JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES

UNIVERSITY EXAMINATION FOR THEDEGREE OF BACHELOR OF EDUCATION (SCIENCE)

1ST YEAR 1ST SEMESTER

MAIN

REGULAR

COURSE CODE: SPH 104

COURSE TITLE: THERMAL PHYSICS

EXAM VENUE: **STREAM: (BED SCI)**

DATE: **EXAM SESSION:**

TIME: 2:00HRS

Instructions:

1. **Answer question 1 (Compulsory) and ANY other 2 questions.**
2. **Candidates are advised not to write on the question paper.**
3. **Candidates must hand in their answer booklets to the invigilator while in the examination room.**

PHYSICAL CONSTANTS

Ideal Gas constant, R	8.3145 J/(mol.K)
Molar mass of iron	$5.6\times10^{-2}\,kg$
Avogadro's number	6.02×10^{23} per mole
Density of air	1.20 kg/m^3
Density of water	1000 kg/m^3
Thermal conductivity of wood	0.08W/(m.K)
Thermal conductivity of Styrofoam	0.001W/(m.K)
Thermal conductivity of glass	0.8W/(m.K)
Thermal conductivity of paper	0.05W/(m.K)
The specific heat capacity of air	1020 $J/(kg.K)$
Specific heat capacity of air	1020 $J/(kg.K)$
Specific heat capacity of water	4190 $J/(kg.K)$
1 Atmosphere	1.013×10^5 Pa
Stefan–Boltzmann constant, σ	$5.6705\times10^{-8}W/(m^2.K^4)$

QUESTION ONE (30 MARKS) (COMPULSORY)

a. Define temperature in terms of energy. (1 mark)

b. A 20 g piece of aluminium at 90 ^oC is dropped into a cavity in a large block of ice at 0 ^oC. (1 mark)

c. Internal energy is determined by the state of the system. Explain what this means. (2 marks)

d. Using the first law of thermodynamics show that for an ideal gas changing isothermally at 0.276 K from (P_1V_1) to (P_2V_2), where $P_1V_1 = P_2V_2$, that the change in heat is $\Delta Q = P_1V_1\ln\left(\frac{V_2}{V_1}\right)$ (2 marks)

e. Why is snow, which is made up of ice crystals, a much better insulator than ice? (1 mark)

f. Give some good reasons why the equation $H = e\sigma AT^4$ is valid only if the temperature is expressed in Kelvins (rather than degrees Fahrenheit or Celsius). (1 mark)

g. Why is it wrong to assume that two objects in thermal equilibrium have the same internal energy? (1 mark)

h. Define the triple point of water (1 mark)

i. A system undergoing a vacuum suction is at a pressure of 1.0×10^4 and temperature of 20 ^{o}C. Estimate the number of gas molecules in a cubic metre of the system. (2 marks)

j. The Figure 1 below shows isotherms X and Y.

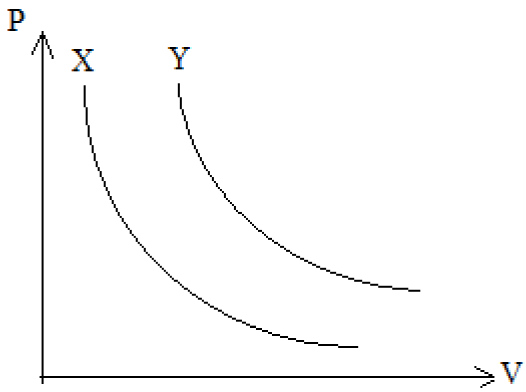

Figure 1

i. State with a reason whether an isotherm can be a straight line. (2 marks)

ii. Which isotherm, X or Y, is at a higher temperature? Explain (2 marks)

k. A fixed mass of an ideal gas undergoes the changes represented by NMON as in figure 2a and figure 2b below.

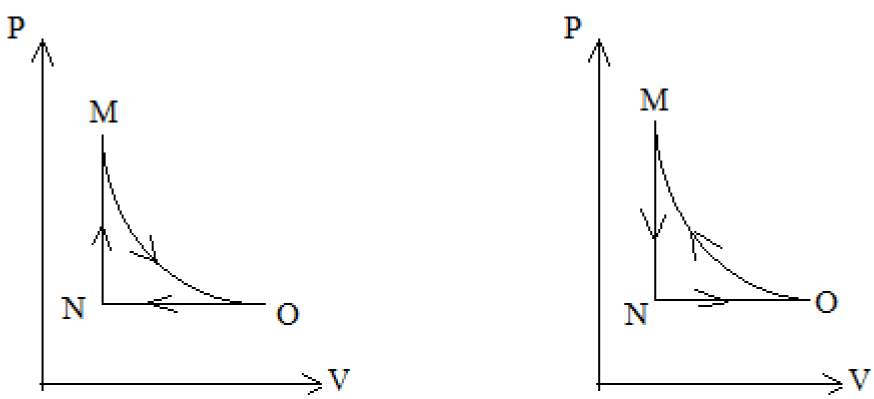

Figure 2a

Figure 2b

i. Which graph, Figure 2a or Figure 2b, denotes net work done ON the system? Explain. (2 marks)

ii. Comment on the net change of internal energy of the gas from the figures.(1 mark)

l. What is wrong with the following statements?

