UNIVERSITY OF CAMBRIDGE LOCAL EXAMINATIONS SYNDICATE

General Certificate of Education Advanced Level

PHYSICS 9243/3

PAPER 3

Tuesday **15 JUNE 1999** Morning 2 hours 30 minutes

Additional materials:
- Answer paper
- Electronic calculator and/or Mathematical tables
- Graph paper
- Ruler (300 mm)

TIME 2 hours 30 minutes

INSTRUCTIONS TO CANDIDATES

Write your name, Centre number and candidate number in the spaces provided on the answer paper/answer booklet.

Answer **six** questions.

Answer **four** questions from Section A and **two** questions from Section B.

Write your answers on the separate answer paper provided.

If you use more than one sheet of paper, fasten the sheets together.

All working for numerical answers must be shown.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets [ ] at the end of each question or part question.

You are advised to spend about 40 minutes on Section B.

You are reminded of the need for good English and clear presentation in your answers.

This question paper consists of 24 printed pages.

MML LOC 708 3/98 QF92917

[Turn over

Section A

Answer **four** questions from this section.

1 **(a)** **(i)** Define *linear momentum*.

(ii) State the principle of conservation of linear momentum.

[3]

(b) **(i)** Name the type of interaction between two bodies when linear momentum and energy, but not kinetic energy, of the system are conserved.

(ii) Explain why the interaction of gas molecules with each other and with the walls of the containing vessel must, on average, be elastic.

[4]

(c) A stationary radium nucleus ($^{224}_{88}Ra$) of mass 224 *u* spontaneously emits an α-particle ($^{4}_{2}He$) of mass 4 *u*. The α-particle is emitted with an energy of 9.2×10^{-13} J and the reaction gives rise to a nucleus of radon (Rn).

(i) Write down a nuclear equation to represent the α-decay of a radium nucleus.

(ii) Show that the speed at which the α-particle is ejected from the radium nucleus is $1.7 \times 10^{7}\,m\,s^{-1}$.

(iii) Calculate the speed of the radon nucleus on emission of the α-particle. Explain how the principle of conservation of linear momentum is applied in your calculation.

[8]

(d) When an α-particle travels through air, it loses energy by ionisation of air molecules. For every air molecule ionised, approximately 5.6×10^{-18} J of energy is lost by the α-particle.

(i) Suggest a typical value for the range of an α-particle in air. Hence estimate the number of air molecules ionised per millimetre of the path of the α-particle, given that the α-particle has an initial energy of 9.2×10^{-13} J.

(ii) It has been discovered that the number of ionisations per unit length of the path of an α-particle suddenly increases just before the α-particle is stopped. State, with a reason, the effect that this observation will have on your estimate.

[5]

2 **(a)** State one similarity and one difference between conduction and convection of thermal energy. [2]

(b) By reference to thermal energy transfer, explain what is meant by

(i) two bodies having the same temperature,

(ii) body H having a higher temperature than body C.

[2]

(c) **(i)** Briefly describe how a physical property may be used to measure temperature on its empirical centigrade scale.

(ii) Hence explain why two thermometers measuring temperature on their empirical centigrade scales do not agree at all temperatures.

[5]

(d) Fig. 2.1 shows data for ethanol.

density	$0.79\ g\ cm^{-3}$
specific heat capacity of liquid ethanol	$2.4\ J\ g^{-1}\ K^{-1}$
specific latent heat of fusion	$110\ J\ g^{-1}$
specific latent heat of vaporisation	$840\ J\ g^{-1}$
melting point	−120 °C
boiling point	78 °C

Fig. 2.1

Use the data in Fig. 2.1 to calculate the thermal energy required to convert $1.0\ cm^3$ of ethanol at 20 °C into vapour at its normal boiling point. [6]

(e) **(i)** State the *first law of thermodynamics.*

(ii) Suggest why there is a considerable difference in magnitude between the specific latent heats of fusion and vaporisation.

[5]

3 **(a)** **(i)** Define *gravitational field strength*.

(ii) State a unit for gravitational field strength.

(iii) The gravitational field strength near the surface of the Earth is also known as the acceleration of free fall. Use base units to check that the unit of gravitational field strength is the same as that of acceleration.

[4]

(b) **(i)** State an equation to represent Newton's law of gravitation, and explain the symbols used.

(ii) Use Newton's law of gravitation and the definition of gravitational field strength to derive an expression for the gravitational field strength g at a distance r from a point mass M.

(iii) At any point above the surface of the Earth, the Earth may be assumed to be a point mass situated at its centre. Explain why the acceleration of free fall is approximately constant between the Earth's surface and a point about 1000 m above it.

[5]

(c) Fig. 3.1 shows the variation with time t of the distance d fallen from rest by an object in a vacuum near the Earth's surface.

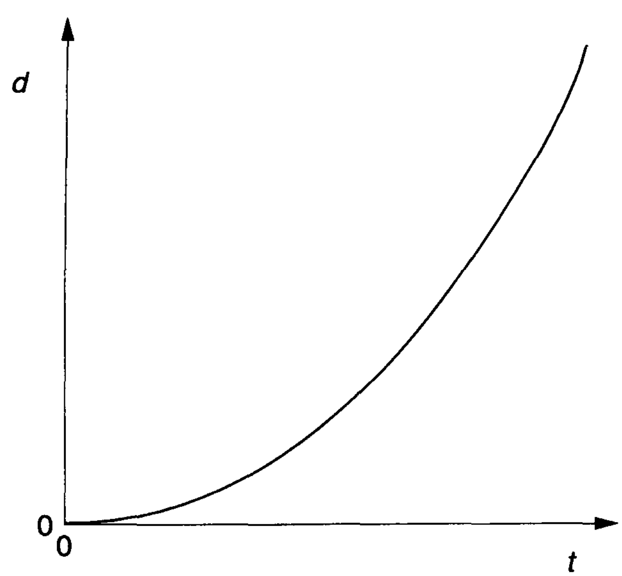

Fig. 3.1

(i) Explain how it is possible to deduce from Fig. 3.1 that the object is undergoing accelerated motion.

