UNIVERSITY OF CAMBRIDGE

NATURAL SCIENCES TRIPOS Part IB

Thursday 2 June 2016 9.00 to 12.00 noon

PHYSICS B (Paper 2)

*Attempt **all** questions from Section A, **two** questions from Section B, and **two** questions from Section C.*

*Section A as a whole carries **approximately** one fifth of the total marks.*

Each question in Sections B and C carries the same mark.

*The **approximate** number of marks allocated to each part of a question in all Sections is indicated in the right margin.*

*Answers for each Section **must** be written in separate Booklets.*

Write the letter of the Section on the cover of each Booklet.

*Write your candidate number, **not** your name, on the cover of each Booklet.*

A single, separate master (yellow) cover sheet should also be completed, listing all questions attempted.

STATIONERY REQUIREMENTS
20-Page Booklets and Treasury Tags
Rough Work Pad
Yellow Cover Sheet

SPECIAL REQUIREMENTS
Physics Mathematical Formulae Handbook (supplied)
Approved Calculators allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator.

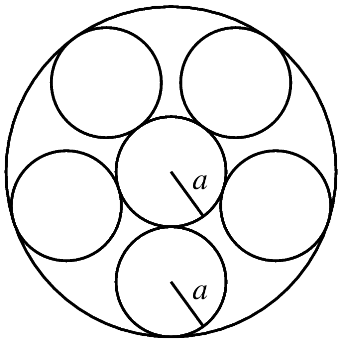
SECTION A

Answers should be concise and relevant formulae may be assumed without proof.

A1 The number of states available to a particular system with total energy E is $\Omega_0(E/E_0)^{5N/2}$, where Ω_0, E_0 and N are constants. Find the temperature and the heat capacity of the system. [4]

A2 A voltage pulse with height 1 V is observed 1 m from the end of a long coaxial cable terminated by a 25 Ω resistor, and an echo with height −0.5 V is observed 10 ns later. What is the impedance of the cable, and the relative permittivity of the insulator between the conductors? [4]

A3 A ball bearing supporting a rotating axle of radius a consists of a number of balls with mass m and radius a rolling (without sliding) between the axle and a fixed outer casing, as in the diagram below. What is the angular momentum of each ball about the centre of the axle when the axle turns with angular velocity ω? [4]



A4 The space between two coaxial circular discs of radius a separated by $d \ll a$ is filled by a liquid with viscosity η. What is the torque needed to drive one disc at angular velocity ω while the other disc is held fixed? [4]

A5 An enclosure holds 750 μJ of radiation in equilibrium with walls at a fixed temperature. How much heat is absorbed from the walls when the volume is doubled reversibly? [4]

SECTION B

B6 Write brief notes on **three** of the following: [20]
(a) electric dipoles;
(b) mutual inductance and transformers;
(c) free and polarisation charges, and the associated fields;
(d) fields in permanent magnets and electromagnets.

B7 Write an essay on methods of calculating electric field distributions in free space and in dielectrics. [20]

B8 Write brief notes on **three** of the following: [20]
(a) wind speeds and atmospheric pressure distributions;
(b) *forced* motion in coupled oscillators (e.g. masses connected by springs);
(c) forces and acceleration in viscous fluids;
(d) reduced mass and the two-body problem.

B9 Write an essay about the elastic behaviour of solids, including the description of stress and strain, elastic moduli and the Poisson ratio, and bending and twisting beams. [20]

SECTION C

C10 A reversible Carnot engine using an ideal gas operates between two heat baths at temperatures T_1 and T_2, where $T_1 > T_2$. By analysing the cycle, determine the efficiency of the engine. [6]

Show that no other heat engine operating between the same two temperatures can be more efficient than the Carnot engine. [2]

A heat engine has as its working substance one mole of an ideal monatomic gas. The engine follows the triangular path on a p, V diagram

$$p_0, V_0 \;\rightarrow\; 2p_0, V_0 \;\rightarrow\; p_0, 2V_0 \;\rightarrow\; p_0, V_0.$$

Calculate the heat input into the engine and the work done by the engine on each of these three paths in units of $p_0 V_0$. [7]

Calculate the efficiency of the engine. [2]

Compare this efficiency to that of a Carnot engine working between the highest and lowest temperatures on the path and explain why the efficiencies are different. [3]

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C11 State the law of equipartition of energy. [2]

Use the Boltzmann distribution to prove this law. [5]

The potential energy of a particular system varies as Qx^4, where x is the displacement from the equilibrium position. Explain why equipartition of energy does not apply to this system. [1]

Use the Boltzmann distribution to calculate the average potential energy of the system at temperature T and, hence, its contribution to the heat capacity. [5]

What would be the molar heat capacity at constant volume, c_V, of a diatomic molecular gas if equipartition applied? [2]

Sketch the actual variation with temperature of c_V for such a diatomic gas, and explain this variation. [5]

C12 The normalised Maxwell velocity distribution for the fraction of atoms in a three-dimensional atomic gas moving at speeds between v and $v + \mathrm{d}v$, and at angles between θ and $\theta + \mathrm{d}\theta$ and ϕ and $\phi + \mathrm{d}\phi$, is

$$\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 \exp\left(-\frac{mv^2}{2kT}\right) \sin\theta \, \mathrm{d}v \, \mathrm{d}\theta \, \mathrm{d}\phi$$

where m is the mass of each atom, and θ and ϕ are the usual spherical polar angles.

An atomic gas with number density n is placed in a container. Use the Maxwell velocity distribution to calculate (as a function of n, m, k and T):

(a) the number of atoms hitting unit area of the container per second; [6]

(b) the pressure exerted by the gas on the container; [5]

(c) the average energy of the atoms hitting the container. [5]

The container is now placed in a much larger evacuated region and a small hole is made in one side of the container. Explain qualitatively how the velocity distribution of the atoms in the container would change if the atoms did not exchange energy with the walls of the container. [2]

How would your answer be changed if the atoms did not undergo collisions? [2]

[*You may use the results* $\int_0^\infty x^n exp(-x^2)\mathrm{d}x = \frac{1}{2}, \frac{3}{8}\sqrt{\pi}$ *and 1 for n = 3, 4 and 5, respectively.*]

C13 Write an essay on phase diagrams and equations of state. You should include in your answer discussions of: phase transitions, the Clausius-Clapeyron equation, equations of state and phase diagrams, with examples. [20]

END OF PAPER