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Exam II,
Physics 117-Spring 2003, Wed. 4/16/2003
Instructor: Dr. S. Liberati

General Instructions

- There are a total of five problems in this exam.
- All problems carry equal weights.
- Do all the four problems by writing on the exam book (continue to work on the back of each page if you run out of room).
- Write your name (in capital letters) on every page of the exam.
- Purely numerical answers will not be accepted. Explain with symbols or words your line of reasoning. Corrected formulae count more than corrected numbers.

What you can do

- You may look at your text book in taking the exam
- Use a calculator

What you can't do

- Speak with nearby colleagues
- Use any wireless device during the exam

Hints to do well

- Read carefully the problem before to compute. Before to start you must have clear in your mind what you need to arrive to the answer.
- Do problems with symbols first (introduce them if you have to). Only put in numbers at the end.
- Check your answers for dimensional correctness.
- If you are not absolutely sure about a problem, please write down what you understand so that partial credit can be given.

Honor Pledge: Please sign at the end of the statement below confirming that you will abide by the University of Maryland Honor Pledge

"I pledge on my honor that I have not given or received any unauthorized assistance on this assignment/examination."

Signature:______________________________

Name: ________________________________

Exercise 1

An ideal gas has the following initial conditions:
V_i=500 cm^3, P_i=3 atm, and T_i=100 °C.

Q-1.1: What is the final temperature if the pressure is reduced to 1 atm and the volume expands to 1000 cm^3?

> For an ideal gas $PV = const \cdot T$
>
> Hence $\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f} \Rightarrow T_f = T_i \frac{P_f V_f}{P_i V_i} \Rightarrow T_f = 373\ K \frac{1\ atm}{3\ atm} \frac{1000\ cm^3}{500\ cm^3} \approx 249\ K = -24\ ^0C$

Q-1.2: How many molecules are in the gas?
(Boltzmann constant k_B=1.38·10^{-23} J/K, 1 atm≈1·10^5 N/m^2)

> $PV = Nk_B T \Rightarrow$
>
> $N = \frac{PV}{k_B T} = \frac{3\ atm \times 500\ cm^3}{1.38 \cdot 10^{-23} J/K \times 373\ K} = \frac{3 \cdot 10^5\ N/m^2 \times 5 \cdot 10^{-4}\ m^2}{514.74 \cdot 10^{-23}\ J} =$
>
> $\approx \frac{150\ N}{515\ N \cdot m} 10^{23} = 0.291 \cdot 10^{23} \approx 3 \cdot 10^{22}$ molecules

alternatively

> $PV = Nk_B T \Rightarrow$
>
> $N = \frac{PV}{k_B T} = \frac{1\ atm \times 1000\ cm^3}{1.38 \cdot 10^{-23} J/K \times 248.66\ K} = \frac{1 \cdot 10^5\ N/m^2 \times 1 \cdot 10^{-3}\ m^2}{343.16 \cdot 10^{-23}\ J} =$
>
> $\approx \frac{100\ N}{343.16\ N \cdot m} 10^{23} = 0.291 \cdot 10^{23} \approx 3 \cdot 10^{22}$ molecules

Q-1.3: Does the number of molecules correspond to more or less than a mole?

> Answer: A mole has an Avogadro Number of molecules N_A=6.022·10^{23}, hence in this case we have less than a mole of gas

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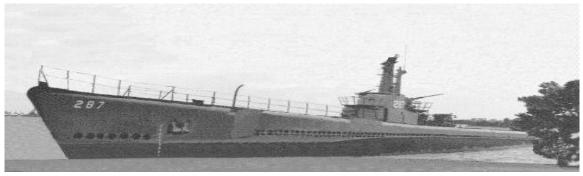
Exercise 2

The relict of the Bowfin Submarine SS288 lies on the bottom of the sea.



Your task is to recover the submarine relict. The submarine has a mass 4 10^6 Kg, and its volume is approximately 3000 m^3. Calculate

Q-2.1: The buoyancy force acting on the submarine. (Assume $D_{water}=10^3$ Kg/m^3).

The buoyancy force is equal to the weight of the volume of water displaced by the submarine.

$$F_{buoy} = m_{displ,water} g = D_{water} V_{sub} g = 10^3 \frac{Kg}{m^3} \times 3\cdot 10^3 m^3 \times 10 \frac{m}{s^2} = 3\cdot 10^7 N$$

Q-2.2: The net force acting on the submarine

The net force is equal to the difference between the submarine weight and the buoyancy force.

$$F_{net} = F_{buoy} - Weight = m_{displ,water} g - m_{sub} g = 3\cdot 10^7 N - 4\cdot 10^7 N = -1\cdot 10^7 N$$

hence the submarine cannot float.

To recover the submarine you plan to attach to the relict several rigid containers full of a gas. Each container has a volume of 50 m^3.

Q-2.3: Neglecting the weight of the containers and the weight of the gas, calculate how many containers do you need in order to lift up the submarine.

The buoyancy force of a container is

$$F_{buoy,cont} = m_{disp,wat} g = D_{water} V_{cont} g = 10^3 \frac{Kg}{m^3} \times 50 \; m^3 \times 10 \frac{m}{s^2} = 5\cdot 10^5 N$$

To raise the submarine one needs to have a net upward (i.e. positive) force

$$F_{net,sub+ball} = N_{ball} F_{buoy,cont} + F_{buoy,sub} - Weight_{sub} = N_{cont}\cdot 5\cdot 10^5 N - 10^7 N$$

$$F_{net,sub+ball} > 0 \text{ if } N_{ball}\cdot 5\cdot 10^5 N - 10^7 N > 0 \;\Rightarrow\; N_{cont} > \frac{10^7 N}{5\cdot 10^5 N} \;\Rightarrow\; N_{cont} > 20$$

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Exercise 3

You want to heat up a ball of aluminum by dropping it from cliff. The specific heat of aluminum is 900 J/(Kg K).