(ii) Copy Fig. 3.1 and on it draw a line to represent the variation with time t of distance d when the object is falling from rest *through air* at the same location on the Earth's surface. Label the line A.

[4]

(d) The potential in the gravitational field of a point mass decreases with decreasing distance from the mass. In the electric field of a point charge, electric potential may increase or decrease with decreasing distance from the charge. Explain this difference. [2]

(e) The radius of a lithium ($^{7}_{3}Li$) nucleus is 2.3×10^{-15} m, and the radius of a proton is 1.2×10^{-15} m.

(i) Calculate the electric potential energy of a proton when it is just in contact with a lithium nucleus. You may assume that the proton and the lithium nucleus act as point charges.

(ii) By reference to your answer to **(i)**, suggest why particle accelerators used for research into the composition of nuclei are referred to as 'high energy' accelerators.

[5]

4 **(a)** **(i)** Explain what is meant by the *frequency* of vibration of an object.

(ii) Distinguish between the *displacement* of a vibrating object and the *amplitude* of vibration.

[3]

(b) Some sand is placed on a flat horizontal plate and the plate is made to oscillate with simple harmonic motion in a vertical direction, as illustrated in Fig. 4.1.

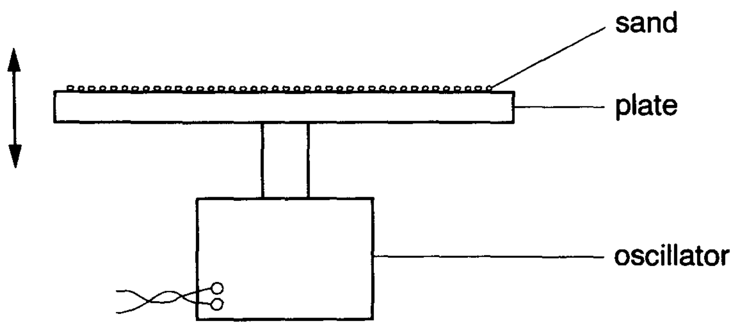

Fig. 4.1

The plate oscillates with a frequency of 13 Hz.

(i) Sketch a graph to show the variation with displacement x of the acceleration a of the plate.

(ii) The acceleration a is given by the expression

$$a = -\omega^2 x,$$

where ω is the angular frequency. Calculate

1. the angular frequency ω,
2. the amplitude of oscillation of the plate such that the maximum acceleration is numerically equal to the acceleration of free fall.

[8]

(c) Suggest, with a reason, what happens to the sand on the plate in **(b)** when the amplitude of oscillation of the plate exceeds the value calculated in **(b)(ii)**2. [3]

(d) One end of a horizontal string is now attached to the oscillating plate. The string passes over a pulley and the string is kept under tension by means of a weight, as illustrated in Fig. 4.2.

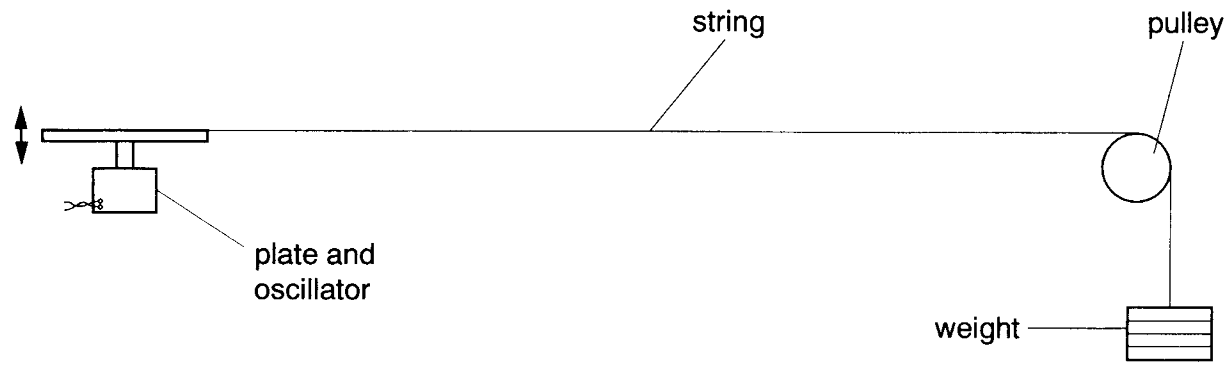

Fig. 4.2

The frequency of oscillation of the plate is increased and at certain frequencies, stationary waves are produced on the string.

(i) Copy Fig. 4.2 and on your diagram show the stationary wave on the string when the frequency is such that the distance between the plate and the pulley corresponds to two wavelengths of the wave on the string.

(ii) On your diagram, label the position of a node on the string.

(iii) Briefly explain why a stationary wave is observed on the string only at particular frequencies of vibration of the plate.

[4]

(e) Some musical instruments rely on stationary waves on strings in order to produce sound.

