# General Physics Lab 10

## Calorimetry

## Objectives:

- To determine the specific heat of a solid **or**
- To determine the latent heat of fusion of water

## Equipment:

**Option 1 – Specific Heat**

- Steel Hex Nut
- Thread (about 1 meter)
- Pot of Boiling Water
- Wooden Spoon or Stick (longer than pot diameter)
- Cold Water

**Option 2 – Latent Heat of Fusion**

- Room Temperature Water
- Ice Cubes or Crushed Ice
- Normal Table Spoon (eating size)

**Both Options**

- Celsius Thermometer (analog or digital)
- Styrofoam Cup with Lid
- Extra Container of Water
- Spring Balance
- Duct Tape
- 2 Single-Quart Size Ziploc Bags
- Twine (about 35 cm)
- Small Towels

# Physical Principles:

### Specific Heat

The amount of heat, Q, that a body absorbs when its temperature is raised by an amount, ΔT, is given by,

$$Q = mc\Delta T \quad (1)$$

where m is the mass of the object and c is the specific heat of the matter in the object.

If heat is removed from the body, Eq. (1) still applies but with a negative value for, ΔT.

### Latent Heat of Fusion

When heat causes the substance to undergo a phase transition, the temperature does not change, but the added thermal energy transforms the substance from solid to liquid or liquid to gas. The latent heat of fusion, $L_f$, is the amount of heat needed to melt a unit mass of the substance.

$$Q = mL_f \quad (2)$$

### Entropy

The change in entropy, ΔS, is determined from the ratio of heat, Q, entering a system divided by the Kelvin temperature, T.

$$\Delta S = \frac{Q}{T} \quad (3)$$

The 2$^{nd}$ Law of Thermodynamics states that the entropy of the Universe must always increase.

$$\Delta S_{Universe} > 0 \quad (4)$$

**Note: You may choose to study either Specific Heat (Option 1) or Latent Heat of Fusion (Option 2). You are not required to do both experiments.**

# Procedure (Option 1):
## Specific Heat of Steel

**IMPORTANT!**
**Read the instructions carefully before starting the experiment so you know exactly what to do. Timing is critical for these experiments so you do not want to waste time figuring out the instructions at the last moment.**

1. Fill a pot about ½ full of water, place it on the stove, and bring to a boil. Meanwhile…
2. Hang the spring balance by the top loop and zero it if necessary.
3. Use the spring balance to measure the mass of the steel hex nut (see Fig. 1a).
4. Tie a piece of thread (about 1 m long) to the hex nut and suspend it from a wooden spoon at midlevel in the pot of water. It must be below the water surface while not touching the sides or bottom of the pot (see Fig. 1).

   Note: Do not tie the thread to the spoon or it will be hard to remove quickly. Wrap the extra thread around the spoon many times to keep it from slipping. This may also make it easier to adjust the height of the nut in the water by turning the spoon.

