Physics 157 Homework 3: due Wed, Oct 2rd by 5pm

This week's homework will mostly be completed in Mastering Physics, but for two of the questions, we'll ask you to write out the solutions and hand them in, to be graded for participation credit. This is to ensure that you have practice actually writing down the solution since a similar style of problem may appear on the midterm.

Classes this past week have focused on the flow of heat and its effect on changes in temperature and phase. In this week's homework you will get practice applying the quantitative relationships that govern these effects. Specific skills you will practice include:

- To calculate the amount of heat required to change the temperature of an object by a fixed amount, or to change the phase of a given amount of material.
- For systems with multiple parts initially at different temperatures and/or in different phases, to calculate the final equilibrium temperature and/or portion of the system in each phase.
- Given data for the temperature as a function of heat added, or the temperature as a function of time for a heat source with a specified power, to deduce the specific heat and/or latent heat of a material
- To calculate the rate of heating/cooling/phase change in situations where heat transfer is taking place via conduction

Part 1: Mastering Physics

Log in to Mastering Physics through Canvas and do **Mastering Physics Assignment 3**. Most of the Mastering Physics questions are fairly straightforward. They are there to help make sure you understand the basic steps that will appear in more complicated problems.

Part 2: Written questions

Two of the Mastering Physics questions ask you to write up solutions and hand them in. For these, you will still put your answers in Mastering Physics, but your written solutions will be checked for participation credit (i.e. full credit just for handing them in). The reason that we are having you hand these in is that these are midterm-style questions and we want you to have practice writing down the solution.

Next page: homework tips

The following pages: extra practice problems from old midterms

Heat/ phase change problems:

In these problems, it's again useful to consider each component of the system separately. Here, a good starting point is to write down an equation for the heat that flows into the system (this may be negative). This will always be of the form $Q = m\,c\,\Delta T$ or $Q = mL$, or some combination. For example, with ice at -20 degrees Celcius going to water at 30 degrees Celcius, we'll have the heat to bring the ice to the melting point, plus the heat to melt the ice, plus the heat to bring the resulting water up to 30 degrees.

If some ice melts and some doesn't you can treat these as separate components of the system.

Next, write down any equations that relate the parts. We always have that the sum of the heats added to each part equals the total heat added to the whole system (which is often zero).

We also have that all parts of the system must have the same final temperature. If the system contains both ice and water at the end, this temperature is 0 degrees.

Conduction problem tips:

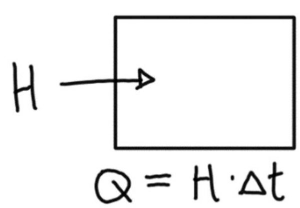
As usual, it's helpful to draw a picture and label it, and break the system into parts.

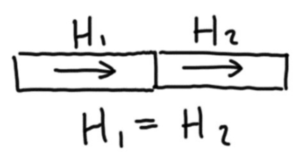
For the part or parts of the system through which heat is flowing, you will need the basic relation:

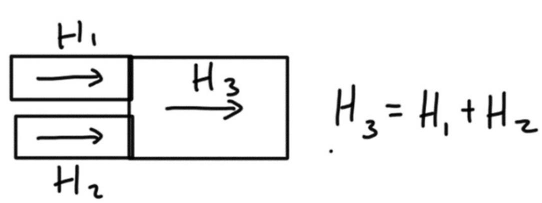
$$\mathbf{H = k\,A\,(T_H - T_C)/L}$$

For parts of the system undergoing a temperature or phase change, you will need the relation $\mathbf{Q = mL}$ or $\mathbf{Q = m\,c\,\Delta T}$.