Suggest why strings made of different materials or with different diameters are sometimes used. [2]

5 **(a)** State what is meant by

(i) the *resistance* of a sample of a metal,

(ii) the *resistivity* of the metal.

[4]

(b) A strain gauge consists of a thin metal foil firmly bonded to a flexible plastic backing sheet, as illustrated in Fig. 5.1.

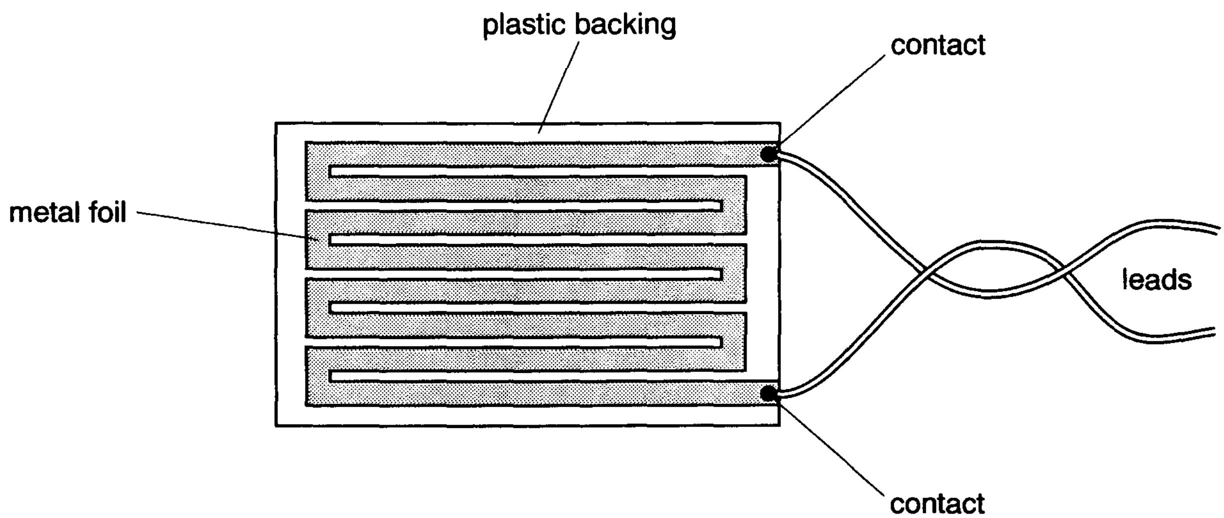

Fig. 5.1

The foil has total length l and total resistance R between the contacts. When the foil is extended by an amount Δl, the resistance changes by an amount ΔR, such that

$$\Delta R/R = 0.485\ (\Delta l/l).$$

(i) Suggest why the device illustrated in Fig. 5.1 is referred to as a *strain* gauge.

(ii) Explain, by reference to the definition of resistivity, why the resistance of the metal foil changes when it is extended.

[4]

(c) In one particular application, the strain gauge S is connected in series with a fixed resistor F of resistance 400 Ω and a battery of e.m.f. 4.50 V and negligible internal resistance, as illustrated in Fig. 5.2.

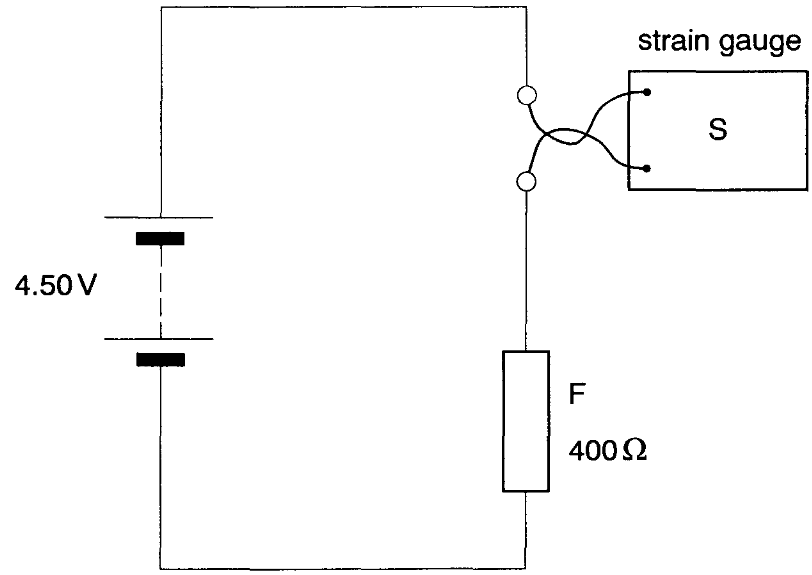

Fig. 5.2

(i) Show that there is a potential difference of 2.40 V across the resistor F when the strain gauge has a resistance of 350 Ω. Explain your working carefully. [3]

(ii) The gauge is given a strain of 1.18%. Using the expression given in **(b)**, calculate the *change* in

1. the resistance of the strain gauge,
2. the potential difference across the resistor F. [5]

(d) The strain gauge is firmly fixed to a structure so that the strain, as calculated from the change in potential difference, is used to determine the stress on the structure. State how the stress on the structure may be determined from the measured strain. [2]

(e) In practice, the method outlined in **(b)**, **(c)** and **(d)** may not give a reliable result for the stress. Suggest two factors, other than a change in strain, which might give rise to a change in the potential difference across the resistor F. [2]

6 **(a)** A stationary negatively-charged particle experiences a force in the direction of the field in which it is placed. State, with a reason in each case, whether or not the field is

(i) magnetic,

(ii) electric,

(iii) gravitational.