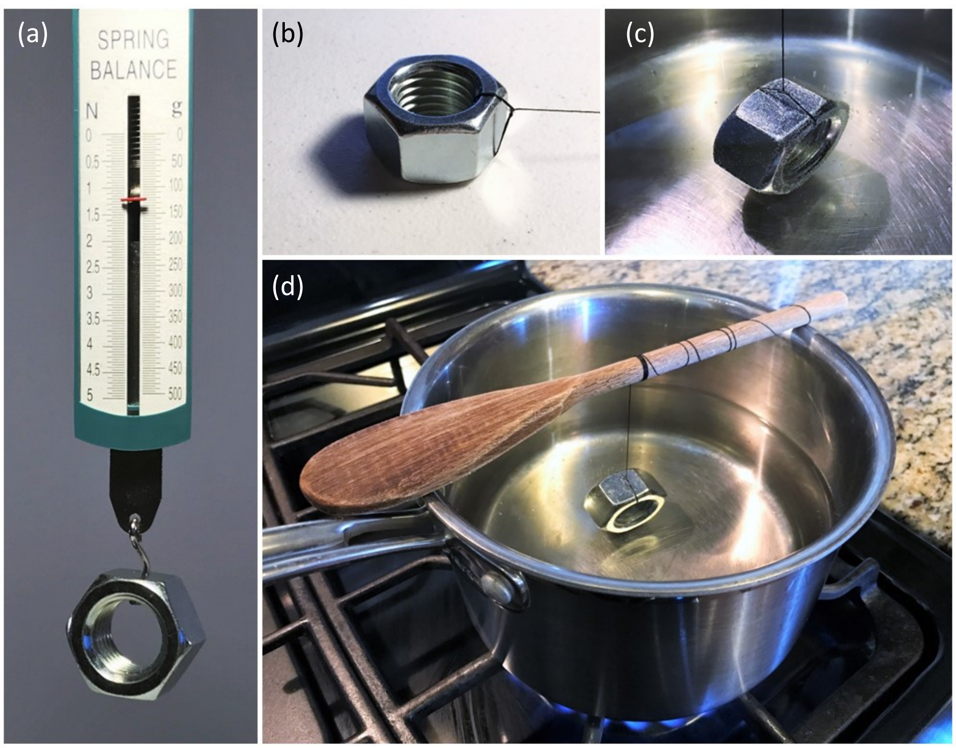


Fig. 1: (a) Weigh the hex nut on the spring balance. (b) Tie a long piece of thread to the nut. (c, d) Wrap the thread around a wooden spoon/stick/etc. and suspend it in the water, below the water surface and above the bottom of the pot. Add more water if necessary.

5. Tape a piece of twine (about 35 cm) to the top of the Ziploc-type plastic bag using duct tape. This makes a loop or handle to hang the bag from (see Fig. 2).
   Make sure the twine handle is secure (you don't want it slipping out while it's holding a cup of water) and check to see that you can easily place the cup in the bag and remove it again without spilling water from the cup.

