[3220/264] 1988

SCOTTISH CERTIFICATE OF EDUCATION

# PHYSICS

**Higher Grade—PAPER II**

**Wednesday, 4th May—1.30 p.m. to 4.00 p.m.**

**In SECTION A answer ALL questions.**

**In SECTION B answer any THREE questions.**

**In SECTION C answer any ONE question.**

**Use the approximation $g = 10\,\mathrm{m\,s^{-2}}$ or $g = 10\,\mathrm{N\,kg^{-1}}$.**

**Any other data required will be found in the Science Data Booklet (1982 edition) provided.**

**Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Examination Board.**

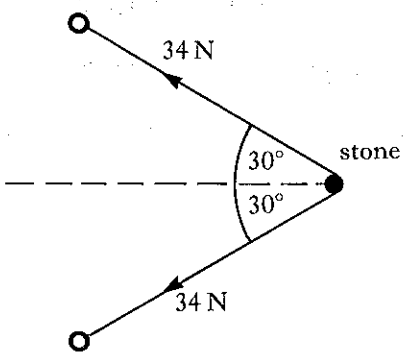
UCP 3220/264 6/3/20560

## SECTION A

**ALL questions in this section should be attempted.**

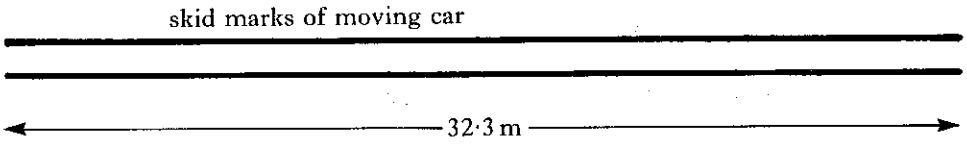
*Marks*

**1.** A catapult is pulled back as shown below until the tension in the elastic is 34 N.




Calculate the magnitude and direction of the resultant force on the stone at the instant the elastic is released. **3**

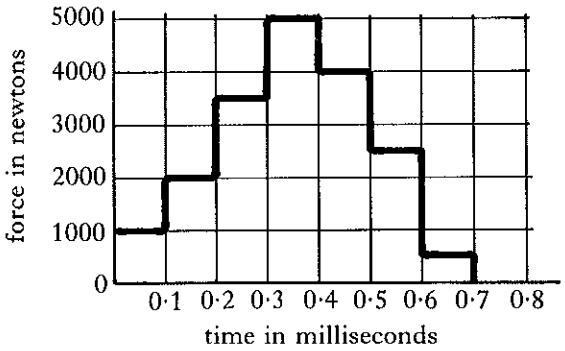
**2.** The driver of a car travelling along a level road brakes sharply. The front wheels of the car lock, producing the skid marks shown below as the car comes to rest.




The mass of the car including the driver is 1050 kg. It is estimated that the frictional force while skidding is 5210 N.