[3]

(b) **(i)** Calculate the magnitude of the electric field strength required to maintain an electron in a fixed position in the gravitational field of the Earth, near its surface.

(ii) Hence explain why gravitational effects are ignored when considering the motion of electrons in electric fields.

[4]

(c) Atoms of Neon-20 are ionised by the removal of one electron from each atom. For a Neon-20 ion,

(i) state the charge on the ion,

(ii) calculate its mass.

[3]

(d) The ions in **(c)** are accelerated from rest in a vacuum through a potential difference of 1400 V. They are then injected into a region of space where there are uniform electric and magnetic fields acting at right angles to the original direction of motion of the ions, as shown in Fig. 6.1.

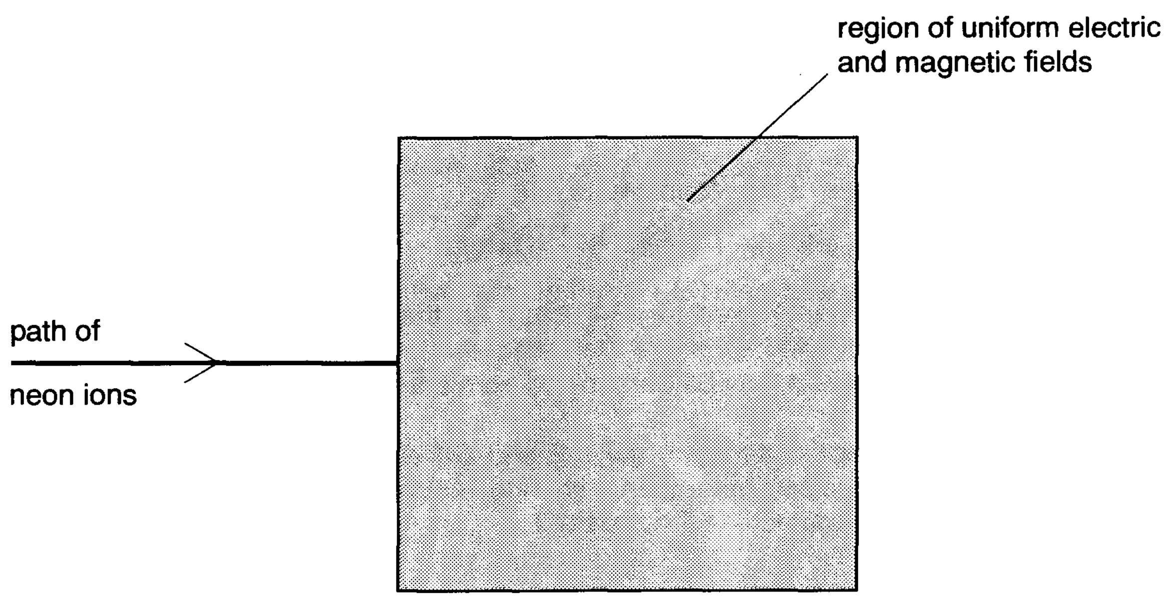

Fig. 6.1

The electric field has field strength E and the flux density of the magnetic field is B.

(i) Copy Fig. 6.1 and on your diagram indicate clearly the directions of the electric and magnetic fields so that the ions pass undeflected through the region.

(ii) Calculate the speed of the accelerated ions on entry into the region of the electric and magnetic fields.

(iii) The electric field strength E is $6.2 \times 10^3\,\mathrm{V\,m^{-1}}$. Calculate the magnitude of the magnetic flux density so that the ions are not deflected in the region of the fields.

[7]

(e) The mechanism by which the neon atoms in **(c)** are ionised is changed so that each atom loses two electrons. State what change occurs in

(i) the speed of the ions entering the region of the electric and magnetic fields in **(d)**,

(ii) the path of the ions in the two fields.

[3]

[Turn over

Section B

Answer **two** questions from this section.

One question is set on each of the seven optional topics, namely

Question 7	Option A	Astrophysics and Cosmology,
Question 8	Option C	The Physics of Materials,
Question 9	Option E	Electronics,
Question 10	Option F	The Physics of Fluids,
Question 11	Option M	Medical Physics,
Question 12	Option P	Environmental Physics,
Question 13	Option T	Telecommunications.

You may choose any **two** questions.

Option A

Astrophysics and Cosmology

7 **(a)** **(i)** With the aid of a labelled diagram, describe the general structure of the Milky Way Galaxy.

(ii) On your diagram, mark the approximate position of the Sun.

[5]

(b) The Earth-Moon distance is approximately 5×10^8 m and the Moon is receding from the Earth at a rate of 0.04 metres per year.

(i) Calculate, in Mpc, the distance of the Moon from the Earth.

(ii) Write down the Hubble equation for the expansion of the Universe relating galactic speed of recession v to distance d.

(iii) One estimate for the Hubble constant H_0 is 60 km s^{-1} Mpc^{-1}. Calculate whether the Moon's recession is faster or slower than that derived from the estimate of H_0.

[7]

(c) Theories for the evolution of the Universe indicate that it may be 'open', 'flat' or 'closed'. Fig. 7.1 is a graph of the variation with time of the size of the Universe to illustrate the three possibilities.