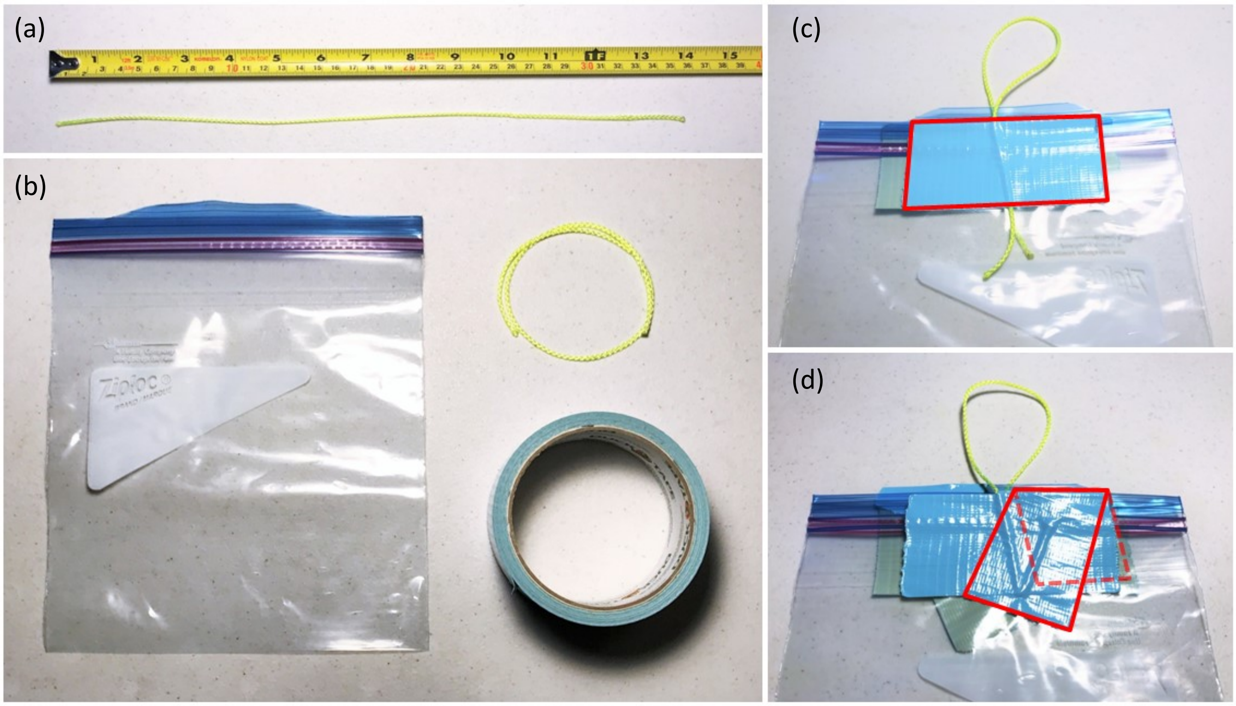


Fig. 2: (a) Cut a length of twine about 35 cm long. (b) Use duct tape to attach the twine to a Ziploc-type bag. (c) Tape the twine to the top of the bag on both sides with a small bit extending below the tape. (d) Fold the extra twine back over the tape and tape it again to keep it from pulling out from under the tape.

6. Place the empty cup in the bag (no water or lid) and measure the mass of the bag and cup on the spring balance (see Fig. 3a).
7. Once the water in the pot has come to a boil, measure the temperature of the boiling water – same temperature as the hot steel (see Fig. 3b).
   **Hold the thermometer in the water near the nut. Do not leave it in the pot.**
   **Be careful as the thermometer may be very hot to touch afterwards.**

8. Keep the pot boiling with the hex nut submerged and place the thermometer in an extra glass of cold water for a few minutes to equilibrate the thermometer temperature (see Fig. 3c).
9. Fill the Styrofoam cup about half way up with **cold** water (don't bother weighing it right now – you will do this later).
10. Wrap towels around the sides and bottom of the cup (to insulate it), and measure the cold water temperature with the thermometer (see Fig. 3e).

11. Use the string to remove the hex nut from boiling water and quickly transfer it into the Styrofoam cup. Then put the lid on the cup, insert the thermometer through the hole in the lid, and cover the lid and all sides of the cup with the towels (keep the heat inside) (see Fig. 3f).
12. Use the thermometer to swirl and stir the water encouraging rapid heat exchange with the nut. All the time, keep the cup and lid covered with the towels to limit the loss of heat to the environment (see Fig. 3f).
13. As soon as the temperature on the thermometer stops rising, record the final temperature of the nut/water combination.
14. Remove the lid and thermometer (shake water off thermometer back into the cup) and weigh the cup, water, and hex nut on the spring balance (see Fig. 3g).
15. Subtract off the weight of the bag, cup, and hex nut to find the mass of the water.


Fig. 3: (a) Weigh the bag and empty cup. (b) Measure the boiling water (hot hex nut) temperature. (c) Place the hot thermometer in a cup of cold water to cool it off. (d) Fill the Styrofoam cup half-way with cold water and get some towels and the thermometer ready. (e) Wrap towels around the bottom and sides of the cup and measure the cold water temperature. (f) Quickly transfer the hot hex nut to the Styrofoam cup, place the lid on top, insert the thermometer, and cover everything with the towels. Stir with the thermometer and swirl the cup gently to encourage rapid heat exchange. When the temperature stops rising, record the final temperature. (g) Remove the thermometer and lid, and weigh the cup with the water and hex nut.