Calculate the speed of the car just before its wheels locked. **3**

**3.** The bar graph indicates how the force of a golf club on a golf ball of mass 0·046 kg varies with time.

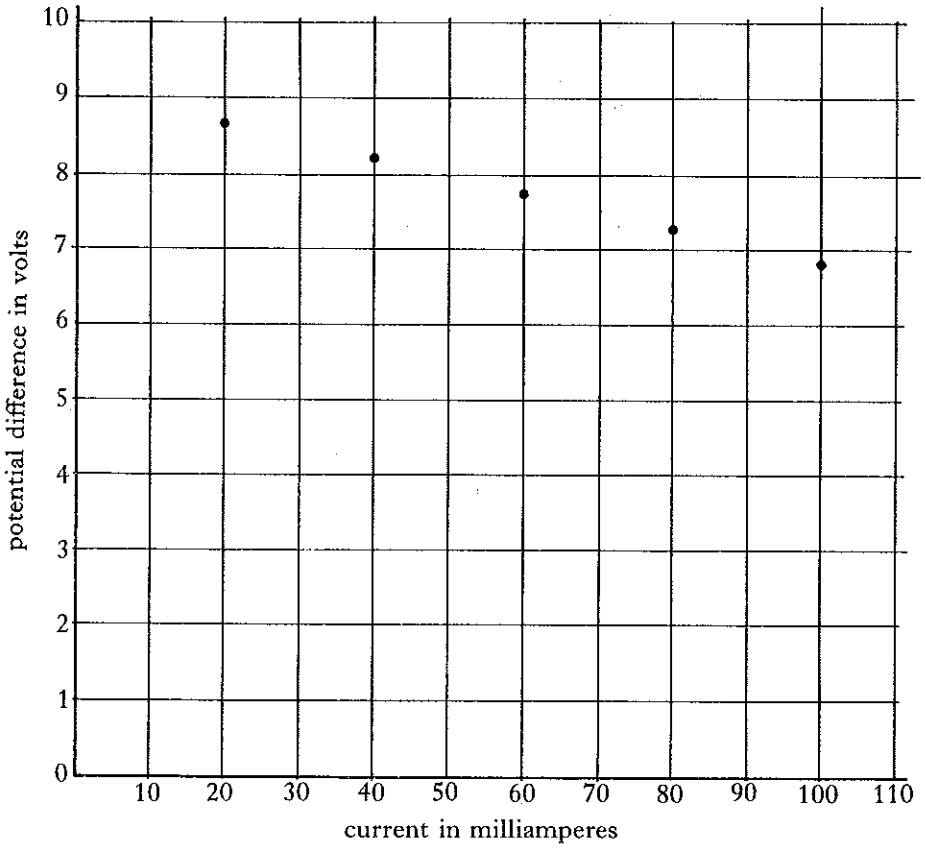



(*a*) Estimate the change in momentum of the golf ball.

(*b*) Calculate the speed of the golf ball as it leaves the club. **4**

*Marks*

**4.** A pupil measures the potential difference across the terminals of a battery when it supplies a number of different currents. The results are shown in the graph.




(*a*) What is the e.m.f. of the battery?

(*b*) Calculate the internal resistance of the battery. **4**

**5.** You are given a fixed 10 V d.c. supply, a 1·5 kΩ resistor and a 1·0 kΩ variable resistor.

(*a*) Show, by means of a circuit diagram, how you would connect these components to supply a variable voltage of up to 4·0 V. Label the output terminals in your diagram.

(*b*) How would the output voltage be affected if current was drawn from the output by a load? **3**

**6.** (*a*) An inductor is connected to an alternating supply of constant peak voltage and the frequency of the supply is varied.

(i) Show, by means of a sketch graph, how the current in the inductor varies with the frequency of the supply.

(ii) What happens to the reactance of the inductor as the frequency of the supply increases?

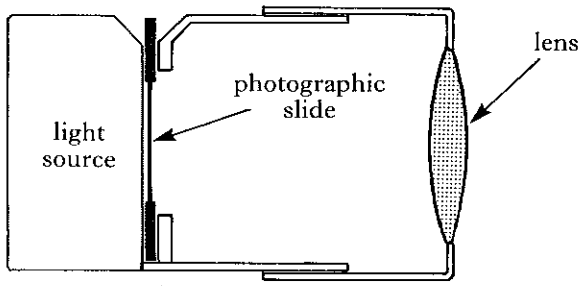
(*b*) A car radio often has a choke fitted in its power supply line from the battery.

Explain briefly how the choke filters out high frequency currents (interference produced by the ignition system) without much effect on the 12 V d.c. supply. **4**

**[Turn over**

*Marks*

**7.** The diagram illustrates a battery-operated slide viewer with variable magnification.




The photographic slide is evenly illuminated from behind. A lens of focal length 50 mm is used to produce a virtual image, the magnification of which can be varied by adjusting the distance between the lens and the slide.

(*a*) Use a ray drawing to find the linear magnification when the distance between the lens and the slide is 31 mm. Draw your diagram on the square-ruled paper provided.

(*b*) How would the linear magnification be affected by moving the lens closer to the slide? **5**

**8.** (*a*) Describe how you would set up apparatus to produce and observe

(i) a continuous emission spectrum;

(ii) an absorption spectrum.

(*b*) Describe briefly the appearance of an absorption spectrum. **5**

**9.** The first artificial transmutation of one element into another was carried out in 1933 by Cockcroft and Walton, who bombarded a lithium target with protons to produce the following reaction:

$$^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He}$$

In one experiment, the kinetic energy of the helium nuclei was $2{\cdot}69 \times 10^{-12}$ J greater than the kinetic energy of the incoming proton.

The masses of the nuclei, when they are at rest, are as follows:

| | |
|---|---|
| lithium nucleus | 7·018 u |
| proton | 1·008 u |
| helium nucleus | 4·004 u |

[1 u = 1 atomic mass unit = $1{\cdot}660 \times 10^{-27}$ kg]

Using the relationship $E = mc^2$, show that these results account for the gain in kinetic energy. **4**

**[END OF SECTION A]**

## SECTION B

**Answer any THREE questions. Each question carries FIFTEEN marks.**

*Marks*

**10.** (*a*) (i) In an experiment to show Brownian motion, smoke is observed in a "smoke cell".

Describe what is seen and explain why the observations lead to a particle model of a gas in which the particles are in continuous random motion, tiny in size, and moving at fast speeds.

