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Department of Physics

This is 100 minutes long, closed-book evaluation.

I, the undersigned, realize that I should have only **one copy of this questionnaire**, and that by the end of this test I will have **to return** it to the proctor with all other materials provided during the test (SCANTRON AND EXAM BOOKLET).

I am also aware of the following:

Failing to return this document results in obtaining 0 for the whole test!

Failing to properly fill out the scantron will result in 0 for the part I of the test!

By signing below, I acknowledge that I am aware of the above conditions and will comply with them.

Cellular phones, unauthorized electronic devices or course notes) are not allowed during this exam. Phones and devices must be turned off and put away in your bag. Do not keep them in your possession, such as in your pockets. If caught with such a device or document, the following may occur: you will be asked to leave immediately the exam, academic fraud allegations will be filed which may result in you obtaining a 0 (zero) for the exam.

By signing below, you acknowledge that you have ensured that you are complying with the above statement.

Student ID: ______________________________

STUDENT'S NAME: ______________________________

Student Signature : ________________________

DATE: ________________

I WANT THE FOLLOWING 4 PROBLEMS FROM PART II TO BE MARKED :________________

Probability of finding the speed of a particle in the range (v;v+dv)is:

$$v_{MP} = \left[\frac{2kT}{m}\right]^{\frac{1}{2}} \qquad v_{rms} = \left[\frac{3kT}{m}\right]^{\frac{1}{2}} \qquad v_{avg} = \left[\frac{8kT}{\pi m}\right]^{\frac{1}{2}} \qquad P(v)dv = 4\pi\left[\frac{1}{2\pi}\frac{m}{kT}\right]^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}} dv$$

$$p = \frac{1}{3}\rho < v^2 > \qquad \rho = \frac{Nm}{V}$$

Gaussian Integrals:

$$\int_0^{+\infty} e^{-ax^2} dx = \frac{1}{2}\sqrt{\frac{\pi}{a}} \qquad \int_0^{+\infty} x e^{-ax^2} dx = \frac{1}{2a} \qquad \int_0^{+\infty} x^2 e^{-ax^2} dx = \frac{1}{4}\sqrt{\frac{\pi}{a^3}}$$

$$\int_0^{+\infty} x^3 e^{-ax^2} dx = \frac{1}{2a^2} \qquad \int_0^{+\infty} x^4 e^{-ax^2} dx = \frac{3}{8}\sqrt{\frac{\pi}{a^5}} \qquad \int_0^{+\infty} \frac{x^3}{e^x - 1} dx = \frac{\pi^4}{15}$$

$$\Delta E_{int} = Q + W \qquad pV = nRT \qquad \Delta S = \int \frac{dQ}{T}$$

Change	ΔEint	W	Q	ΔS
P = const	$nC_v\Delta T$	$-p(V_f-V_i)$	$nC_p\Delta T$	$nC_p \ln\frac{T_f}{T_i}$
V = const	$nC_v\Delta T$	0	$nC_v\Delta T$	$nC_V \ln\frac{T_f}{T_i}$
T = const	0	$-nRT\ln\frac{V_f}{V_i}$	$nRT\ln\frac{V_f}{V_i}$	$nR\ln\frac{V_f}{V_i}$
Q = 0	$nC_v\Delta T$	$\frac{1}{\gamma-1}\left(p_fV_f - p_iV_i\right)$	0	0

$$pV^{\gamma} = const. \qquad \gamma = \frac{C_P}{C_V} \qquad C_p - C_v = R$$

$$\epsilon_{CRN} = \frac{W}{Q} = \left|\frac{Q_H - Q_L}{Q_H}\right| = 1 - \frac{T_C}{T_H} \qquad \textbf{COP} = \frac{\textbf{what we want}}{\textbf{what we pay for it}}$$

$\Delta L = \alpha L \Delta T$ $\qquad$ $\Delta S = \beta S \Delta T$ $\qquad$ $\Delta V = \gamma V \Delta T$

$P = e\,\sigma\, A\, T^4$; $\sigma = 5.67\times 10^{-8} W/(K^4m^2)$ $\qquad$ $P = kA\left|\frac{dT}{dx}\right|$

$Q = mc\Delta T$ $\qquad$ $Q = Lm$

c(water) = 4186 J/(kg C); c(ice) = 2090 J/(kg C); c(steam) = 2010J/(kg C)

