The University Of Sheffield.

DEPARTMENT OF PHYSICS AND ASTRONOMY

Spring Semester 2006-2007

PHYSICS **3 HOURS**

Answer questions ONE, FOUR and SEVEN plus ONE other from each section, 6 in all.

Answers to different sections must be written in ***separate books****, the books tied together and handed in as one.*

A formula sheet and table of physical constants is attached to this paper.

All questions are marked out of ten. The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

SECTION A

1. COMPULSORY

(a) An oil drop of radius 1.2 μm carries a positive charge corresponding to the loss of three electrons. The density of the oil is 875 kg m^{-3}. The drop is between two horizontal plates 25 mm apart. What voltage must be applied between the plates to hold the drop stationary? [2]

(b) If three α particles merge to make a single carbon–12 nucleus, how much kinetic energy does the latter receive? [1.5]

[Nuclear mass of carbon–12 =11.997 u, and the mass of an α–particle is 4.0015 u. 1.0 u = 1.661×10^{-27} kg.]

(c) A radioactive sample containing 9×10^{24} undecayed radioactive atoms is found to emit 6.5 α particles per second. What is the half-life of this decay process? [2]

(d) $^{132}_{51}\mathrm{Sb}$ decays by β^- emission to $^{y}_{x}\mathrm{Te}$. What are the values of x and y? Explain your reasoning. [1]

(e) An atom has an empty ground state and an occupied excited state 6.3×10^{-19} J above it. What momentum have the photons emitted when an electron makes a transition downwards between these two states? [1.5]

(f) Electrons of energy 45 keV hit a metal target in an X–ray generator. This accelerating voltage is too low to produce line emission. Sketch the spectrum of the X-rays (intensity versus wavelength) and calculate the shortest wavelength produced. [2]

2.

What is meant by the term mass spectrometer? Discuss the essential features of such an instrument in terms of that designed by Dempster, with a diagram and comments on the ion source, path and detector used. Indicate the orientation of the magnetic field on your diagram. [2]

Show that the condition for ion detection is that the mass to charge ratio is

$$\frac{B^2R^2}{2V},$$

where V is the accelerating voltage, B is the magnetic field and R the radius of curvature of the ion path. [2]

If singly and doubly charged ions of the same atom are examined together using the same accelerating voltage, which requires the higher magnetic field for detection and what is the ratio of fields at which the two ions are detected? [1.5]

Which of the two nuclear parameters Z (proton number) and A (mass number) determines

(i) the chemistry of an atom and

(ii) its mass? [1.5]

Hence define what is meant by an isotope, explaining the role of neutrons. [1.5]

Sulphur has three isotopes with A = 32, 33 and 34. If sulphur–32 produces a detection peak with B = 800 mT, at what magnetic fields are the other two isotopes detected? [1.5]

3.

Write down the de Broglie relationship between the wavelength and momentum of a photon. Briefly describe one experiment that supports this equation. Is it easier to demonstrate the wavelike behaviour using

(i) light, fast particles,
(ii) heavy, fast particles,
(iii) light, slow particles, or
(iv) light, fast particles?

Explain your reasons for your choice. [3]

Use the de Broglie relationship to show that an electron mass m_e orbiting a proton at a distance r has momentum

$$m_e v = \frac{hn}{2\pi r},$$

where h is Planck's constant and n an integer. [2]

Use this equation to **derive** the expression for the radius of the orbit

$$r = \frac{n^2 h^2 \varepsilon_0}{\pi e^2 m_e},$$

where ε_0 is the permittivity of free space and e the electronic charge. [2]

Given that the total energy of the orbiting electron is half its electrostatic potential energy, **show** that the energy of the n^{th} hydrogen energy level is

$$E_n = -\frac{m_e e^4}{n^2 8\varepsilon_0^2 h^2}.$$ [2]

Hence calculate the energy difference between the $n = 3$ and $n = 5$ energy levels of hydrogen. [1]

SECTION B

4. COMPULSORY

(a) A body of mass 8.0 g executes simple harmonic motion with an amplitude of 3.5 cm and a period of 0.63 s. Calculate the total energy stored in the oscillating system. [2]

(b) Distinguish clearly between a **transverse** and a **longitudinal** wave. [2]

(c) Calculate the frequency of a microwave generator which emits radiation of wavelength 25 mm. [1]

(d) Explain the term **critical angle** as applied to a glass-air interface. [2]

(e) Sketch a simple diagram showing the location of nodes and antinodes when the **fundamental** mode is excited in an **open** pipe. [2]

(f) State what is meant by the **angular magnification** of an optical instrument. [1]

[Speed of light in a vacuum = 3.0×10^{8} m s^{-1}]