(ii) A comparison of the spacing of molecules in the solid and gas states can be based on the experiment shown in Figure 1.

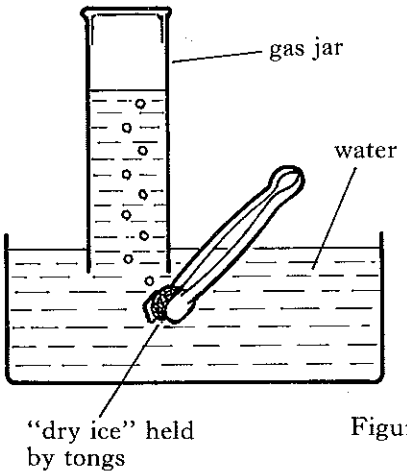



Figure 1

If the "dry ice" (solid carbon dioxide) has an initial volume of 1 $cm^3$, give an estimate of the volume of gaseous carbon dioxide obtained in the gas jar, and state what your answer implies about the separation of molecules in the gas state compared to the solid state.

(iii) For gas molecules, kinetic theory predicts that $E_k \propto T$ (the symbols having their usual meanings).

In the above experiment, solid carbon dioxide changes to a gas at a temperature of $-78°C$.

If the r.m.s. velocity of carbon dioxide molecules at $-78°C$ is $324\,m\,s^{-1}$, calculate their r.m.s. velocity at room temperature of 20°C. **8**

(*b*) Various atomic models have been proposed and rejected on the evidence of later experiments.

Figure 2 illustrates the Thomson "plum pudding" model.

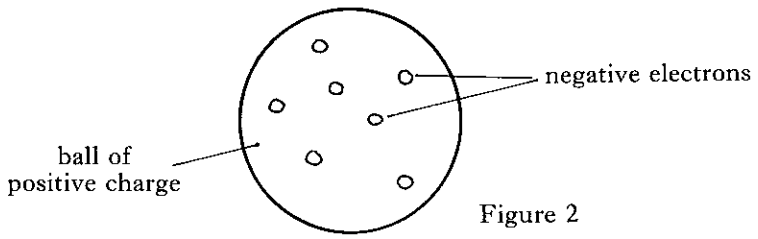



Figure 2

In this model, a solid atom of positively charged matter has the negative electrons distributed throughout it.

(i) What observation in Rutherford's scattering experiments led to this model being rejected?

(ii) As a result of these experiments, Rutherford proposed a new model. Give two ways in which Rutherford's model differed from Thomson's model.

(iii) Rutherford's model was modified to take account of the formation of line spectra.

(A) What was the modification?

(B) How does it account for the formation of line spectra? **6**

(*c*) When a crystal is placed in a beam of electrons in a vacuum tube, a diffraction pattern is observed.

What does this suggest about the nature of electrons? **1**

**(15)**

*Marks*

**11.** (*a*) A golf ball is dropped and falls freely. A strobe photograph is taken with the stroboscope set to a flash-rate of 14 Hz.

Figure 1 is an accurate diagram of the photograph.

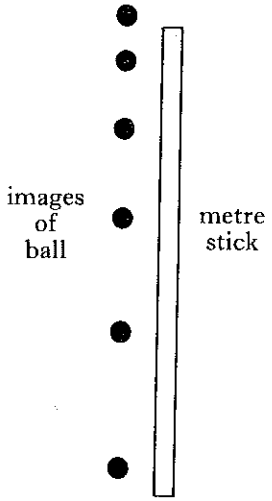



Figure 1

(i) Why is the metre stick included in the photograph?

(ii) Using measurements from Figure 1, calculate the acceleration of the golf ball. (Write down the measurements you take and show how they are used in your calculation.)

(iii) In designing this experiment, the flash rate must be carefully chosen.

Suggest why (A) the flash rate should not be set too low;

(B) the flash rate should not be set too high. **8**

(*b*) (i) The golf ball in Figure 1 is moving with constant acceleration.

Give an example of an object moving with varying acceleration.

(ii) State why the acceleration varies in the example you have chosen. **2**

*Marks*

(*c*) Figure 2 shows a simplified diagram of a hydro-electric power station.