## Analysis (Option 1):

1. Apply Eq. (1), assuming that all the heat added to the water flowed out of the hot steel.

$$m_{steel}\, c_{steel}\, |\Delta T_{steel}| = m_{water}\, c_{water}\, |\Delta T_{water}| \tag{5}$$

2. Solve Eq. (5) for the specific heat of steel, $c_{steel}$, and calculate the value in units of J/kg·°C and cal/g·°C. The specific heat of water, $c_{water}$, is 4186 J/kg·°C or 1 cal/g·°C.
3. Use a percent error to compare your measured specific heat with the theoretical value for low carbon steel of 465 J/kg·°C [1] or 0.111 cal/g·°C.

$$\%Error = \frac{|c_{theory} - c_{meas}|}{c_{theory}} \times 100\% \tag{6}$$

4. Compute the change in entropy of the steel from

$$\Delta S_{steel} = -\frac{m_{steel}\, c_{steel}\, |\Delta T_{steel}|}{T_{steel\ ave}} \tag{7}$$

where $T_{steel\ ave}$ is the average **Kelvin** temperature of the steel.

$$T_{steel\ ave} = \frac{T_{steel\ initial} + T_{steel\ final}}{2} \text{ [Kelvin]} \tag{8}$$

Report entropy in units of J/K.

5. Compute change in entropy of the water from

$$\Delta S_{water} = +\frac{m_{water}\, c_{water}\, |\Delta T_{water}|}{T_{water\ ave}} \tag{9}$$

where $T_{water\ ave}$ is the average **Kelvin** temperature of the water.

$$T_{water\ ave} = \frac{T_{water\ initial} + T_{water\ final}}{2} \text{ [Kelvin]} \tag{10}$$

6. Compute the change in entropy of the Universe.

$$\Delta S_{Universe} = \Delta S_{steel} + \Delta S_{water} \tag{11}$$

Is your result in agreement with the 2$^{nd}$ Law of Thermodynamics?

[1] Metals Thermal Properties, Engineers Edge

 

## Procedure (Option 2):
### Latent Heat of Fusion of Water

**IMPORTANT!**
**Read the instructions carefully <u>before</u> starting the experiment so you know exactly what to do. Timing is critical for these experiments so you do not want to waste time figuring out the instructions at the last moment.**

1. Tape a piece of twine (about 35 cm) to the top of the Ziploc-type plastic bag using duct tape. This makes a loop or handle to hang the bag from (see Fig. 2).
   Make sure the twine handle is secure (you don't want it slipping out while it's holding a cup of water) and check to see that you can easily place the cup in the bag and remove it again without spilling water from the cup.
2. Hang the spring balance by the top loop and zero it if necessary.
3. Hang the empty bag from the spring balance and record the mass (see Fig. 4a).
4. Place the empty Styrofoam cup in the bag (no water or lid) and measure the mass of the bag and cup on the spring balance (see Fig. 4b).
5. Fill the cup about half full of room temperature water, place the cup in the bag, and check the mass of the water ($m_{water} = m_{total} – m_{bag+cup}$). Add or remove water until you have about 100g of water (see Fig. 4c-e). Then record the mass of the water.