i. Absolute zero is the temperature at which the molecules in all objects have zero energy (1 mark)

ii. The specific heat capacity of a substance is defined as the amount of energy needed to raise the temperature of 1 kg mass by unit temperature. (1 mark)

m. A metal of mass 0.2 kg at $100\ ^oC$ is dropped into $0.08\ kg$ of water at $15\ ^oC$ contained in a calorimeter of mass $0.12\ kg$ and specific heat capacity $400 J/kgK$. If the final temperature reached is $35\ ^oC$, determine the specific heat capacity of the metal. (3 marks)

n. A carpenter builds an exterior house wall with a layer of wood 3.0 cm thick on the outside and a layer of Styrofoam insulation 2.2 cm thick on the inside wall surface. The average area of cross section is $200m^2$, the interior surface temperature is $25\ ^oC$ and the exterior surface temperature is $23\ ^oC$.

i. What is the temperature at the plane where the wood meets the Styrofoam? (2 marks)

ii. What is the rate of heat flow through this wall? (2 marks)

o. Calculate the Q, W and ΔU when a system of ideal gas gives out 200 J of heat without a change in volume (2 marks)

QUESTION TWO (20 MARKS)

a. A metal cylinder of mass 0.5 kg is heated electrically by a 12 W heater in a room at $15\ ^oC$. The cylinder temperature rises to $25\ ^oC$ in 5 minutes and later becomes constant at $45\ ^oC$.

i. What is the rate of loss of heat to the surrounding at $45\ ^oC$? (1 mark)

ii. Assuming the rate of heat loss is proportional to the excess temperature over the surroundings; calculate the rate of loss of heat of the cylinder at $20\ ^oC$. (2 marks)

b. An electric kettle with a 2 kW heating element has a heat capacity of 400 J/K. 1 kg of water at $20\ ^oC$ is placed in the kettle. The kettle is switched on and it is found that 13 minutes later the mass of water in it is 0.5 kg. Calculate the specific latent heat of vaporization of the water in the kettle. (3 marks)

c. The volume of a solid cube of iron of mass 0.504 kg is $6.4 \times 10^{-5} m^3$.

Calculate

i. The number of moles of iron atoms in the cube (3 marks)
ii. the mass of an iron atom (3 marks)
iii. the number of iron atoms in the cube (3 marks)
iv. the number of iron atoms along one edge of the cube assuming they are arranged side by side. (2 marks)

d. Two vessels X and Y of volumes $10 \times 10^{-4} m^3$ and $5 \times 10^{-4} m^3$ respectively, are connected by a tube of negligible volume and kept at temperatures 400 K and 200 K respectively. Both contain the same ideal gas. What is the value of the ratio: $\frac{Number\ of\ molecules\ in\ X}{Number\ of\ molecules\ in\ Y}$? (3 marks)

QUESTION THREE (20 MARKS)

a. Before beginning on a long trip on a hot day, a driver inflates an automatic tire to a gauge pressure of 1.8 atmospheres at 300 K. At the end of the trip, the gauge pressure increases 2.2 atmospheres.

   i. Assuming that the volume has remained constant, what is the temperature of the air inside the tire? (3 marks)

   ii. What percentage of the original mass of air in the tire should be released so that the pressure returns to the original value? Assume that the temperature remains as in (i) and the volume of the tire remains constant as air is released. (4 marks)

b. Three gas molecules have velocities 2 m/s, 3 m/s and -5 m/s respectively. Calculate

   i. Their mean speed (3 marks)

   ii. Their mean square speed (3 marks)

c. Five gas molecules have speeds 100 m/s, 200 m/s, 300 m/s, 400 m/s and 500 m/s respectively. Calculate the root-mean-square speed. (3 marks)

d. The mean square speed of the molecules of an ideal gas at $27\ ^{o}C$ is $3.7 \times 10^{\ 6} m^{\ 2} s^{\ -2}$. Calculate the mean square speed of the molecules of a gas of twice the mass, at $-50\ ^{o}C$ (4 marks)

QUESTION FOUR (20 MARKS)

a. Calculate the heat Q, work done W and change in internal energy ΔU for the given scenarios

i. A system of ideal gas does 100 J of work on the surroundings at constant temperature.

(1 mark)

ii. 50 J of work is done on a system of ideal gas while 50 J of heat is removed from it. (1 mark)

iii. 70 J of heat is supplied to a system of ideal gas without a change in temperature. (1mark)

b. A fixed mass of an ideal gas absorbs 2000 J of heat and does 500 J of work in expansion under constant pressure of 20 kPa.

   i. How much does the volume change? (2 marks)

   ii. What is the change in internal energy of the gas? (2 marks)

c. The gas in the cylinder can be considered to be ideal as it undergoes a cycle of changes of pressure, volume and temperature as shown in figure 3. The internal energy at B is 1200 J.

