Physics 272: Problem Set 1

•Due on **Sep 20th, 2025** by Midnight, **no exceptions**
•Each question worth 10 points, total of 5 questions
•Based mostly on University Physics 17.1-17.5
•Help sessions: Mon 6:00-7:00 pm and Thur 6:00-7:00 pm, HAS 306
•Upload your work as a PDF to the Problem Set 1 Assignment on Canvas. After your pdf is uploaded, you will need to tell the assignment where each question is on the pdf. For instance, if your work for Question 1 is all on page 1 then click on Question 1 in the Outline and then click on page 1 of your pdf. Page 1 will then have a large green checkmark. It will also show Q1 (question 1) at the bottom of the page. In the Question Outline you will also see P1 (page 1). These also have an "x" if you make a mistake choosing the appropriate page. If your work for a question spans more than one page, you should choose multiple pages. Then be sure to click Submit.

A link to the **Latex Source file** of this problem set can be found here: . If you are unable to open the .tex file, please try using Adobe Acrobat pdf Reader.

•**Upload Format:** LaTeX generated homework is strongly preferred. If you submit at least 8 out of 10 Homeworks in LaTeX, you will receive 2% bonus for overall score of the course. Note that 4% is one grade higher.View sample Overleaf LaTeX templates `here`. The **LaTeX Cheat Sheet is available** **`here`.** Further guidelines on Canvas.

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(1) **Specific Heat of an Unknown Metal**
A 250 g mass of an unknown metal at the boiling temperature of water is placed in an insulated box containing 500 g of water at a temperature of 20.0° Celsius. Eventually the system comes to equilibrium at 22.0° C. Assume the system is isolated, so no heat is exchanged with the environment.
(a) What can we say about the sum of heats absorbed: $\Delta Q_{\text{unknown}} + \Delta Q_{\text{water}} =?$
(b) Find the specific heat of the metal, C_u, in units of J/kg·K.

Rubrics:
(a) Correct result (3 points)

(b)Correct expression for C_u (4 points)
Correct answer fo C_u (3 points)

(2) **Hot Air in Physics 272 Lecture Hall**
(a) A typical student has a heat output of almost 100 W. How much heat do the 85 students of Physics 272 produce in the 50 minute class?
(b) If the room has a volume of roughly 3000 m^3, the specific heat of air is 1020 J/kg·K, and the density of air is 1.20 kg/m^3, what is the temperature rise in the lecture hall if the room is perfectly insulated and the air conditioning is off? Rubrics:
(a) Correct expression for ΔQ (3 points)
Correct result for ΔQ(2 points)

(b)Correct expression for ΔT (3 points)
Correct answer fo ΔT (2 points)

(3) **Specific Heat and a Three-Component System**
Consider a container (such as a travel mug) with an interior made of metal, that is perfectly insulated from the environment. Coffee at the boiling temperature of water is added to the container along with a smaller amount of cream. Assume the metal liner and cream were initially at 20°C

(so $T_{i,met} = T_{i,cr} = 20°\text{C}$).
(a) We denote the heat exchanged by the coffee by ΔQ_{cf}. By convention, if $\Delta Q_{cf} > 0$, heat was absorbed by the coffee. When the system (coffee, cream, metal) reaches equilibrium, what can we say about the sum of the heat exchanged by the three components:
$\Delta Q_{\text{cf}} + \Delta Q_{\text{met}} + \Delta Q_{\text{cr}} =$? (b) What is the sign of each term, ΔQ_{cf}, ΔQ_{met}, ΔQ_{cr}? (c) Denote the masses and specific heats of the metal, cream, and coffee by m_{met}, m_{cr}, m_{cf} and c_{met}, c_{cr}, c_{cf}. Find the general formula for the equilibrium temperature in terms of these quantities and the initial temperatures $T_{i,met}$, $T_{i,cr}$, $T_{i,cf}$.

(d) Suppose the specific heat of the metal is: $c_{met} = \frac{1}{10} c_{cf}$ which is quite reasonable, and that the specific heat of cream is the same as coffee, $c_{cr} = c_{cf}$. Let the relation between the masses of the metal, cream, and coffee be: $m_{met} = m_{cr} = \frac{1}{10} m_{cf}$. Using this information, and your answer from part (a), what is the equilibrium temperature in degrees Celsius? Rubrics:
(a) Correct result for ΔQ_{total} (2 points)

(b)Correct result for each ΔQ(3 points)

(c)Correct expression for ΔT_f (3 points)

(d)Correct answer fo ΔT (2 points)

(4) **Debye's T^3 Law**
The molar heat capacity of rock salt, C_{rs}, varies with temperature according to Debye's T^3 law: $C_{rs}(T) = k\,(T/T_D)^3$ where $k = 1940$ J/mol·K and $T_D = 281$K (the latter is a constant called the Debye temperature).
(a) How much heat is required to raise the temperature of 1.50 mol of rock salt from 10.0 K to 40.0 K? (Hint: Use the equation $\Delta Q = nC\Delta T$ in the form $dQ = nCdT$ and integrate, noting that C can be a function of T)

Rubrics:
(a) Correct integration (3 points)
Correct result for algebraic expression (5 points)
Correct result for Q (2 points)

(5) **Temperature Effects on Accuracy of a Clock**
A pendulum clock has a heavy bob attached to an aluminum shaft of negligible mass (it can be ignored). The clock is designed so at 20°C a complete period is 1.0000 seconds (swinging from one side to the other then back). We want to see how the accuracy is affected by temperature changes. The latter cause changes in length of the shaft.

(a) Show that the fractional change in period $\Delta\tau/\tau$ caused by a small fractional change in length $\Delta L/L$ obeys the relation:
$\frac{\Delta\tau}{\tau} = \frac{1}{2}\frac{\Delta L}{L} = \frac{1}{2}\alpha\Delta T$

where α is the coefficient of linear expansion of aluminum, and ΔT is the change in temperature. (Hint: find the equation for the period of a pendulum, then use Taylor Expansion or Binomial Theorem/Expansion)

(b) In very hot weather ($T \gg 20^\circ$ C) will a pendulum clock show a later time compared to a perfect clock, or an earlier time?

(c) What is the fractional change in the length of the aluminum shaft when it is cooled from 20°C to 10.0°C?

(d) Suppose a particular pendulum clock keeps perfect time at 20.0°C, but it is operated at 10.0°C. After exactly 24 hours (as determined by a perfect clock), what is the difference in reading of the pendulum clock compared to a perfect clock? Give your answer in seconds and explain whether the pendulum clock was slower (shows earlier time than perfect clock) or faster (shows a later time).

(e) How closely must the temperature be controlled if the clock is not to gain or lose more than 1.00 second per day?

(f) Look up a table of coefficients of thermal expansion and recommend a better material than aluminum for a pendulum shaft.

Rubrics:

(a) Correct process of proving for $\frac{\Delta\tau}{\tau} = \frac{1}{2}\frac{\Delta L}{L} = \frac{1}{2}\alpha\Delta T$ (2 points)

(b)Correct conclusion(1 point)

(c)Correct $\frac{\Delta L}{L}T$ (2 points)

(d)Correct Δt (2 points)

(e) Correct ΔT(2 points)

(f) Correct materials (1 point)