THE UNIVERSITY OF HULL

Final Examination: Part II

For the Special Degree of Bachelor of Science
PHYSICS I
1971

Monday, 24th May, 2 p.m. to 5 p.m.

Answer FOUR *questions. Answers to questions from the two Sections must be written in separate answer books.*

SECTION A

1. Give a critical account of the status of two-fluid theories in explaining the phenomena observed in superconductors and liquid helium.

2. Explain what consequences of the third law of thermodynamics are relevant to

   (a) the behaviour of physical properties of materials as $T \to 0$,

   (b) calculations of entropy,

   (c) cryogenics.

   When one of the hydrogen atoms in methane (CH_4) is replaced by deuterium, the resultant gas has at its boiling point a calorimetric entropy of 36.7 e.u. and a statistical entropy of 39.5 e.u. Suggest a reason for this difference. (Assume $R = 2$ e.u.).

3. A cloud of charged particles, each of charge e, moves at a velocity u relative to an observer located at the origin of a coordinate system S. To a second observer situated at the origin of a second coordinate system S', moving at uniform velocity with respect to S, the relative velocity of the charge cloud is u'. Assuming the Lorentz transformations, but deriving any other formulae required, express the density of particles in the cloud as observed from S' in terms of the density of particles observed in S. Hence derive the relativistic transformations for charge density and current density between two coordinate systems in uniform relative motion.

4. The Special Theory of Relativity predicts that a particle of rest mass m_0 moving with velocity v relative to an observer in an inertial frame of reference behaves as though it posseses an inertial mass m given by

$$m = m_0(1 - u^2/c^2)^{-1/2}$$

   where c is the velocity of light in vacuo. Give an outline account of how this expression may be derived, stating any assumptions made. Hence show that the total energy of a particle having inertial mass m may be expressed in the form $E = mc^2$.

   The total energy received at normal incidence by unit Area at the distance of the earth from the sun (1.5×10^8 km) is $1.4 \times 10^3 \quad \mathrm{J\,m^{-2}\,s^{-1}}$. Assuming that the thermonuclear reaction producing the solar energy involves the transmutation of four hydrogen nuclei (${}_1H^1$) into one helium nucleus (${}_2He^4$) calculate the mass of hydrogen required per second to maintain the sun's output of energy.

(Nuclear masses: ${}_1H^1 = 1.008$ a.m.u.;
${}_2He^4 = 4.003$ a.m.u.

Velocity of light in vacuo: $c = 3 \times 10^8 \quad \mathrm{m\,s^{-1}}$).

SECTION B

5. The ground state of the sodium atom has orbital and spin angular momentum quantum numbers $L = 0$, $S = \frac{1}{2}$ respectively; the first excited state has $L = I$ and $S = \frac{1}{2}$. Assuming a spin-orbit coupling energy equal to $\lambda \langle \mathbf{L} \cdot \mathbf{S} \rangle$ find the energies of the electron states when a magnetic field is applied. If the atom is excited so that emission takes place by transitions from the first excited state to the ground state, show that 10 lines will be emitted in a direction perpendicular to the direction of the magnetic field.

   (Note: $\lambda \langle \mathbf{L.S} \rangle = \frac{\lambda}{2} \langle \mathbf{J^2} - \mathbf{L^2} - \mathbf{S^2} \rangle$.)

6. The magnetic susceptibility of MnO behaves as $\chi = \dfrac{C}{T + \theta}$ above the temperature $T_N = 116\,^\circ\mathrm{K}$. Below T_N, the susceptibility falls as the temperature is reduced. Describe in detail the magnetic properties of this material and discuss bow neutron diffraction could confirm your conclusions.

7. Discuss how exchange interaction gives rise to co-operative magnetic effects in solids. Show that spin waves can be excited in materials exhibiting these effects and briefly describe an experiment which will allow observation of these waves.