

PHYS 212 Examination 1

Name (print): _____

Signature _____

Problem 1 _____

Problem 2 _____

Problem 3 _____

Problem 4 _____

Problem 5 _____

Problem 6 _____

Total _____

Directions: This exam contains six problems worth 20 points each for a possible 120/100 points. Your solutions should be written as neatly as possible and arranged in a logical manner. Credit will be awarded on the basis of thought, compactness, and neatness of the written solution. Remember to use basic physical principles in solving the problems. Show all of your work. I will not award full points for a problem with a solution that I am unable to decipher even if the answer is correct.

An equation sheet has been provided. CRC handbooks are allowed. Calculator rule is in effect. Good Luck!

Problem 1. A copper slug having a mass of 75 grams is heated to a temperature of 312°C. The slug is dropped into a beaker containing 220 grams of water. The initial temperature of the water and beaker is 12°C. What is the final equilibrium temperature of the system? (Hint: *heat capacity C*, is not the same as specific heat which is heat capacity per unit mass)

Note: $C_{\text{beaker}} = 45 \text{ cal/K}$ (heat capacity) , $c_{\text{water}} = 1.00 \text{ cal/g}\cdot\text{K}$, $c_{\text{copper}} = 0.0923 \text{ cal/g}\cdot\text{K}$

$$-m_{\text{Cu}}c_{\text{Cu}}\Delta T = m_{\text{w}}c_{\text{w}}\Delta T + C_{\text{beaker}}\Delta T$$

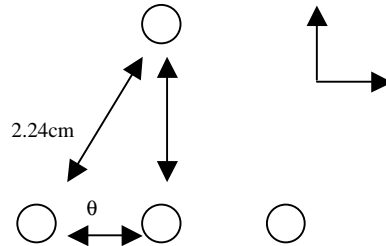
$$m_{\text{Cu}}c_{\text{Cu}}(T - T_f) = m_{\text{w}}c_{\text{w}}(T_f - T_i) + C_{\text{beaker}}(T_f - T_i)$$

$$T_f = \frac{m_{\text{Cu}}c_{\text{Cu}}T + C_{\text{beaker}}T_i + m_{\text{w}}c_{\text{w}}T_i}{m_{\text{Cu}}c_{\text{Cu}} + C_{\text{beaker}} + m_{\text{w}}c_{\text{w}}}$$

$$T_f = \frac{(0.0923 \text{ cal/g}\cdot\text{K})(75 \text{ g})(312^\circ \text{C}) + (45 \text{ cal/K})(12^\circ \text{C}) + (1.00 \text{ cal/g}\cdot\text{K})(220 \text{ g})(12^\circ \text{C})}{(0.0923 \text{ cal/g}\cdot\text{K})(75 \text{ g}) + (45 \text{ cal/K}) + (1.00 \text{ cal/g}\cdot\text{K})(220 \text{ g})}$$

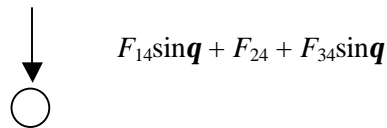
$$T_f = \frac{5339.8 \text{ cal}}{271.9 \text{ cal/C}^\circ} \approx 20^\circ \text{C}$$

Problem 2. Three point charges of $+5 \text{ nC}$ are arrayed 1 cm apart along a line as shown below. Compute the electric force on a fourth charge of -5 nC located 2 cm from the line containing the other three charges. What is the electric field at this point?



Some trigonometry yields 2.24 cm and $\sin \theta = \frac{\text{opp}}{\text{hyp}} = \frac{2 \text{ cm}}{2.24 \text{ cm}} \therefore \theta \approx 63^\circ$

By symmetry all x components cancel so we have a FBD consisting of:



This yields:

$$F_{\text{net}} = k \frac{q_1 q_4}{r^2} \sin \theta + k \frac{q_2 q_4}{r^2} + k \frac{q_3 q_4}{r^2} \sin \theta = k \left(\frac{q_1 q_4}{r^2} \sin \theta + \frac{q_2 q_4}{r^2} + \frac{q_3 q_4}{r^2} \sin \theta \right)$$

$$= k \left(\frac{25 \text{ nC}}{5 \times 10^{-4} \text{ m}^2} (0.89) + \frac{25 \text{ nC}}{4 \times 10^{-4} \text{ m}^2} + \frac{25 \text{ nC}}{5 \times 10^{-4} \text{ m}^2} (0.89) \right) = 1.36 \times 10^4 \text{ N} \therefore \vec{F} = 1.36 \times 10^4 \text{ N} - \hat{j}$$

$$E = F / q = 2.72 \times 10^8 \text{ V / m}$$

Problem 3.