Q-3.2 What is the height of the cliff if the temperature increases by 3 K at each drop?

For each drop all the GPE is transformed in heat given to the ball.

$$GPE = mgh = Q \quad \Rightarrow \quad \Delta T = \frac{Q}{cm} = \frac{mgh}{cm} = \frac{gh}{c}$$

$$h = \frac{c\Delta T}{g} = 900 \frac{J}{Kg \cdot K} \times 3 \ K \times \frac{1}{10 \ m/s^2} = 270 \frac{J}{Kg \cdot m/s^2} = 270 \ m$$

Q-3.2 Assume that no heat is transferred to the ground or otherwise dissipated, how many times you have to drop the ball to increase its temperature by 90 K?

For each drop all the GPE is transformed in heat given to the ball.

$$\Delta T = \frac{Q}{cm} = \frac{Nmgh}{cm} \Rightarrow N = \frac{cm\Delta T}{mgh} = \frac{c\Delta T}{gh} = \frac{81000}{2700} = 30$$

Q-3.2: Assume that the final temperature of the ball after this procedure is 100 °C. You now want to cool down the ball by dropping it in a tank of water. How much water at 4 °C do you need in order to get a final temperature of 20 °C for both the water and the ball? Assume the mass of the ball to be 3 Kg.

The heat received by the water must be equal to the heat released by the auminum

$$c_{alum} m_{alum} \Delta T_{alum} = Q_{exchanged} = c_{water} m_{water} \Delta T_{water}$$

$$m_{water} = \frac{c_{alum} m_{alum} \Delta T_{alum}}{c_{water} \Delta T_{water}} = \frac{900 \ (J/Kg \cdot K) \times 3 \ Kg \times 80 \ K}{4186 \ (J/Kg \cdot K) \times 16 \ K} = 3.225 \ Kg = 3225 \ gr$$

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Exercise 4

A heat engine has a real efficiency of 0.4. It works taking in 1000 J of heat from a hot source at 100 °C and exhausting part of this heat to a cold source at 25 °C.

Q-4.1: What is the mechanical work that can be extract from this real heat engine? What is the heat exhausted?

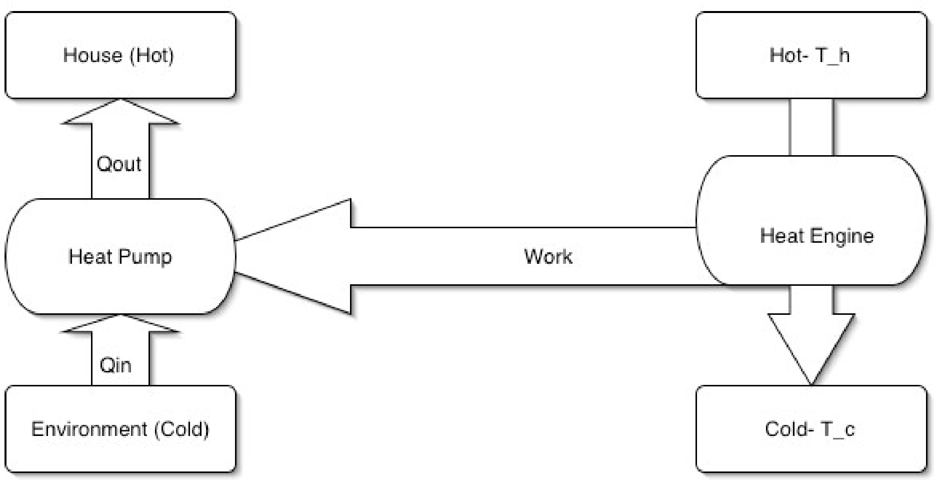
$$\eta_{real} = \frac{W}{Q_{in}} \Rightarrow W = \eta_{real} Q_{in} = 0.4 \times 1000 \; J = 400 \; J$$
$$W = (Q_{in} - Q_{out}) \Rightarrow Q_{out} = Q_{in} - W = 600 \; J$$

Q-4.2: How the real efficiency of this engine compares to the ideal efficiency? (the one it would have if it was an ideal engine)

$$\eta_{ideal} = 1 - \frac{T_{cold}}{T_{hot}} = 1 - \frac{298 \; K}{373 \; K} \approx 0.20 \Rightarrow 20\%$$
$$\eta_{real} = 0.4 \Rightarrow 40\% \Rightarrow \eta_{ideal} \approx 0.5 \cdot \eta_{real}$$

This is impossible so this engine cannot work in reality

The work extracted from the heat engine powers a heat pump used to heat up a house during the winter.



Q-4.3: The coefficient of performance of the pump is the ratio of the heat extracted from the colder system to the work required. If the coefficient of performance (COP) is 4 how much energy is taken from the external environment and absorbed by the pump?

$$COP = \frac{Q_{in}}{W} \Rightarrow Q_{in} = W \times COP = 400 \; J \times 4 = 1600 \; J$$

Q-4.4: How much energy is delivered into the house by the pump?
(i.e. how much is Q_{out} in the above picture)

$$Q_{out} = W + Q_{in} = 400 \; J + 400 \; J \times 4 = 2000 \; J$$