L(melting) = 3.33×10^5 J/kg $\qquad$ L (vaporization) = 2.26×10^6 J/kg

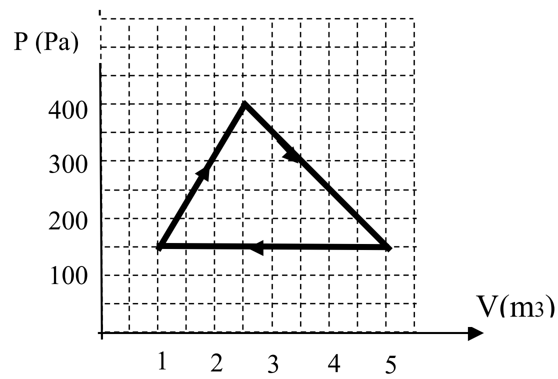
density of Cu = 8940kg/m^3 ; α(Cu)=$17\times 10^{-6} K^{-1}$; c(Cu)= 385J/kgC ;

A(disk)=πR^2, C=πR^2, V=$4/3\pi R^3$, A=$4\pi R^2$

Part 1. In the scantron sheet to answer all MC questions below. (Best 6 count towards 48% of your test mark)

1 A reversible heat engine has a pV diagram shown on the graph. The net heat transferred between the engine and environment in one cycle is approximately:

a) -0.5 kJ b) +0.5kJ c) -4.2kJ
d) +4.2kJ e) none of the above

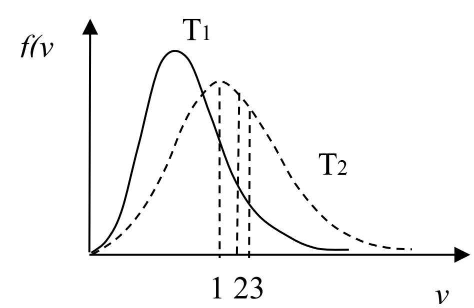


2 Given is the two–dimensional gas made out of diatomic molecules. At sufficiently high temperatures the gas molecules are free to move around within the two dimensional plane, as well as to rotate and oscillate. Which of the following pairs correctly represents the average energy of single molecule E_{avg}; and the C_p of the gas, at the intermediate temperatures (250K <T<600K).

a) $E_{avg} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2$ $C_p = R$
b) $E_{avg} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}I\omega^2$ $C_p = 3/2R$
c) $E_{avg} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}I\omega^2$ $C_p = 5/2R$
d) $E_{avg} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}I\omega^2 + \frac{1}{2}kr^2 + \frac{1}{2}mv_{osc}^2$ $C_p = 7/2R$
e) $E_{avg} = \frac{1}{2}mv_x^2 + \frac{1}{2}mv_y^2 + \frac{1}{2}I_1\omega_1^2 + \frac{1}{2}I_2\omega_2^2 + \frac{1}{2}kr^2 + \frac{1}{2}mv_{osc}^2$ $C_p = 4R$

3 The figure shows the distribution of the molecular speeds of gas for two different temperatures T_1(solid) and T_2 (dashed). Which of the following sentences is true:

a) $T_1 < T_2$, and the point labeled "1" corresponds to the maximum speed of molecules whose temperature is T_2
b) $T_1 > T_2$ and the point labeled "3" corresponds to the maximum speed of molecules whose temperature is T_2
c) $T_1 < T_2$ and the point labeled "3" corresponds to the most probable speed of molecules at T_2
d) $T_1 > T_2$, and the point labeled "1" corresponds to the average speed of molecules at T_2
e) $T_1 < T_2$, and the point labeled "1" corresponds to the most probable speed of molecules at T_2



4. 2 moles of gas in a container expand at a constant temperature of 500K. Find |W|, the amount of work done (in kJ) by the gas if the initial volume is 5 liters, and the final volume is 10 liters.
a) 0 b) 4.61 c) 5.76_ d) 10.96 e) none of the above

5. The air in an automobile engine at 20°C is compressed from an initial pressure of 1.0 atm and a volume of 300 cm^3 to a final volume of 10 cm^3. Find the final temperature of the air, if the it behaves like a gas with γ= 4/3 and the compression is adiabatic. (Take 0°C=273K)

a) 237°C b) 385 °C c) 495°C d)637°C e) none of the above

6. A heat pump (in heating mode) has a coefficient of performance 3.0. How much heat (in kJ) is exhausted to the hot reservoir when 100kJ of heat are removed from the cold reservoir?
a)100 b)150 c)200 d)250 e) none of the above