Finally, you will need to relate the heat currents and heats for the various parts. For example, if a heat current H is going into a system, the amount of heat that enters in time Δt is $Q = H\,\Delta t$. If heat is flowing through two adjacent objects in series, the heat current is the same for both. If they are side-by-side, the heat currents add up. These ideas are summarized below:







Extra practice (not to be handed in): old midterm questions

2. A Russian nuclear icebreaker named "50 Let Pobedy", has a length of about 160 m, width of about 30 m and 2 nuclear reactors delivering about 60 MW of power. It can clear a 35 m wide path in 2m thick ice (at -10°C) for other ships moving at a speed of 5 knots (2.5 m/s). Somebody suggested that instead of breaking the ice one should melt it with a gigantic heater mounted at the front of the ship.

a) What power heater would be required?
b) Explain in one sentence whether or not such a heater would work on this or a similar ice breaker.

Specific heat of ice: 2050 J/(kgK), latent heat of ice $334 \times 10^3 J/kg$: density of ice 916 kg/m^3

3. A bicycle tire can (but rarely!) become over-pressurized and blow out when the cyclist applies the brakes to reduce her speed when travelling down steep hills. A particular road bike tire is rated to 120 psi (924 kPa absolute pressure) and is initially filled to this pressure. The pressure specification has a safety margin of 25% before failure occurs. What amount of heat transferred into the air in the tire would cause failure? The volume of the tire is 1 L (0.001 m^3). You can assume the volume change is negligible and treat the air as a diatomic ideal gas ($c_v = \frac{5}{2}R$).

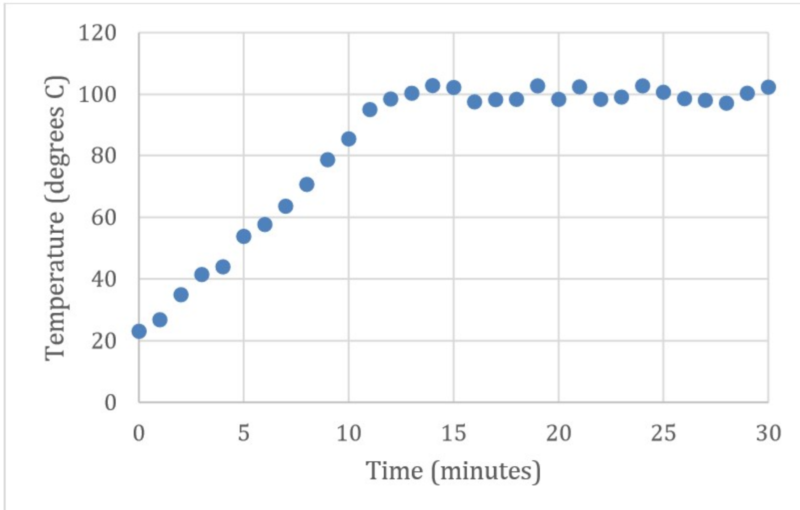
Problem 1. A professional level range for the home has a high-output 12,000 BTU burner which delivers heat to the pot at a rate of 5,000 BTU/hr. You turn the stove on high, place a large copper pot full of water to boil on the burner, and, being a physicist, connect a temperature recording device before walking away. (Don't try this at home if your system does not have an alarm!) When you come back 30 minutes later, the pot is at a rapid boil. Given the temperature versus time graph below:

a. How much water (in litres) was in the pot at the start?
b. What mass of water boiled off? (Changed into water vapor?)

State your assumptions.

Data:

c_{copper} = 390 J/kg K
k_{copper}= 385 W/m K
c_{water} = 4190 J/kg K
$L_{v,\ water}$ = 2256 kJ/kg
ρ_{water} = 1 kg/L
1 BTU = 1055 J