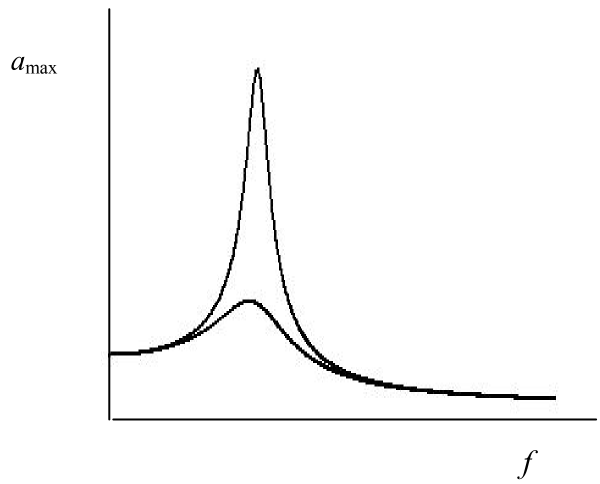
5.

(a) Define **simple harmonic motion**. [1]

(b) A body of mass 0.32 kg attached to a spring executes simple harmonic oscillations with a frequency of 1.54 Hz and amplitude 4.5 cm. Calculate the value of the spring constant. [2]

(c) Calculate the total energy of this system. Sketch a **labelled** graph showing the variation of potential energy U_p and kinetic energy U_k of the body (on the same energy scale) as a function of displacement. Include the numerical values of maximum energy and maximum displacement on the appropriate axes. Calculate the value of the displacement when $U_p = U_k$. [4]

(d) The curves opposite show how the maximum displacement amplitude a_{max} of a mass-spring oscillator varies with the frequency f of an applied force. What phenomenon is occurring where the two curves show maximum values and why do the two curves have different maxima? [3]



6.

(a) Explain what is meant by **diffraction**.
Draw a diagram showing diffraction of plane waves of fixed wavelength at
(i) a wide aperture,
(ii) a narrow aperture. [4]

(b) Sketch a typical diffraction pattern as produced by a single slit. What slit width will produce first-order diffraction minima at angles of ± 23° from the central maximum with light of wavelength 670 nm? [3]

(c) A diffraction grating with 355 lines mm^{-1} is 0.95 m in front of a screen.
What is the wavelength of light whose first-order maxima will be 164 mm from the central maximum on the screen? [3]

CONTINUED

SECTION C

7. COMPULSORY

(a) Gold, in the solid state, has a number density of 5.87×10^{28} atoms per cubic metre. If its relative atomic mass is 197.9, obtain a value for the density of solid gold. [2]

(b) Distinguish between the terms *strength* and *stiffness* as applied to an engineering material. [2]

(c) Calculate the reduction in length when a 2.5 m aluminium cable is cooled from 20 °C to −40 °C. [1]

(d) How many atoms are there in the unit cell of a body-centred cubic crystalline material? Explain your answer. [2]

(e) If the resistivity of titanium is 530 nΩ m, calculate its conductivity. [1]

(f) State two microscopic factors which affect the electrical conductivity of a metal. [2]

$$\left[\begin{array}{l}\text{Avogadro constant, } N_A = 6.02\times10^{23}\ \text{mol}^{-1} \\ \text{Linear expansivity of aluminium} = 2.3\times10^{-5}\ \text{K}^{-1}\end{array}\right]$$

TURN OVER

8.

(a) Sketch a graph showing the potential energy variation with separation (r) for a pair of molecules. Indicate on your graph the equilibrium separation r_0. Define the dissociation energy ε and mark it on your graph. [4]

(b) Sketch a second graph showing the variation of intermolecular force with separation of the molecules. Indicate r_0 on this graph. [2]

(c) Suppose that the intermolecular force is given by

$$F = \frac{A}{r^{13}} - \frac{B}{r^{7}}$$

where A and B are constants.

Explain the physical significance of the two terms (A/r^{13}) and ($-B/r^{7}$) and obtain an expression for the equilibrium separation r_0 in terms of A and B. [4]

9.

(a) With reference to electrons, explain, with a clear diagram, how the Hall Effect gives rise to a small transverse electric field when a magnetic field is applied to a metallic conductor. [4]

(b) The Hall voltage across such a conductor is given by

$$V_H = \frac{BI}{neb}$$

where, in one experiment, the data were

B = 0.10 T, I = 16 A, V_H = 0.25 μV.

The metallic conductor was a strip of thickness b = 0.50 mm and width 2.0 mm.
Evaluate the number density (n) of the electron charge carriers.
Also, use the data to find the drift speed of the electrons. [4]

(c) If the conducting strip had been a semiconductor of the same dimensions under the same conditions, state whether you would expect a larger or smaller Hall voltage. Give a reason. [2]

[Elementary charge $e = 1.6 \times 10^{-19}$ C]

END OF QUESTION PAPER