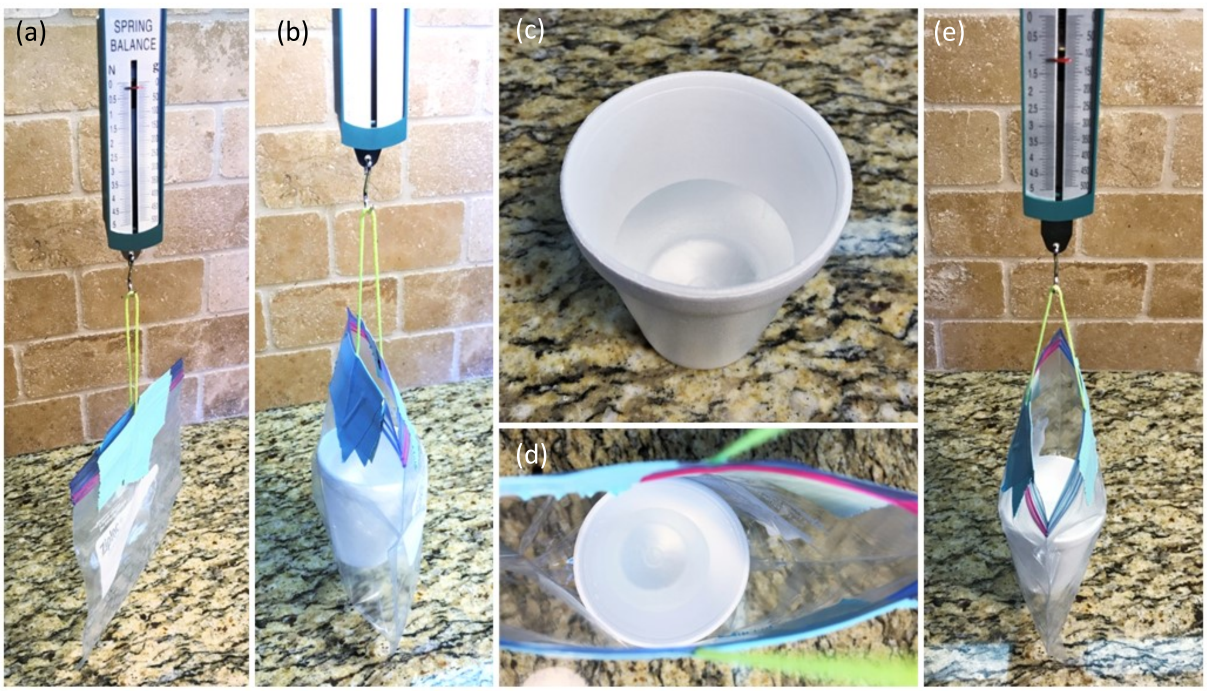


Fig. 4: (a) Weigh the empty bag. (b) Weigh the bag and empty cup. (c) Fill the Styrofoam cup about half-way with room temperature water. (d, e) Place the cup in the bag and weigh the water. Adjust the amount of water in the cup until you have about 100g of water. Subtract the mass of the bag and cup from the total mass to get the mass of the water.

6. Use the thermometer to measure the water temperature (see Fig. 5a).
7. Prepare some ice for the experiment.
    a. If you have access to crushed ice (not too crushed), dispense a small amount (equal to the size of 1 large ice cube) into a **second** Ziploc bag.
    b. If you do not have crushed ice, take 1 large ice cube (see Fig. 5b), or several smaller ice cubes, place it in a **second** Ziploc bag and smash it until you have at least 10 larger, roughly equal-sized chunks. If there are any smaller ice pieces or water in the bag, these will be left behind when you remove the larger pieces.
8. Put the thermometer in the ice bag. Once a small amount of ice has melted (ice temperature near 0 $^{o}$C), measure the temperature of the ice in the bag (see Fig. 5c).
9. Place the thermometer in an extra glass of warm/room temperature water to bring the thermometer back up to room temperature (see Fig. 5d).
10. Use a spoon to remove about 10 larger roughly equal-sized ice chunks from the bag (leave the water and powdered ice behind) and place the chunks in the bag with the twine handle. Weigh the ice/bag combo (see Fig. 5e) and subtract the mass of the bag to get the mass of the ice (do this calculation later after the experiment is over).
11. Empty the ice chunks into the Styrofoam cup of water and use the thermometer to stir/swirl (speed up the melting) until the ice melts completely (see Fig. 5f & g). You do not need the lid for this since the ice should melt quickly and you need to see when the ice is fully melted.
12. **As soon as the last bit of ice has melted**, record the final temperature on the thermometer. You need to watch carefully so you can record this temperature right when the ice finishes melting, otherwise the cold water (melted ice) will decrease the water temperature further.