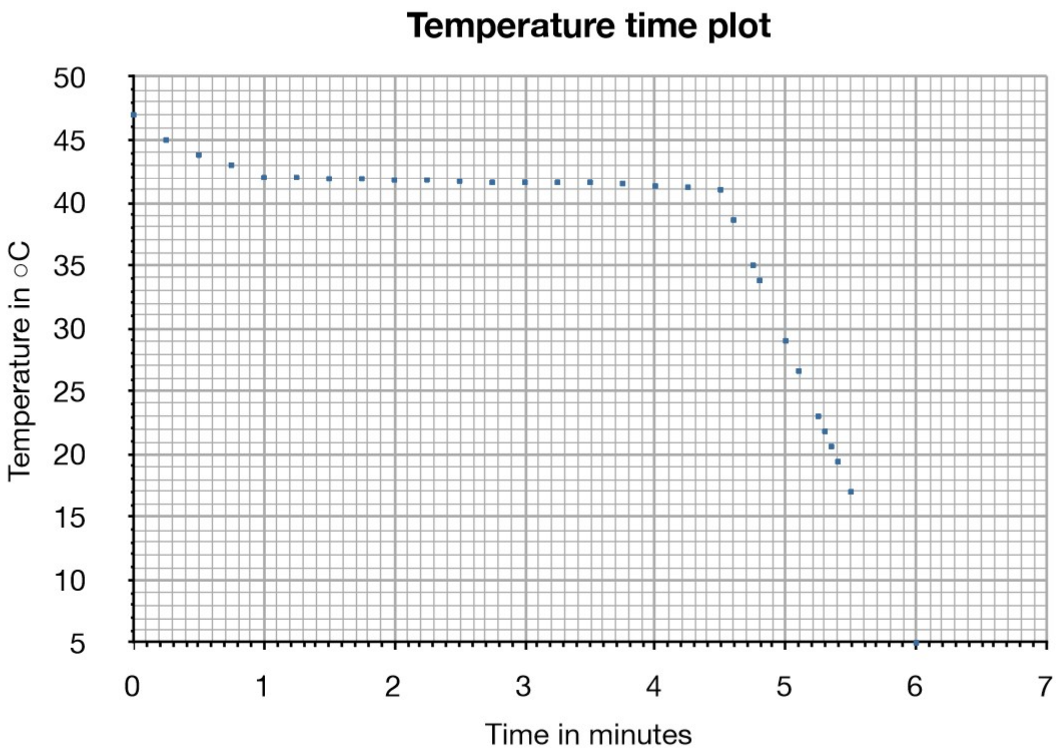


3. Lauric acid is a saturated fat found in a number of foods which is also used in the construction of thermal energy storage systems. An engineer trying to develop a better material to be used in a heating unit runs several experiments on a sample of Lauric acid and presents the cooling curve below. The 689 gram sample of liquid Lauric acid is cooled starting at 47°C. During the experiment, the Lauric acid changes states. The cooling source provides a constant cooling power of 600 W to the sample.

a) Find melting point of this sample of Lauric acid.

b) Find the latent heat of fusion of this sample of Lauric acid.

c) Find the specific heat of the sample of Lauric acid when in its solid state.



2. On a hot day, a student mixes 25 grams of fruit juice at $10°C$ with 250 grams of crushed ice at temperature of $-25°C$ in an insulated cup. Assume that the thermal properties of the fruit juice are the same as those of water. Find the final temperature of this tasty treat.

(Neglect the heat capacity of the cup and heat exchange with the environment.)
Useful Constants: $c_{\text{ice}} = 2100 J/kg\,K$, $c_{\text{water}} = 4190 J/kg\,K$, heat of fusion for water/ice is $L_f = 334,000 J/kg$.

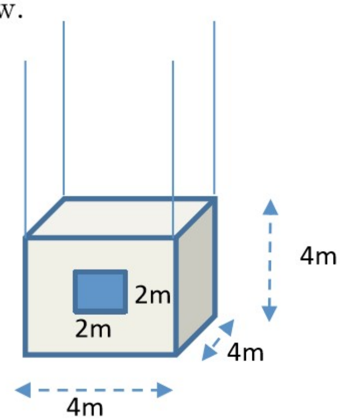
Questions involving conduction

2. A lab was asked to perform an experiment to measure an R-value of double glazed windows. They had an insulated cubic chamber with the dimensions of 4 m × 4 m × 4 m and walls made of a material with an R-value of 5 $\text{ft}^2 \cdot {}^\circ F \cdot h/BTU$ suspended from the ceiling of the lab on ropes. The inside of the chamber was heated with a heater to keep the temperature constant at 40°C. The lab outside the chamber had a stable temperature of 22°C.

a) Find the power of the heater inside.

b) It was observed that after replacing a part of one of the walls with a square window of 2 m × 2 m, the power of the heater had to be increased by 100 W to maintain the temperature inside. Find the R-value of the window.