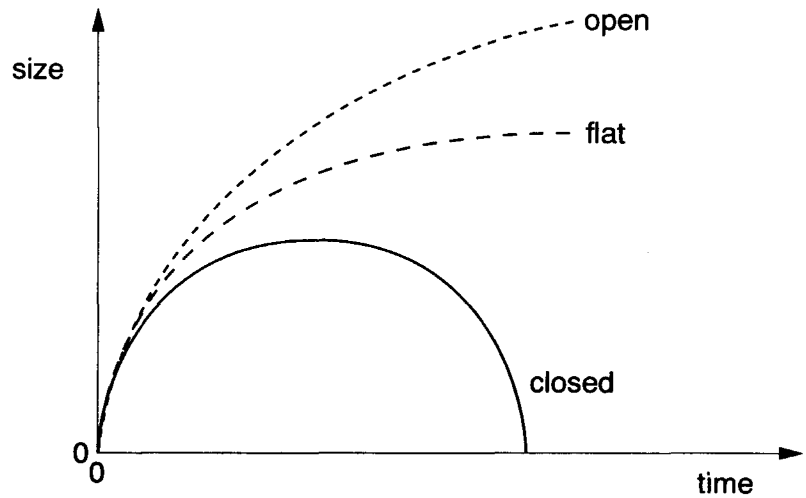

Fig. 7.1

(i) Name the physical quantity on which the ultimate fate of the Universe is dependent.

(ii) Suggest why it is not yet possible to arrive at an accurate value for the magnitude of this quantity.

[3]

Option C

The Physics of Materials

8 **(a)** Fig. 8.1 represents a Bravais lattice.

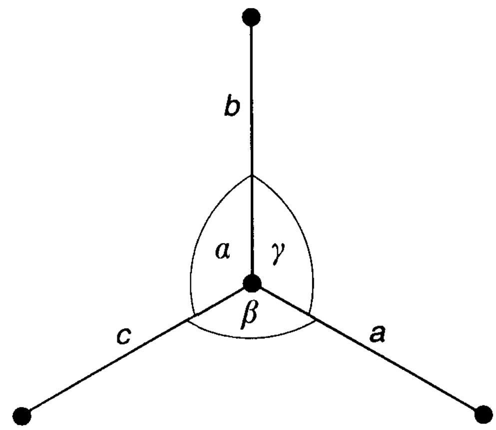

Fig. 8.1

Name the crystal structure described by a Bravais lattice when

(i) $a = b = c$, and $\alpha = \beta = \gamma = 90°$,

(ii) $a = b$, $\alpha = \beta = 90°$ and $\gamma = 120°$.

[2]

(b) Fig. 8.2 illustrates a bubble raft in which there is a fault at X.

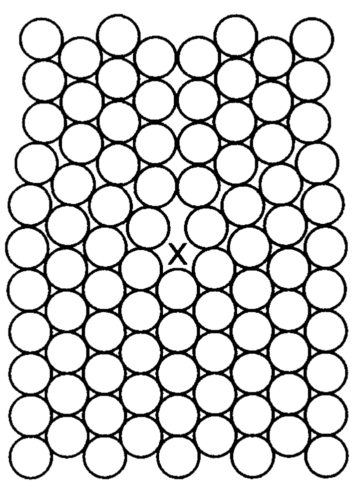

Fig. 8.2

(i) Name the type of fault illustrated.

(ii) Explain why increasing the number density of such faults in a material affects its strength and hardness.

[4]

(c) Fig. 8.3 shows the variation with applied stress of the number of cycles through which two samples of different metals are put before fatigue fracture occurs.

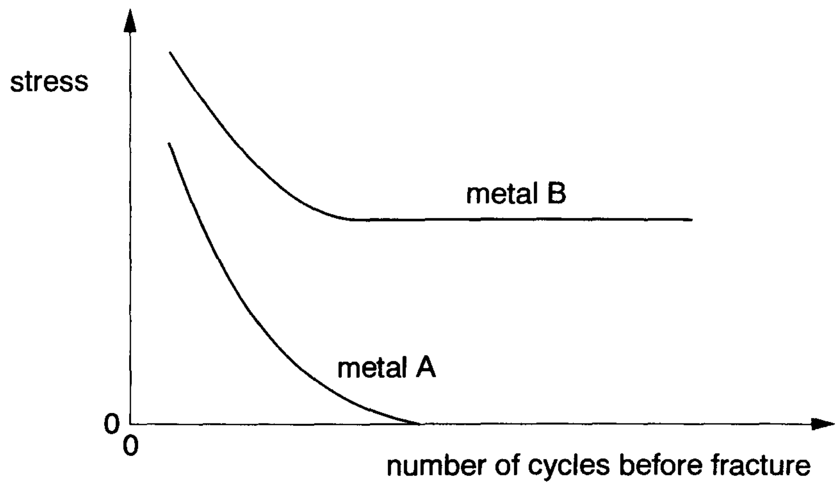

Fig. 8.3

(i) State the mechanism within a metal sample by which fatigue fracture occurs. Hence suggest how fatigue may be diagnosed at an early stage of development. [3]

(ii) An engine component is made of metal A but after a few hours use in the engine, the component fails. The faulty component is replaced by one made of metal B. The new component does not fail, even after many hours of use.

1. Name a possible metal for A and for B.

2. Explain why, although both metals could fail through fatigue, metal B does not fail even after prolonged use. [6]

Option E

Electronics

9 (a) Fig. 9.1 shows the variation with input voltage V_{IN} of the output voltage V_{OUT} for an amplifier.

