PRIFYSGOL ABERYSTWYTH UNIVERSITY

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DEPARTMENT OF PHYSICS

SEMESTER 1 EXAMINATIONS, JANUARY 2026

PH21510 – Thermodynamics

Time allowed – 2 hours

- **Full marks can be attained for complete answers to ALL six questions in Section A and TWO questions from Section B**
- **The numbers in brackets after the questions indicate the allocation of marks for each question.**
- **Only calculators from the Casio FX83, FX85 or FX991 range may be used.**
- **A booklet of mathematical formulae and standard constants will be provided.**
- **Only a 1 side of A4 size crib sheet is allowed.**
- **MAE MODD I FYFYRWYR GYFLWYNO ATEBION I'R PAPUR HWN NAILL AI YN Y GYMRAEG NEU'R SAESNEG**
- **STUDENTS MAY SUBMIT ANSWERS TO THIS PAPER IN EITHER WELSH OR ENGLISH**

Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

DO NOT TURN THE EXAMINATION QUESTION PAPER OVER UNTIL INSTRUCTED TO DO SO.

Section A

Attempt ALL questions in the booklets provided

1 Describe the difference between intensive and extensive state variables, give an example of each, and define what is meant by a state function. [5]

2 Define the term relaxation in a thermodynamic context. Give an example of a relaxation process. [5]

3 State the Kelvin-Planck statement of the Second Law and interpret it in terms of the direction of velocity vectors of individual molecules in a gas sample. [5]

4 A balloon is inflated with helium gas to an initial volume of 1 litre, and is then sealed. The gas is at room temperature, a pressure of 1.0×10^5 Pa, and a density of 0.16 kg m^{-3}. The balloon is left sitting in the sun, and it absorbs energy at a constant rate of 0.010 J s^{-1}. Calculate the increase in temperature of the gas inside the balloon after 2 hours. [5]

You may assume an ideal gas, a constant pressure, and a molar heat capacity at constant pressure of $c_p = 20.8$ J mol^{-1} K^{-1}.

5 Show that the work done on or by an ideal gas during a quasi-static isothermal process depends on the ratio of the volume the gas occupies before and after the process. [5]

6 For an ideal gas, how is the momentum of a typical molecule related to the macroscopic pressure on the walls of its container. [5]

Section B

Answer TWO questions

7 A thermodynamic system is described by the Helmholtz free energy (A) in terms of its natural state variables, temperature (T) and volume (V).

(a) Write the total differential of the state function $A(T, V)$.

[2]

(b) Given that the differential of the Helmholtz free energy may be expressed as $dA = -pdV - SdT$, identify the partial derivatives that correspond to entropy (S) and pressure (p).

[3]

(c) Using Schwarz's theorem, derive the Maxwell relation in terms of S and p.

[4]

(d) The same thermodynamic system is also described by the state function $S(T, V)$. The system undergoes reversible isothermal expansion at temperature T. Using the Maxwell relation derived in (c), derive an expression for the infinitesimal heat transfer dQ_{rev}.

[6]

8 (a) Sketch the pressure-volume diagram for a Carnot cycle. Clearly label all four steps of the cycle. For each step, write down the type of thermodynamic process occurring, and the corresponding direction of heat transfer.

[7]

(b) A Carnot engine operates between two reservoirs at temperatures $300\ \mathrm{K}$ and $400\ \mathrm{K}$. Calculate the efficiency of the cycle.

[2]

(c) The same Carnot engine as in (b) performs 50 J of work per cycle. Calculate the change in entropy of the engine's working substance during the reversible isothermal expansion path of the cycle.

[6]

9 (a) If we want to double the average root-mean-square speed of the molecules of an ideal gas, explain by what factor should we increase the temperature.

[3]

(b) The Maxwell-Boltzmann law says that the probability that the component v_x of the velocity in the x-direction lies in the range a to b is $\int_a^b f(v_x)dv_x$ where:

$$f(v_x) = \sqrt{\frac{m}{2\pi\, kT}}\, e^{-mv_x^2/2kT},$$

and where k is the Boltzmann constant and m is the mass of the molecule.

Write down the full Maxwell-Boltzmann distribution $f(v_x, v_y, v_z)$ for all three components stating any assumption you make. Show that it may be rewritten as:

$$f(v_x, v_y, v_z) = \frac{1}{Z}\, e^{-\beta\, K.E.}$$

where $K.E.$ is the kinetic energy of the molecule and Z and β are constants to be determined.

[6]

(c) The Equipartition of Energy Theorem applied to the ideal gas implies the equation

$$U = \frac{1}{2}\, Nd\, kT.$$

Identify the various terms appearing in this equation and explain how the rule of thumb of the Theorem holds here.

Two gases have polyatomic molecules. They differ in that one has no vibrational degrees of freedom, but the other one has. How do their heat capacities compare?

[6]

END OF PAPER