Note: 1 $\text{ft}^2 \cdot {}^\circ F \cdot h/BTU = 0.17\ m^2 \cdot K \cdot s/J$



Problem 2. You are trying to boil water in a beaker (cylindrical container), but you only have a beaker made of a plastic, polycarbonate, that softens above 150°C. The beaker is 10cm in diameter; the walls and bottom of the beaker are 1mm thick. The beaker is filled with 100 ml of boiling water, then placed on a hotplate. The power of the hotplate is as high as possible while not allowing the bottom surface of the beaker to become soft.

Some possibly relevant data:

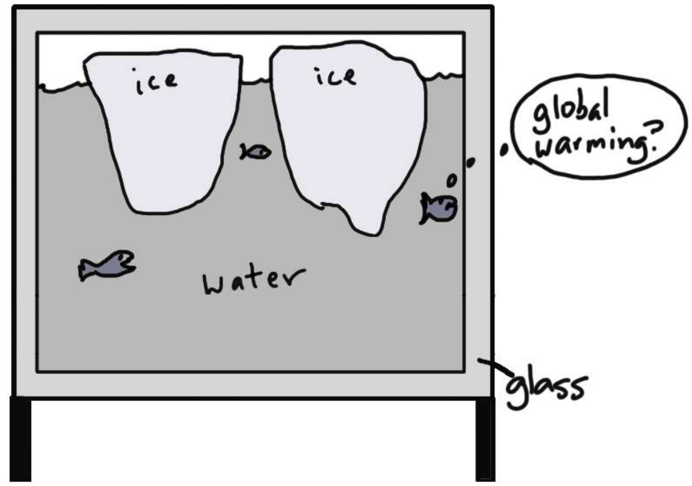
Thermal conductivity for polycarbonate is 0.2 $\frac{W}{m \cdot K}$,
$L_{fusion}^{water} = 334 \times 10^3 \frac{J}{kg}$, $L_{vap}^{water} = 2256 \times 10^3 \frac{J}{kg}$, $c_{water} = 4190 \frac{J}{kg\,K}$, $\rho_{water} = 1 \frac{kg}{L}$,
$c_{ice} = 2100 \frac{J}{kg\,K}$.

(a) What is the power of the hot plate?

(b) How long does it take for the water to boil completely away, so nothing is left in the beaker?

Assume no heat is lost out the walls of the beaker.

7) Jojo sets up a "Fish-of-the-North" aquarium of dimensions 30x30x30cm with all six walls made of 0.5cm thick glass. The aquarium is filled with 8kg of water and 8kg of ice. Both the ice and the water start at 0°C. There are also a few small fish. The aquarium sits in a room whose temperature is controlled to stay at 25°C.



Immediately after filling, the ice starts melting. In half an hour, all the ice is gone.

a) What is the temperature of the outside surface of the aquarium walls as the ice is melting, assuming that this is constant over the entire surface? *Note: this will be less than the temperature of the room (which is not relevant for this part). Neglect any heat generated by the fish.* ***(8 points)***

Constants: $k_{glass} = 1W/(m\ K)$, $L_f = 334{,}000 J/kg$

b) On the axes, sketch the temperature of the water as a function of time, starting from the time the ice started to melt and extending several hours. Provide a few short notes below the graph to explain the important features of your graph. (2 points)

(*Note: No fish are harmed since Jojo moves them to another container)*

c) BONUS: Can you explain why the outside temperature of the aquarium must be cooler than the ambient room temperature while the ice is melting? (1 point)