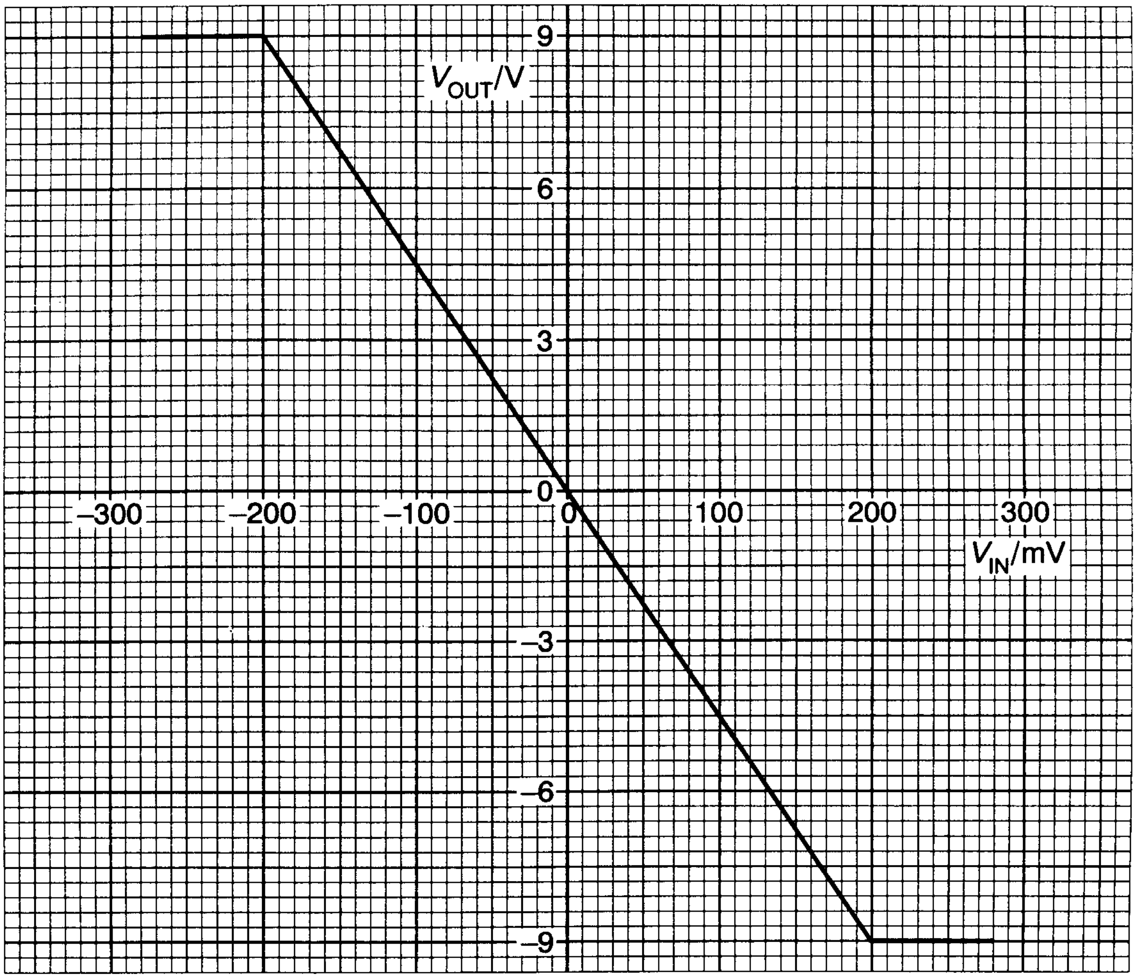

Fig. 9.1

(i) State whether the amplifier is an inverting or a non-inverting amplifier.

(ii) Use Fig. 9.1 to calculate the magnitude of the voltage gain of the amplifier.

(iii) Draw a circuit diagram for this amplifier, based on an ideal operational amplifier. On your diagram, indicate the input and output connections and also suitable values of any components used.

[8]

(b) Fig. 9.2 shows a circuit with two NOR gates.

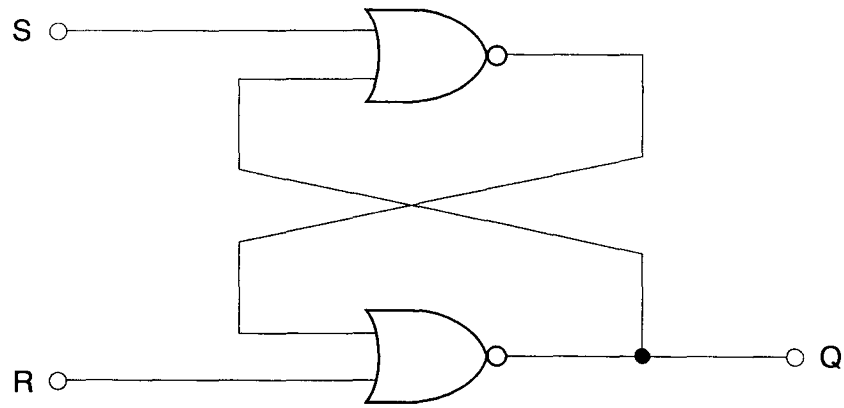

Fig. 9.2

Initially, the input states of S and R are logic 1 and logic 0 respectively. The states of S and of R are then changed in the order shown in Fig. 9.3.

S	R	Q
1	0	1
0	0	
0	1	
0	0	

Fig. 9.3

(i) Copy Fig. 9.3 and complete the table to show how the output Q depends on the logic states of S and of R.

(ii) Comment on the output Q with reference to the input logic states 0, 0.

[4]

(c) **(i)** State one example of an electronic device in the home which includes a logic circuit.

