
   C) Fourth tick mark.
   D) Fifth tick mark.
   E) Sixth tick mark.
   F) The seventh tick.
   G) The eighth tick.
   H) Ninth tick mark.
   I) Tenth tick mark.
9. Each tick mark on the thermometer represents a temperature increase of how many Celsius degrees?
   A) 2°C
   B) 5°C
   C) 10°C
   D) 15°C
   E) 20°C
   F) 25°C
   G) 50°C
   H) 100°C

Now we can read the temperature for our other materials as well! Again, we assume that everything in the room starts out at the same room temperature, T_i (in Celsius degrees).



DETERMINE THE SPECIFIC HEAT (2 POINTS EACH)

To find the specific heat of the brick and the oil, we will have to figure out exactly how much heat energy we are adding when we drag the slider. Since the bucket slider isn't calibrated, what do we do? Notice that we can link the heaters, which means that they will generate identical output for both buckets. So if we place the iron on one stand and the brick on the other, they will receive the same amount of energy when we turn up the slider. Now we only need to figure out how much energy one cube absorbs!

Since we know the specific heat of iron, we can calculate how much energy that cube will absorb:

$$Q_{Fe} = m_{Fe}c_{Fe}\Delta T = m_{Fe}c_{Fe}(T_{Fe} - T_i)$$

$$Q_{Fe} = m_{Fe}\left(0.113\frac{\text{cal}}{\text{g}\cdot°\text{C}}\right)(150°\text{C} - T_i)$$

10. Use the mass of iron m_{Fe} from Question 2 above to calculate the energy that the cube will absorb when raised from T_i (from Question 7, in °C) to $T_{Fe} = 150°\text{C}$.
    - A) $Q_{Fe} = 1{,}110\text{cal}$
    - B) $Q_{Fe} = 2{,}050\text{cal}$
    - C) $Q_{Fe} = 11{,}100\text{cal}$
    - D) $Q_{Fe} = 20{,}500\text{cal}$
    - E) $Q_{Fe} = 111{,}000\text{cal}$
    - F) $Q_{Fe} = 205{,}000\text{cal}$

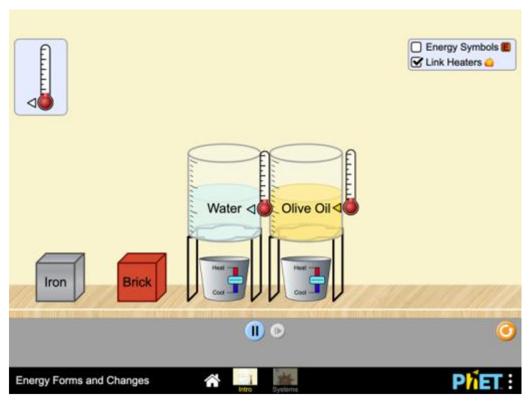
Now what? Well, now you need to heat both of these cubes until the iron reaches $T_{Fe} = 150°\text{C}$. When the iron cube reaches $T_{Fe} = 150°\text{C}$, quickly release the heat slider and hit the PAUSE button. If you wait too long, both cubes will begin to lose heat and come down in temperature. If you need to repeat the measurement, make sure you click the orange RESET button and start fresh with both cubes at room temperature.

11. When the iron cube reaches $T_{Fe} = 150°\text{C}$, what is the temperature of the brick cube?
    - A) $T_{br} = 200°\text{C}$
    - B) $T_{br} = 175°\text{C}$
    - C) $T_{br} = 150°\text{C}$
    - D) $T_{br} = 125°\text{C}$
    - E) $T_{br} = 100°\text{C}$
    - F) $T_{br} = 75°\text{C}$

Now let's calculate the specific heat c_{br} for the brick, using the same method that we used for the iron cube. Because the heaters were linked, the total energy absorbed by each cube will be the same:

$$Q_{br} = m_{br}c_{br}\Delta T = m_{br}c_{br}(T_{br} - T_i) = Q_{Fe}$$
$$Q_{Fe} = m_{br}c_{br}(T_{br} - T_i)$$
$$c_{br} = \frac{Q_{Fe}}{m_{br}(T_{br} - T_i)}$$

