MACHAKOS UNIVERSITY

University Examinations 2023/2024 Academic Year

SCHOOL OF PURE AND APPLIED SCIENCES

DEPARTMENT OF PHYSICAL SCIENCES

SECOND YEAR FIRST SEMESTER EXAMINATION FOR THE BACHELOR OF EDUCATION (SCIENCE), BACHELOR OF EDUCATION (SPECIAL NEEDS), BACHELOR OF SCIENCE IN TELECOMMUNICATION INFORMATION TECHNOLOGY (TIT) AND BACHELOR OF SCIENCE MATHEMATICS.

SPH 203: THERMAL PHYSICS I

DATE: **TIME: 2**

INSTRUCTIONS:

- The paper consists of **two** sections.
- Section **A** is **compulsory** (30 marks).
- Answer any **two** questions from section **B** (each 20 marks).

You may find the following information useful

Stefan Boltzmann Constant $= 5.67 \times 10^{-8}\ W/m^2K^4$

Universal gas constant, $R = 8.314\ Jmol^{-1}K^{-1}$

Molar mass of Oxygen $= 32$

Standard atmospheric pressure $= 1$ atm $= 1.013 \times 10^5\ N/m^2$

$\frac{\mathrm{C_p}}{\mathrm{C_v}}$ for Nitrogen, $\gamma = 1.4$

Volume expansivities: $\beta_{glass} = 27 \times 10^{-6}K^{-1}$, $\beta_{water} = 207 \times 10^{-6}K^{-1}$

Linear expansivity of Aluminium, $\alpha_{Al} = 32 \times 10^{-6}K^{-1}$

Ice point $= 0°\mathrm{C} \equiv 273.15K$, Steam point $= 100°\mathrm{C} \equiv 373.15K$, Triple point of water $= 273.16K$

Thermal conductivity: $K_{steel} = 16.5\ \mathrm{W}m^{-1}K^{-1}$, $K_{concrete} = 0.8\ \mathrm{W}m^{-1}K^{-1}$, $K_{brick} = 0.51\ \mathrm{W}m^{-1}K^{-1}$

$\text{Wien's constant} = 2.898 \times 10^{-3}\ mK$

Specific heat capacity; $c_{ethanol} = 2.5\ Jg^{-1}{}^{\circ}\mathrm{C}^{-1}$

SECTION A

QUESTION ONE (30 MARKS)

a) i) Explain how a temperature scale can be set up using a thermometric property P (2 marks)

ii) The temperature θ on a thermometric scale in terms of a property P is given by $t = a.\mathrm{Inp} + b$ where, t is temperature, a and b are constants. If the values of P at ice point and steam points are 1.86 and 6.81 respectively, determine the temperature corresponding to a reading of $P = 2.5$ on the Celsius scale. (answer to 2 d.p) (5 marks)

b) i) State Zeroth Law of thermodynamics. (2 marks)

ii) Systems A, B and C are gases with pressure and volume coordinates $p, v; p^1v^1$and $p^{11}v^{11}$ respectively. Thermal equilibrium between A and B satisfies the equation $abpv - pvv^1 + p^1(v^1)^2 = 0$. Thermal equilibrium between A and C satisfies the equation $\frac{1}{pv} - cd - \frac{mp^{11}v^{11}}{pv} = 0$, where a, b, c, d and m are constants. Find the equation expressing thermal equilibrium between B and C. (3 marks)

c) Define volume expansivity, β, linear coefficient of expansion, α, and adiabatic compressibility κ (3 marks)

ii) Show that β and α are approximately related by $\beta = 3\alpha$ (2 marks)

d) A balloon contains 0.3 mole of Helium. It rises, while maintaining a constant 300 K temperature, to an altitude where its volume has expanded 5 times. Determine the amount of work done in the process (2 marks)

ii) A thermodynamic system with volume $V_1 = 500\ cm^3$ undergoes an isovolumetric decrease in pressure from $P_1 = 3\ atm$ to $P_2 = 1\ atm$ followed by an isobaric expansion to $V_2 = 2000\ cm^3$. Calculate the work done during the process (2 marks)

iii) An ideal gas undergoes an isobaric expansion at 2.5 kpa from 1 m^3 to 3 m^3. Given that it was initially at 300 K and 12.5 kJ of heat energy is transferred to the gas, determine the change in its internal energy (2 marks)

e) The inner surface of a brick wall is at 60 ˚C and the outer surface is at 35 ˚C. Calculate the rate of heat transfer per m^2 of surface area of the wall, which is 220 mm thick (2 marks)

f) A constant volume-gas thermometer gives readings of 1.333×10^5Pa, 1.821×10^5Pa and 1.528×10^5Pa, at ice point, steam point and when immersed in a boiling liquid respectively. Calculate the temperature in ˚C at which the liquid boils (3marks)

g) An aluminium rod has a length of exactly one meter at 300 K. Determine its final length when it is placed in a 400 ˚C oven. (answer to 4 d.p) (2 marks)

SECTION B

QUESTION TWO (20 MARKS)

a) A constant pressure gas thermometer has a volume of 200.02 cm^3 at ice point, 273.2 cm^3 at steam point and 521.1 cm^3 at the boiling point of sulphur. A resistance thermometer has resistance of 2.000 Ω, 2.779 Ω and 5.280 Ω at the same corresponding temperatures. Calculate the boiling point of sulphur given by the two sets of observations. Comment on the results (5 marks)

b) i) Show that for a gas obeying the ideal gas equation,
$\beta = \frac{P}{\theta} k$ where β is volume expansivity and k isothermal compressibity (3 marks)
ii) By taking the temperature θ of a hydrostatic system to be a function of p and v. Show that at constant pressure
$d\theta = \frac{dv}{v\beta}$ (5 marks)

c) A glass of water with volume 1 liter is completely filled at 5 ˚C. Determine the amount of water that will spill out of the glass when the temperature is raised to 85 ˚C. Leave your answer in liters and to 3 d.p (4 marks)

d) If the normal boiling point of water is 99.974 ˚C on the Celsius scale, determine the temperature on the Fahrenheit scale. (answer to 2 d.p) (3 marks)