(ii) Give two advantages of this device over similar devices not incorporating logic circuits.

[3]

Option F

The Physics of Fluids

10 **(a)** **(i)** State, with reference to a submarine floating on the surface of the sea, what is meant by

1. the centre of buoyancy,
2. the metacentre,
3. stability.

(ii) Suggest why, when the submarine submerges, the stability of the boat may be altered. [6]

(b) Fig. 10.1 is a diagram of a Bunsen burner.

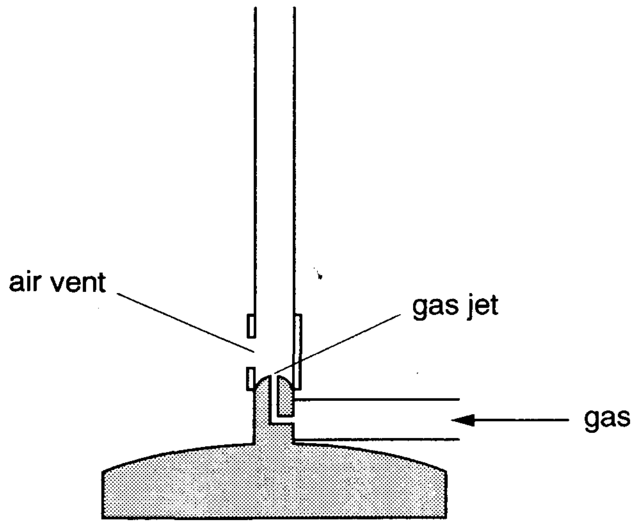

Fig. 10.1

Suggest why, when gas flows into the Bunsen burner, air is drawn in through the air vent. [3]

(c) Hypodermic syringes and needles are designed so that liquid may be injected by exerting a reasonable force on the syringe. In one particular application, the needle has an internal diameter of 0.030 cm. Liquid, of density $\rho = 1.0 \times 10^3\,\text{kg m}^{-3}$ and viscosity $\eta = 9.3 \times 10^{-4}\,\text{kg m}^{-1}\,\text{s}^{-1}$ is to be injected at a rate of $0.20\,\text{cm}^3\,\text{s}^{-1}$.

(i) Calculate the speed v of the liquid inside the needle.

(ii) Determine whether the flow along the needle is streamline or turbulent.

[6]

Option M

Medical Physics

11 **(a)** X-rays are used for imaging internal body structures.

(i) State two factors which affect the contrast of the image produced on an X-ray plate.

(ii) The attenuation in matter of a parallel X-ray beam may be represented by the expression

$$I = I_0 e^{-\mu x}.$$

1. State what is meant by *attenuation*.

2. State and explain what change occurs in the constant μ when the X-ray beam passes from muscle into bone.

[5]

(b) Briefly describe the use of a laser in

(i) clinical therapy as a scalpel,

(ii) pulse oximetry.

[6]

(c) The intensity of sound at a certain position is $2.9\,\text{mW}\,\text{m}^{-2}$.

(i) Calculate the intensity level of this sound.

(ii) Comment on the loudness of the sound as experienced by a person with normal hearing when the frequency of the sound increases gradually from 3 kHz to 12 kHz.

[4]

Option P

Environmental Physics

12 **(a)** **(i)** Distinguish between a *solar cell* and a *solar panel*.

(ii) State one practical application of

1. a solar cell,
2. a solar panel.

(iii) Static large-scale solar panels and solar cells in use in the United Kingdom are generally sited so that they face south at an angle of about 30° to the horizontal. Suggest why the panels

1. face south,
2. are inclined at an angle of about 30° to the horizontal.

[4]

(b) In a pumped-water hydro-electric scheme, the upper reservoir has a capacity of $2.3 \times 10^6 \, m^3$ of water of density $1.0 \times 10^3 \, kg \, m^{-3}$. The reservoir is at a mean height of 270 m above the turbines. The generators produce 240 MW of electrical power.

(i) Calculate

1. the total potential energy (in MW h) stored in the reservoir,
2. the length of time the generators may operate before re-filling the reservoir if 65% of the total potential energy of the water can be converted into electrical energy. [5]

(ii) The pumped storage scheme is one part of a generating system producing electric power for a district. Fig. 12.1 illustrates the variation with time of day of the total load on the generating system.