- The surface of the sun has a temperature of about 5800K. If the radius of the sun is 6.96×10^8 m, calculate the total energy radiated by the sun each day. Assume that the sun has an emissivity of unity.

$$P = \epsilon A e T^4 \therefore P = (5.6696 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4) \left(4\pi (6.96 \times 10^8 \text{ m})^2 \right) (1)(5800 \text{ K})^4 = 3.9 \times 10^{26} \text{ J/s}$$

$$(3.9 \times 10^{26} \text{ J/s})(86400 \text{ s/day}) = 3.4 \times 10^{31} \text{ J !}$$

- A wall of a house whose face area, A , is 100 ft^2 , is made up of 4 inch bricks ($R = 4.00 \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}$), a thin dead air space ($R = 0.17 \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}$), 0.5 inches of sheathing ($R = 1.32 \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}$), fiberglass insulation 3.5 inches thick ($R = 10.90 \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}$) and 0.5 inches of drywall ($R = 0.45 \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}$). If the outside temperature on a cold day is 15°F and the inside temperature is 68°F , what is the rate of heat transfer through the wall? In Idaho, where surface mounted evaporators are only about 10% efficient at temperatures below 25°F , how much power, in watts, would the compressor of a heat pump have to develop to compensate for this energy loss?

Note: 1 Btu = 1055 J

$$H = A \frac{(T_2 - T_1)}{\sum_i R_i}$$

$$H = 100 \text{ ft}^2 \frac{(68^\circ \text{F} - 15^\circ \text{F})}{(4.00 + 0.17 + 1.32 + 10.90 + 0.45) \text{ ft}^2 \cdot \text{F}^0 \cdot \text{h/BTU}} = 315 \text{ BTU/hr}$$

$$\frac{315 \text{ BTU}}{1 \text{ hr}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{1055 \text{ J}}{1 \text{ BTU}} = 92.3 \text{ W}$$

$$.9 \times 92.3 \text{ W} = 83 \text{ W}$$

Problem 4. How much heat is needed to take ice of mass 720 grams at -10°C to a liquid state at 15°C ?

$$c_{\text{ice}} = 2220 \text{ J/kg} \cdot \text{K}$$

$$c_{\text{w}} = 4190 \text{ J/kg} \cdot \text{K}$$

$$L_f = 333 \text{ kJ/kg}$$

$$\begin{aligned} Q_1 &= mc\Delta T = (0.720\text{kg})(2220\text{J} / \text{kg} \cdot \text{K})(10^{\circ}\text{C}) = 15.98\text{kJ} && \text{ice @ } -10^{\circ}\text{C} \text{ to ice @ } 0^{\circ}\text{C} \\ Q_2 &= mL_f = (0.720\text{kg})(333\text{kJ} / \text{kg}) = 239.8\text{kJ} && \text{ice @ } 0^{\circ}\text{C} \text{ to water @ } 0^{\circ}\text{C} \\ Q_3 &= mc\Delta T = (0.720\text{kg})(4190\text{J} / \text{kg} \cdot \text{K})(15^{\circ}\text{C}) = 45.25\text{kJ} && \text{water @ } 0^{\circ}\text{C} \text{ to water @ } 15^{\circ}\text{C} \end{aligned}$$

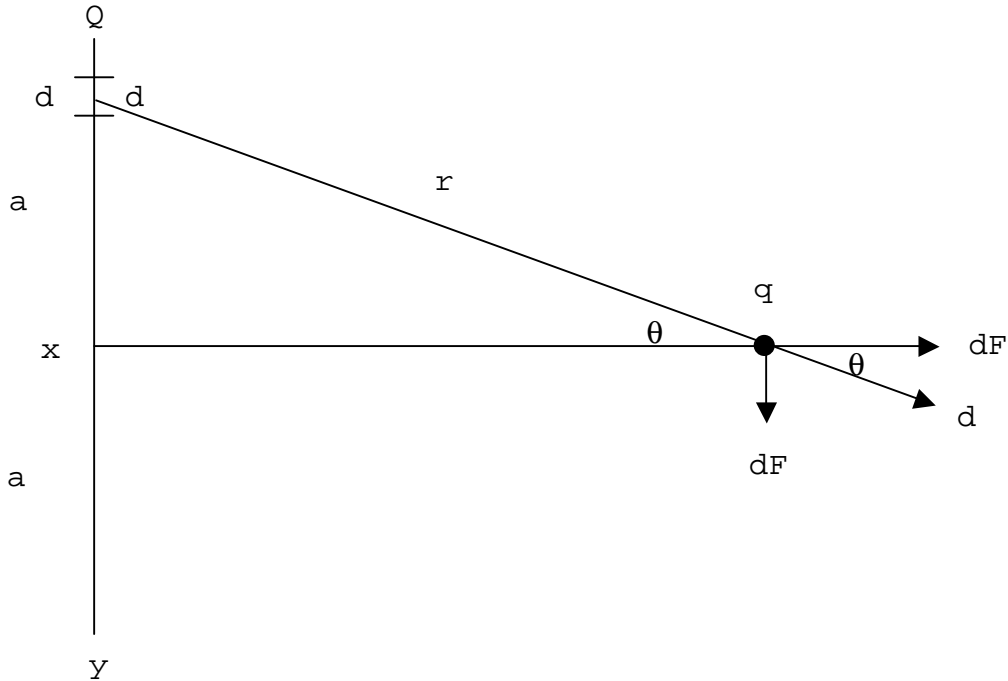
$$Q_1 + Q_2 + Q_3 = 300\text{kJ}$$

If we supply the ice with a total heat of only 210 kJ, what is the final state of the system?

$$m = \frac{Q_{\text{leftover}}}{L_f} = \frac{194\text{kJ}}{333\text{kJ} / \text{kg}} \approx 0.580\text{kg}$$

580 grams of water and 140 grams of ice.