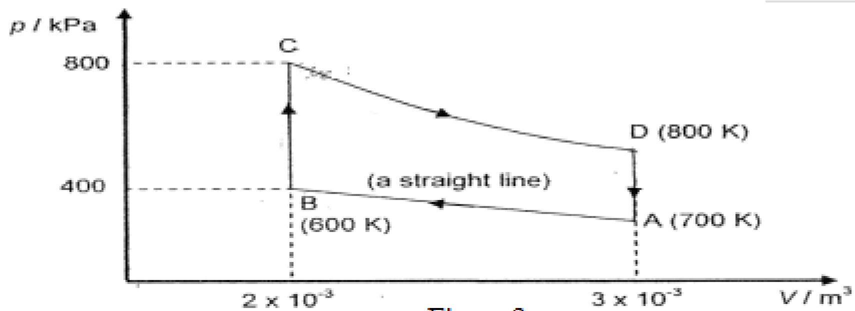

Figure 3

The change in internal energy from A to B is -200 J, heat supplied from A to B is -555.6 J and work done from A to B is 355 J. The change in internal energy from B to C is 1200 J, heat supplied from B to C is 1200 J and work done from B to C is 0 J. Given that the process in section C to D is adiabatic, use the information in the graph to find

(i) Change in internal energy from C to D if work done during that change is 800 J (1 mark)

(ii) Change in internal energy from D to A if heat supplied during that change is -200 J (1 mark)

(iii) Heat supplied from C to D (1 mark)

(iv) Work done on gas from D to A (1 mark)

d. Explain why the work done on the gas is sometimes negative (1 mark)

e. Explain why the total change in internal energy of the gas during a complete cycle must be zero. (1 mark)

f. Assuming that the efficiency of a heat engine is defined by the ratio of the work output to heat input, calculate the efficiency of this engine. (1 mark)

g. 1 mole of helium gas at $20\ ^{o}C$ which behaves like an ideal gas, is contained in a vessel and has an internal energy of 3700 J. Given that the temperature of the gas increases to $40\ ^{o}C$ under constant pressure of 244000 Pa, with the initial and final volumes of the gas being $1.0 \times 10^{-2} m^{3}$ and $1.07 \times 10^{-2} m^{3}$ respectively, calculate

i. The change in the internal energy (2 marks)

ii. The work done by the gas (2 marks)

h. The heat supplied to the gas (1 mark)

QUESTION FIVE (20 MARKS)

(a) (i) State **Stefan –Boltzmann law** (1 mark)

(ii) A box-shaped wood stove has dimensions of $0.75\ m \times 1.2\ m \times 0.4\ m$, an emissivity of 0.85, and a surface temperature of $205\ ^oC$. Calculate its rate of radiation into the surrounding space. (2 marks)

(iii) If the total surface area of a man's body is 1 m^2 and his skin temperature is 29 °C and he *absorbs* radiation from his surroundings. If the surroundings are at a temperature of 25 °C, what is her *net* rate of heat loss by radiation? The emissivity of the body is very close to that of **a black body**, irrespective of skin pigmentation. (3 marks)

(b) A picture window has dimensions of $40\ m \times 2.5\ m$ and is made of glass 5.20 mm thick. On a winter day, the outside temperature is -20 °C, while the inside temperature is a comfortable 19.56°C.

(i) At what rate is heat being lost through the window by conduction? (2 marks)

(ii) At what rate would heat be lost through the window if you covered it with a 0.750-mm-thick layer of paper? (2 marks)

(c) Conventional hot-water heaters consist of a tank of water maintained at a fixed temperature. The hot water is to be used when needed. The drawback is that energy is wasted because the tank loses heat when it is not in use, and you can run out of hot water if you use too much. Some utility companies are encouraging the use of *on-demand* water heaters (also known as *flash heaters*), which consist of heating units to heat the water as you use it. No water tank is involved, so no heat is wasted. A typical household shower flow rate is 2.5 gal/min (9.46 L/min) with the tap water being heated from 10 °C to 49°C to by the on-demand heater. What rate of heat input (either electrical or from gas) is required to operate such a unit, assuming that all the heat goes into the water? (3 marks)

(d) A typical student listening attentively to a physics lecture has a heat output of 100 W.

i. How much heat energy does a class of 90 physics students release into a lecture hall over the course of a 50 min lecture? (2 marks)

ii. Assume that all the heat energy in part (i) is transferred to the $3200\ m^3$ of air in the room. If none of the heat escapes and the air-conditioning system is off, how much will the temperature of the air in the room rise during the 50 minutes lecture? (3 marks)

iii. If the class is taking an exam, the heat output per student rises to 280 W. What is the temperature rise during 50 min in this case? (2 marks)