UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2015-2016

TITLE OF PAPER: THERMODYNAMICS

COURSE NUMBER: P242/EE202

TIME ALLOWED: THREE HOURS

ANSWER ANY **FIVE** QUESTIONS. ALL QUESTIONS CARRY EQUAL MARKS

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## Question 1

(a) In an adiabatic expansion of an ideal gas $pV^{\gamma}$ is a constant. Show that

(i) also in an adiabatic process $TV^{\gamma-1}$ = constant.

[3 marks]

(ii) the workdone in an adiabatic expansion from state ($p_1$, $V_1$) to a state ($P_2$, $V_2$) can be given

$$W = \frac{1}{\gamma}(p_2V_2 - p_1V_1).$$

[5 marks]

(b) Distinguish between isothermal and adiabatic procceses.

[2 marks]

(c) An ideal monatomic gas is held in a perfectly insulated cyclinder fitted with a movable piston. The initial pressure of the gas is $p_1$ and its initial temperature is $T_1$. By pushing down the piston you are able to increase the pressure to $p_2$.

(i) During the process did the temperature of the gas increase, decrease or stay the same? Explain.

[6 marks]

(ii) Given that $T_1$ = 280K, $p_1$ = 110kPa, $p_2$ = 140kPa and $\gamma = 5/3$ calculate $T_2$.

[4 marks]

## Question 2

(a) Which of the following is equivalent to a temperature change of 37°C ? Justify your answer.

i) $37K$ ii) $360K$

[2 marks]

(b) A gas expands in a piston-cylinder device during which 5 kJ of boundary work occurs. At the same time, 10 kJ of electrical work is transferred to the gas. Which of the following is the net work for the gas. Justify your answer with equations.

i) $15\,kJ$ ii) $-5\,kJ$ iii) $5\,kJ$ iv) $0\,kJ$

[4 marks]

(c) Consider the isothermal heating process of an ideal gas. What happens to the internal energy during the heating process. Justify your answer with an equation.

i) *Increases* ii) *Decreases* iii) Remains the same

[3 marks]

(d) A gas inside a closed piston-cylinder assembly undergoes the following thermodynamic cycle:

- Process 1-2: Constant pressure, $p$=1.4 bar, $V_1 = 0.028$ m$^3$, $W_{12} = -10.5$ kJ.
- Process 2-3: Compression with $pV = constant$, $U_3 = U_2$
- Process 3-1: Constant volume, $U_1 - U_3 = -26.4$ kJ.

(i) Sketch the cycle on a $p - V$ diagram.

[2 marks]

(ii) Calculate the net work (kJ) for the cycle.

[5 marks]

(iii) Calculate the heat transfer for process 1-2, in kJ

[4 marks]

## Question 3

A Power plant produces $1GW$ (giga watt) of electricity, at an efficiency of 0.4. Recall that the specific heat of water is $4.19kJ/kg \cdot K$ and the latent heat of vaporization is $2.33MJ/kg$.

(a) At what rate does this plant expel waste heat into its environment?

(b) Assume first that the cold reservoir for this plant is a river whose flow rate is $100m^3/s$. By how much will the temperature of the river increase?

(c) To avoid this thermal pollution of the river, the plant could instead be cooled by evaporation of the river. At what rate must the water evaporate, i.e how much water needs to evaporate per unit time? What fraction of the river must be evaporated?



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## Question 4

A heat pump is an electrical device that heats a building by pumping heat in from the cold outside. In other words, its the same as a refrigerator, but its purpose is to warm the hot reservoir rather to cool the cold reservoir(even though it does both). Let us define the following standard symbols, all taken to be positive quantities: $T_h$ temperature inside building; $T_c$ temperature outside; $Q_h$ heat pumped into building in 1 day; $Q_c$ heat taken from outside in 1 day; $W$ electrical energy used by the heat pump in 1 day

(a) Explain why the *coefficient of performance* (COP) for a heat pump should be defined as $Q_h/W$.

(b) What relation among $Q_h$, $Q_c$, and $W$ is implied by energy conservation alone? Will energy conservation permit the COP to be greater than 1?

(c) Use the second law of thermodynamics to derive an upper limit on the COP, in terms of $T_h$ and $T_c$.

(d) Explain why a heat pump is better than an electric furnace, which simply converts electrical work directly into heat.

## Question 5

(a) Using kinetic theory of gases, derive the expression for the pressure of an ideal gas $P = \frac{2}{3}\left(\frac{N}{V}\right)\left(\frac{1}{2}\right)m\overline{v^2}$ where the symbols have their usual meanings.

[6 marks]

(b) State how the above equation establishes a link between microscopic and macroscopic properties of gases. [2 marks]

(c) One mole of oxygen gas is contained in a cubic box of side 10 cm at 300 K. Molar mass = 32 g /mol. Calculate

- (i) The average kinetic energy of the oxygen molecule. [2 marks]
- (ii) Total kinetic energy of the gas. [2 marks]
- (iii) The rms speed of the oxygen molecule. [2 marks]

(d) Distinguish between *internal energy and kinetic energy* of a material. [2 marks]

(e) State the *theorem of equipartition of energy.* [2 marks]

(f) Each atom in a solid has 6 degrees of freedom. What is its internal energy of the solid having $N$ atoms in terms of $R$? [2 marks]

**Question 6**

(a) Explain why a gas has two specific heats: the specific heat at constant volume $C_v$ and the specific at constant pressure $C_p$. [3 marks]

(b) Derive the relation $C_p - C_v = R$ for any ideal gas. [5 marks]

(c) Show that for an ideal monatomic gas the molar specific heat at constant volume $C_v = (3/2)R$. [4 marks]

(d) Using the theorem of equipartition of energy, prove that specific heat at constant volume $C_V$ of a solid at high temperatures is equal to $3R$. [4 marks]

(e) Draw a sketch showing how the specific heat of a solid varies with temperature and comment on the adequacy of classical physics in the theory of specific heats. [4 marks]