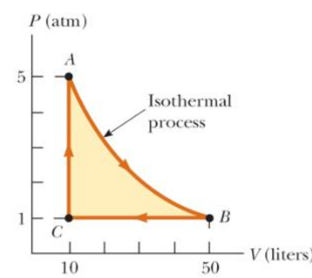
7 The 4 moles of ideal gas monoatomic gas are initially in the 100-liters container at a pressure of 500kPa. The gas is released to fill an additional volume of the vacuum system (initially at p=0) of volume 400-liters, in such a way that no heat is exchanged with the surroundings, and no gas is lost. What is the final temperature of the gas?

a) 237K b) 329K c) 514K d) 549K e) none of the above

PART 2 In examination booklets solve 4 out of 5 problems below. Each question has the same weight. (13p)
For full marks you need a neat diagram (when applicable) and all steps to be clearly demonstrated.

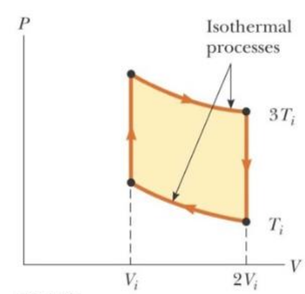
1 A 3.00-kg full copper sphere is taken from a forge at 500°C and dropped into 5.00 kg of water at 10.0°C.
Assuming that no energy is lost by heat to the surroundings, determine
a) final temperature of the system. (8p)
b) the change of the volume of the copper sphere as result of its temperature change . (2p)
c) the total power radiated by the copper sphere just before it was dropped into the water, and after the final temperature was established. (3p)
the specific heats and other useful constants for copper and of water/ice/steam as well as latent heats are given on the formula sheet.
density of Cu = 8.94g/cm^3 α(Cu) = 17·10^{-6} K^{-1} c(Cu)=385 J/(kgC)
The specific heat of water/ice/steam as well as latent heats are given on the formula sheet.

2 A) At 45.0 m below the surface of the sea (ρ= 1 025 kg/m^3), where the temperature is 7.00°C, a diver exhales an air bubble having a volume of 1.00 cm^3. If the surface temperature of the sea is 25.0°C, what is the volume of the bubble just before it breaks the surface? (7P)



B) A 1.00-mol sample of an ideal monatomic gas is taken through the cycle shown. The process $A \rightarrow B$ is a reversible isothermal expansion. Calculate (i) the net work done by the gas, (ii) the energy added to the gas by heat, (iii) the energy exhausted from the gas by heat, and (iv) the efficiency of the cycle. (6P)

3 In 1816 Robert Stirling, a Scottish clergyman, patented the *Stirling engine*, which has found a wide variety of applications ever since. Fuel is burned externally to warm one of the engine's two cylinders. A fixed quantity of inert gas moves cyclically between the cylinders, expanding in the hot one and contracting in the cold one. Figure below represents a model for its thermodynamic cycle. Consider *n* mol of an ideal monatomic gas being taken once through the cycle, consisting of two isothermal processes at temperatures $3T_i$ and T_i and two constant-volume processes. Determine, in terms of *n*, *R*, and T_i, (a) the net energy transferred by heat to the gas. (b) its efficiency.



4 Given is one mole of N_2 gas at 37°C. (Molar mass of N_2 is 28g).
a) Use Maxwell Boltzmann distribution to <u>write the case-specific full expression</u> for the number of N_2 molecules having speeds between 530m/s and 532m/s. (The expression has to contain data specific for this problem – but there is no need to finish the calculations!) (6P)
b) Find the most probable velocity of N_2 at the temperature of 37°C (2P)
c) At what temperature would the rms velocity of N_2 gas molecules be the same as in part (b)? (3P)
d) Demonstrate that the most probable velocity of gas molecules is indeed equal to v_{MP}= (2 kT/m)^{½} (2P)

5 a) Present detailed <u>proof of the one</u> of the two below: (4P)

i)using the summary of thermodynamic processes table (from your formula sheet) and known Laws of Thermodynamics prove that C_p=C_v+R for ideal gas.
ii) using the summary of thermodynamic processes table (from your formula sheet) and known Laws of Thermodynamics prove that C_p/C_v=γ for ideal gas.

b) Present <u>one</u> of the following proofs below: (9P)

i) Using the first principles, show that pV_{γ}=const for adiabatic transformation

ii) Use Maxwell-Bolzmann Speed Distribution $P(v)dv$ to obtain the expression for Boltzmann Energy Distribution $P(E)dE$.