QUESTION THREE (20 MARKS)

a) A 1g quantity of nitrogen undergoes the following sequence of quasi-static process in a piston-cylinder arrangement.
a constant- pressure expansion in which the volume doubles;
an adiabatic process in which the volume is reduced to its initial value;
a constant-volume process back to its initial state.
If the nitrogen is initially at 5 atm pressure and temperature of 150 ˚C, calculate the net work done during these sequences of processes. (6 marks)

b) The specific heat capacity of a material varies with temperature according to the equation $\mathrm{C} = 10^{-6}\theta^3 + 10^{-3}\theta\ \mathrm{Jkg^{-1}K^{-1}}$, where θ is the temperature. If the above equation is obeyed for $\theta = 0^{\circ}\mathrm{C}$ and $\theta = 100^{\circ}\mathrm{C}$. Calculate the heat absorbed by 2 kg of the material when the temperature is raised from $\theta = 0^{\circ}\mathrm{C}$ to $\theta = 100^{\circ}\mathrm{C}$ (4 marks)

c) The mean specific heat capacity of a certain gas during a certain process is given by,

$$\mathrm{C} = (0.4 + 0.004\mathrm{T})\mathrm{kJkg^{-1}K^{-1}}$$

If the mass of the gas is 6 kg and its temperature changes from 25 ˚C to 125 ˚C, determine;
i) The amount of heat energy transferred (3 marks)
ii) Mean specific heat capacity of the gas (2 marks)

d) The internal energy for a certain 4 moles monatomic gas is given by $\mathrm{U} = 1.5\mathrm{nRT}$. Determine;
i) The heat capacity at constant volume (3 marks)
ii) The heat capacity at constant pressure (2 marks)

QUESTION FOUR (20 MARKS)

a) i) Define thermal conductivity K of a material (2 marks)

ii) Two perfectly lagged metal bars x and y have equal length, L, equal cross-sectional area A, and thermal conductivities K_x and K_y respectively. The two metals are connected in series with the free ends of x and y at temperatures θ_1˚C and θ_2˚C respectively. If θ_1 is greater than θ_2 show that the total rate of heat across the composite material is given by; (6 marks)

$$\frac{dQ}{dt} = \frac{K_x K_y A(\theta_1 - \theta_2)}{L(K_x + K_y)}$$

b) i State Newton's Law of cooling (1 mark)

ii) The temperature θ of an object falls from 200 ˚C to 100 ˚C in 40 minutes, in a surrounding temperature of 10 ˚C. Show that at any time, the temperature of the object is given by

$\theta = 10 + 190e^{-kt}$ and $K = -\frac{1}{40} \text{In} \left(\frac{9}{19}\right)$ (6 marks)

c) 10 moles of an ideal gas are compressed isothermally and reversibly from a pressure of 1 atm to 10 atm at 300K. Determine the work done (2 marks)

d) During a certain thermodynamic process, the initial temperature of 150 g of ethanol was 22 ˚C. Determine the final temperature (in ˚C) of the ethanol if 3240 J of heat energy was needed to raise its temperature (3 marks)

QUESTION FIVE (20 MARKS)

a) One end of a 1.5 m long steel rod is placed in fire that is at 850 K temperature. The cross-sectional radius of the rod is 1 cm, and the cool end of the rod is at 300K. Calculate the rate of heat transfer through the rod (2 marks)

ii) Show that the total thermal resistance of a wall that is a composite of two walls arranged in parallel can be given by:

$$R_{thermal(total)} = \frac{L}{K_1 \cdot A_1 + K_2 \cdot A_2}$$

Where, L is length of the wall, K_1 and K_2 are thermal conductivities of wall 1 and 2 respectively, A_1 and A_2 are cross-sectional areas of wall 1 and 2 respectively (5 marks)

iii) The wall of a certain building is a composite of two walls, a 0.3 m thick outer brick wall and a 0.4 m thick inner Styrofoam wall. Given that the walls have the same cross-sectional area of 15 m^2, temperature of 24 ˚C and 5 ˚C at the inner and outer surfaces of the composite respectively, and a temperature of 23.4 ˚C at the interface, determine the rate of heat loss through the wall using the concept of thermal resistance. (3 marks)

b) i) The temperature of a 40 W tungsten lamp is 2170 ˚C and the effective surface area of the filament is $6.6 \times 10^{-5} m^2$. Assuming the energy radiated to be 0.31 of that from a black body in similar conditions and that any effect due to radiation from its glass envelop is negligible, determine the value of Stefan-Boltzmann constant. (2 marks)

ii) A blackbody at 3000 K emits radiation. Calculate the following:

a) Wavelength at which emission is maximum (2 marks)

b) Emissive power per m^2 (2 marks)

c) Emissive power if it is assumed to be a real surface having emissivity equal to 0.85

(2 marks)

d) Calculate the rate of heat loss by radiation per m^2 when a body initially at 1000 C is placed in a surrounding that is at 500 C. Assume the emissivity of the body to be 0.42

(2 marks)