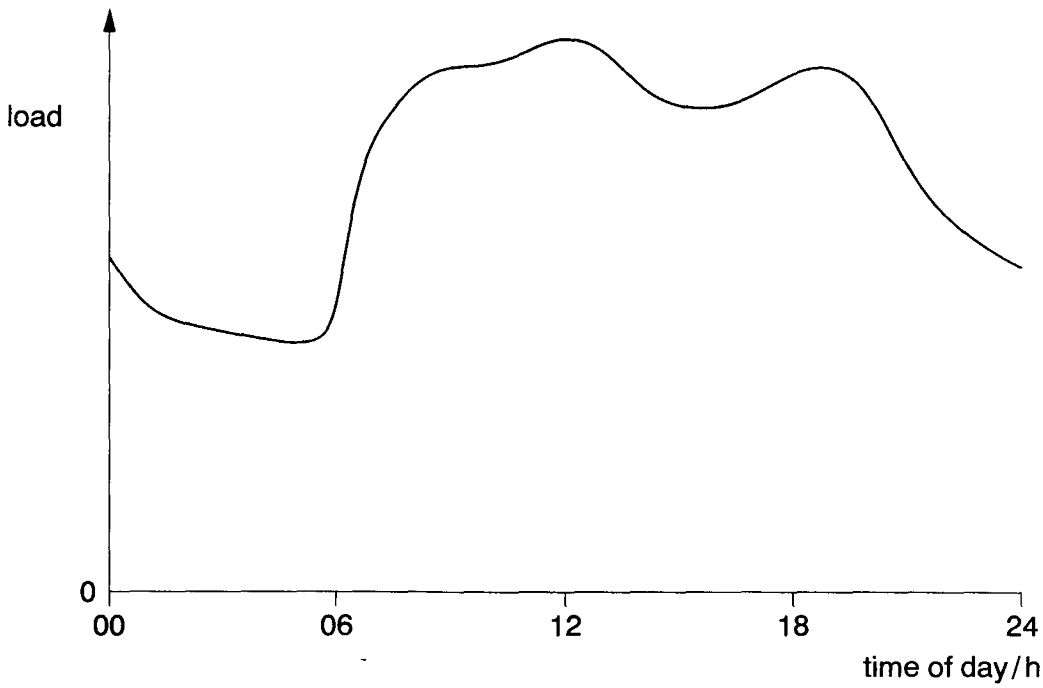

Fig. 12.1

Suggest, with a reason, times at which the pumped storage scheme should be

1. generating power for the system,
2. pumping water back into the upper storage reservoir. [3]

(c) **(i)** State one form of pollution, other than that associated with radioactive waste, produced by nuclear power stations.

(ii) Suggest what measures are taken to minimise the effects of this pollution.

[3]

Option T

Telecommunications

13 **(a)** Fig. 13.1 shows the voltage variation V with time t of a message which is to be transmitted by amplitude-modulation of a carrier wave.

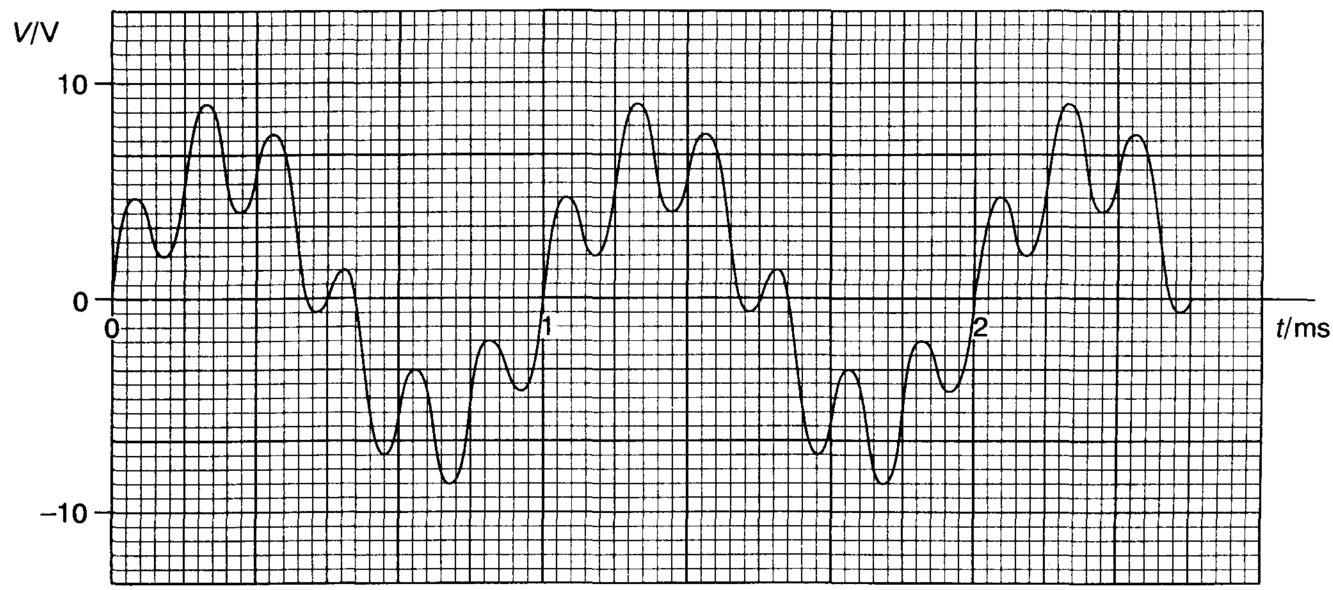

Fig. 13.1

The carrier wave has frequency 25 kHz.

(i) Determine the number of cycles of the carrier wave in one cycle of the message.

(ii) Sketch a graph to show the variation with frequency of the power in the AM waveform (label relevant points on the frequency axis).

(iii) 1. State what is meant by *bandwidth*.

2. Determine the bandwidth of the AM transmission.

[8]

(b) A signal is to be transmitted along a length of coaxial cable.

(i) Explain why there is a limit to the length of uninterrupted cable along which the signal can be transmitted. Suggest what must be done before this limit is reached.

(ii) The input signal to a cable has a power of 4.0 W and the minimum acceptable signal power in the cable is 0.50 mW. The cable has a loss of 3.0 dB km^{-1}. Calculate the maximum uninterrupted length of cable along which the signal may be transmitted.

You may wish to use the equation

$$\text{number of dB} = 10\,\lg(P_1/P_2),$$

where (P_1/P_2) is the ratio of two powers.

[4]

(c) Telephone signals may be transmitted using microwaves or coaxial cables.

(i) State a typical wavelength for microwave communication.

(ii) State two advantages of transmitting on a microwave link rather than by coaxial cable.

[3]