Problem 5. Consider a uniform charge distribution Q , distributed along a line of length $2a$ from $-a$ to $+a$, along the y axis, and the force exerted by it on a charge, q , some distance x from the line.



$$\mathbf{F}_{Qq} = ? \quad dF = k \frac{q dQ}{r^2}$$

Note: $\frac{dQ}{Q} = \frac{dy}{2a} \therefore dQ = \frac{Q dy}{2a}$

$$dF = k \frac{q Q dy}{2a r^2}, r = (x^2 + y^2)^{\frac{1}{2}} \therefore dF = \frac{1}{4\pi\epsilon_0} \frac{q Q dy}{2a(x^2 + y^2)} \quad (1)$$

$$dF_x = dF \cos \theta, \cos \theta = \frac{x}{r} = \frac{x}{(x^2 + y^2)^{\frac{1}{2}}} \quad (2)$$

$$dF_y = dF \sin \theta, \sin \theta = \frac{y}{r} = \frac{y}{(x^2 + y^2)^{\frac{1}{2}}}$$

by symmetry, all dF_y 's cancel

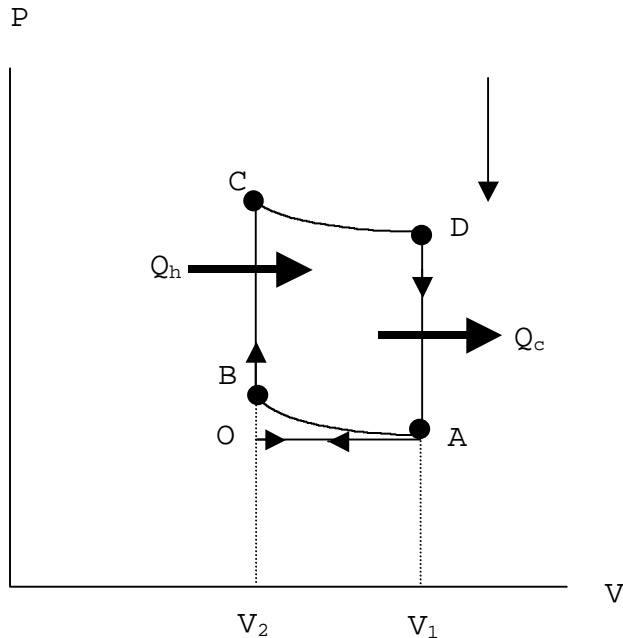
$$(2) \rightarrow (1) \quad dF = dF_x = dF \cos \mathbf{q} = \frac{qQ}{4\pi\epsilon_0} \frac{xdy}{2a(x^2 + y^2)^{\frac{3}{2}}}$$

$$F = F_x = \frac{qQ}{4\pi\epsilon_0} \int_{-a}^a \frac{xdy}{2a(x^2 + y^2)^{\frac{3}{2}}}$$

$$\vec{F}_{net} = \frac{qQ}{4\pi\epsilon_0} \frac{1}{x\sqrt{x^2 + a^2}} \hat{i}$$

Problem 6. With the aid of PV diagrams, explain the Otto cycle heat engine.

Otto Cycle Gasoline Engines



1. During the *intake stroke* ($O \rightarrow A$), air at atmospheric pressure is drawn into the cylinder and the volume increases @ atmospheric pressure from V_2 to V_1 (isobaric).
2. During the *compression stroke* ($A \rightarrow B$), the fuel-air mixture is compressed adiabatically from volume V_1 to volume V_2 , and the temperature increases from T_A to T_B . The work done on the gas is the area under the AB curve.
3. Combustion occurs in the process $B \rightarrow C$ and heat Q_H is added to the gas. This heat is not from the outside of the system. It is heat released during the combustion process. During this process the pressure and temperature increase rapidly but the volume remains essentially constant (isovolumetric). No work is done on the gas.
4. During the *power stroke* ($C \rightarrow D$), the gas expands adiabatically from V_2 to V_1 , causing the temperature to drop from T_C to T_D . The work done by the gas is the area under the CD curve.
5. In the process $D \rightarrow A$, heat Q_C is extracted from the gas as its pressure decreases at constant volume (hot gas is replaced by cool gas). No work is done during this process.
6. During the *exhaust stroke* ($A \rightarrow O$), the residual gases are exhausted at atmospheric pressure and the volume decreases from V_1 to V_2 (isobaric).