12. Use the values of m_{br}, Q_{Fe}, and T_{br} from the previous Questions 3, 10, and 11 to calculate the specific heat of the brick, c_{br}.
    - A) $c_{br} = 0.385\frac{\text{cal}}{\text{g·°C}}$
    - B) $c_{br} = 0.485\frac{\text{cal}}{\text{g·°C}}$
    - C) $c_{br} = 0.585\frac{\text{cal}}{\text{g·°C}}$
    - D) $c_{br} = 0.685\frac{\text{cal}}{\text{g·°C}}$
    - E) $c_{br} = 0.785\frac{\text{cal}}{\text{g·°C}}$
    - F) $c_{br} = 0.885\frac{\text{cal}}{\text{g·°C}}$
13. If the specific heat of brick is greater than the specific heat of iron, how is it possible for the brick cube to have a higher final temperature than the iron cube?
    - A) It's not; the final temperature of the brick cube is 25°C lower than the final temperature of the iron cube!
    - B) The cubes absorb the same amount of energy, but there are far fewer brick molecules than iron molecules. As a result, each brick molecule receives (on average) more energy than each iron molecule, and raises the brick temperature accordingly.
    - C) The cubes absorb the same amount of energy, and they also have the same total number of molecules. The higher specific heat of the brick means it will convert more of the absorbed energy into waste heat.
14. (1 point) Use this link: https://www.engineeringtoolbox.com/specific-heat-solids-d_154.html to look up the typical specific heat for brick. Is our calculated value for c_{br} too large or too small?
    - A) Too small.
    - B) Exactly identical.
    - C) Too large.



Let's do the same experiment with our beakers of water and oil and see if we can also find the specific heat c_{oil} of the olive oil. We know that the water will only heat up to $T_{H_2O} = 100°\text{C}$, so we can calculate the total amount of energy the water absorbs just like we did for the iron cube:

$$Q_{H_2O} = m_{H_2O}c_{H_2O}\Delta T = m_{H_2O}c_{H_2O}(T_{H_2O} - T_i)$$
$$Q_{H_2O} = m_{H_2O}\left(1\frac{\text{cal}}{\text{g·°C}}\right)(100°\text{C} - T_i)$$

15. Use the mass of iron m_{H_2O} from Question 5 above to calculate the amount of energy that the cube will absorb when raised from T_i (from Question 7, in °C) to $T_{H_2O} = 100°\text{C}$.
    - A) $Q_{H_2O} = 368\text{cal}$
    - B) $Q_{H_2O} = 1{,}200\text{cal}$
    - C) $Q_{H_2O} = 3{,}680\text{cal}$
    - D) $Q_{H_2O} = 12{,}000\text{cal}$
    - E) $Q_{H_2O} = 36{,}800\text{cal}$
    - F) $Q_{H_2O} = 120{,}000\text{cal}$

As you did previously, heat both beakers until the water reaches $T_{H_2O} = 100°\text{C}$. Release the heat slider and hit the PAUSE button so you can measure and record the temperature of the oil, T_{oil}.

16. When the water reaches $T_{H_2O} = 100°\text{C}$, what is the temperature of the olive oil?
    - A) $T_{oil} = 225°\text{C}$
    - B) $T_{oil} = 200°\text{C}$
    - C) $T_{oil} = 185°\text{C}$
    - D) $T_{oil} = 175°\text{C}$
    - E) $T_{oil} = 150°\text{C}$
    - F) $T_{oil} = 125°\text{C}$

Now let's calculate the specific heat c_{oil} for the brick, using the same method that we used previously. The total energy absorbed by the oil will be the same as the energy absorbed by the water:

$$Q_{oil} = m_{oil}c_{oil}\Delta T = m_{oil}c_{oil}(T_{oil} - T_i) = Q_{H_2O}$$
$$Q_{H_2O} = m_{oil}c_{oil}(T_{oil} - T_i)$$
$$c_{oil} = \frac{Q_{H_2O}}{m_{oil}(T_{oil} - T_i)}$$

17. Use the values of m_{oil}, Q_{H_2O}, and T_{oil} from the previous Questions 6, 15, and 16 to calculate the specific heat of the oil, c_{oil}.
    - A) $c_{oil} = 0.211\frac{\text{cal}}{\text{g·°C}}$
    - B) $c_{oil} = 0.311\frac{\text{cal}}{\text{g·°C}}$
    - C) $c_{oil} = 0.411\frac{\text{cal}}{\text{g·°C}}$
    - D) $c_{oil} = 0.511\frac{\text{cal}}{\text{g·°C}}$
    - E) $c_{oil} = 0.611\frac{\text{cal}}{\text{g·°C}}$
    - F) $c_{oil} = 0.711\frac{\text{cal}}{\text{g·°C}}$
18. (1 point) Use this link: https://www.engineeringtoolbox.com/specific-heat-fluids-d_151.html to look up the specific heat for olive oil. True or false: Our calculated value for c_{oil} is more accurate than our calculated value for the brick, c_{br}.

19. Once the water reaches $T_{H_2O} = 100°\text{C}$, it stops increasing. Why doesn't the temperature keep getting higher?
    A) Because the water stops absorbing energy at this point.
    B) Because the absorbed energy results in the water turning to steam.
    C) Because the glass beaker takes over energy absorption at this point, and the water cannot get any additional energy.