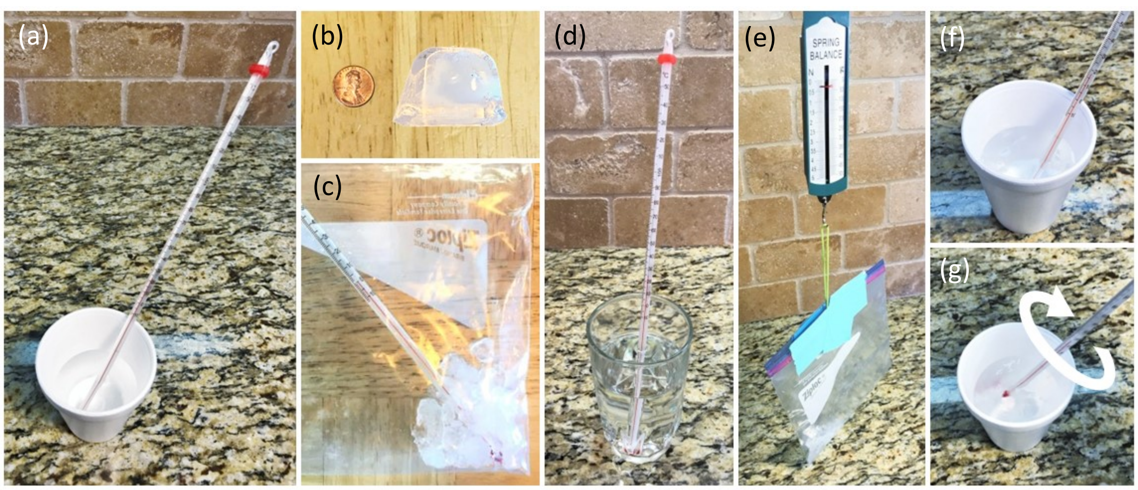


Fig. 5: (a) Measure the temperature of the room temperature water. (b) Use crushed ice or crush 1 large ice cube (or several smaller ice cubes), (c) Measure the temperature of the ice in the bag. (d) Place the thermometer in an extra glass of warm/room temp water. (e) Scoop out about 10 larger roughly equal-sized chunks of ice and weigh them in the bag hanging from the spring balance. (f) Dump the ice in the Styrofoam cup of water and (g) stir with the thermometer until the ice melts. Then immediately check the final temperature.

## Analysis (Option 2):

1. Apply Eq. (2), assuming that all the heat added to the ice flowed out of the room-temperature water.

$$m_{ice}\, L_{ice} = m_{water}\, c_{water}\, |\Delta T_{water}| \quad (12)$$

2. Solve Eq. (12) for the latent heat of fusion of water, $L_{ice}$, and calculate the value in units of J/kg and cal/g. The specific heat of water, $c_{water}$, is 4186 J/kg·°C or 1 cal/g·°C.
3. Use a percent error to compare your measured value with the theoretical value, $L_{f\ water}$ = 334,000 J/kg or 79.8 cal/g.

$$\%Error = \frac{|L_{f\ theory} - L_{f\ meas}|}{L_{f\ theory}} \times 100\%$$

(13)

4. Compute the change in entropy of the ice from

$$\Delta S_{ice} = +\frac{m_{ice}\, L_{ice}}{T_{ice}} \quad (14)$$

where $T_{ice}$ is the constant **Kelvin** temperature of the ice. Report entropy in units of J/K.

5. Compute the change in entropy of the water from

$$\Delta S_{water} = -\frac{m_{water}\, c_{water}\, |\Delta T_{water}|}{T_{water\ ave}} \quad (15)$$

where $T_{water\ ave}$ is the average **Kelvin** temperature of the water.

$$T_{water\ ave} = \frac{T_{water\ initial} + T_{water\ final}}{2} \text{ [Kelvin]} \quad (16)$$

6. Compute the change in entropy of the Universe.

$$\Delta S_{Universe} = \Delta S_{ice} + \Delta S_{water} \quad (17)$$

Is your result in agreement with the 2nd Law of Thermodynamics?