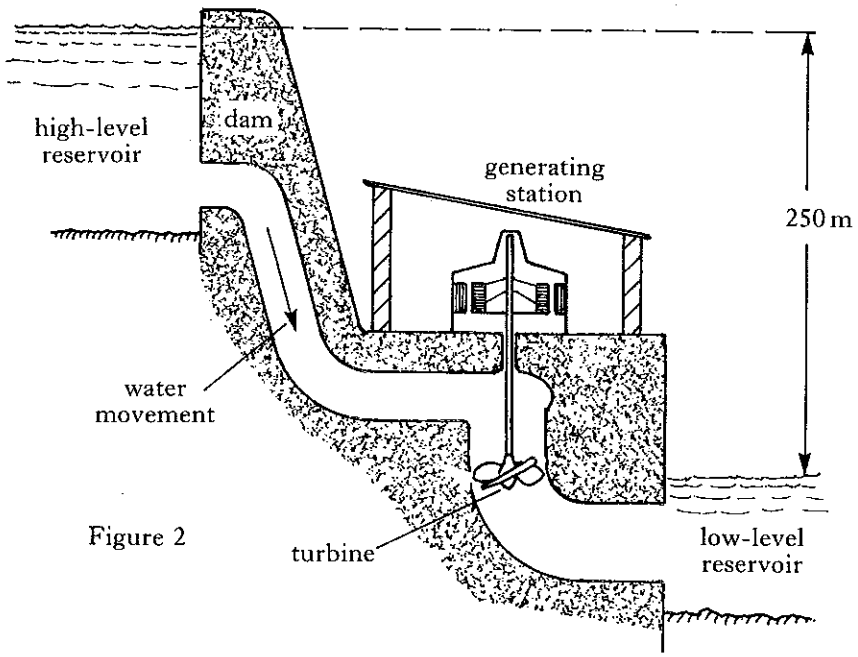



Figure 2

(i) Water flows from the high-level to the low-level reservoir through a vertical height of 250 m and at a rate of $21{\cdot}6 \times 10^6$ kg per hour.

Calculate the power output available from the generating station if the system is 60% efficient.

(ii) Some hydro-electric power stations are designed as pumped storage systems in which electricity from the National Grid is used to pump water back up to the high-level reservoir.

(A) When is this likely to be carried out?

(B) What is the advantage in doing this?

**5**

**(15)**

**[Turn over**

*Marks*

**12.** (*a*) In the apparatus shown in Figure 1, a beam of electrons is deflected in an electric field.

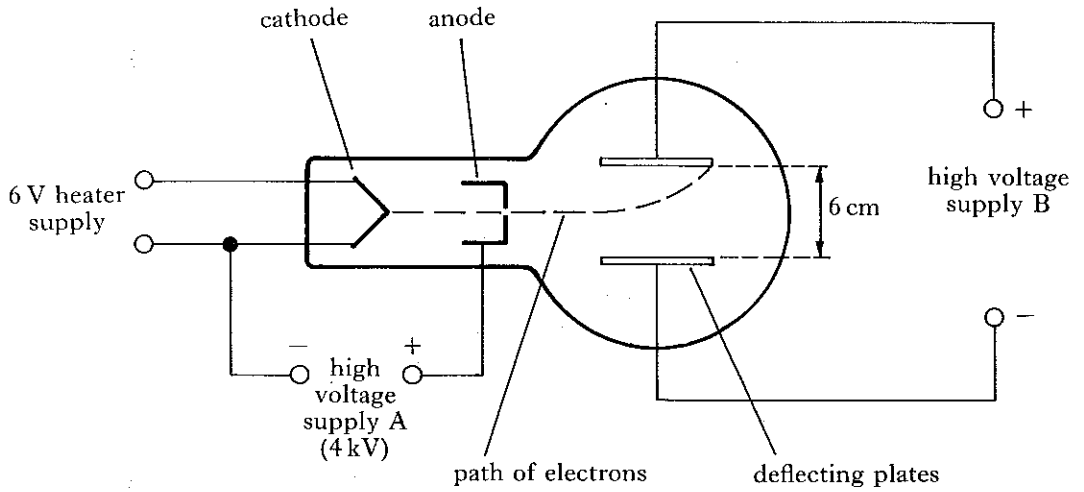



Figure 1

Between the cathode and the anode, an electron is accelerated from rest through a potential difference of 4 kV.

(i) Calculate the velocity of the electron as it passes through the hole in the anode.

(ii) If a constant force of $8{\cdot}0 \times 10^{-15}$ N acts on each electron as it passes between the deflecting plates, calculate

(A) the magnitude of the electric field strength between the deflecting plates;

(B) the voltage of supply B given that the plates are 6 cm apart. **7**

(*b*) A simplified circuit diagram for the high voltage supply units used above is given in Figure 2.

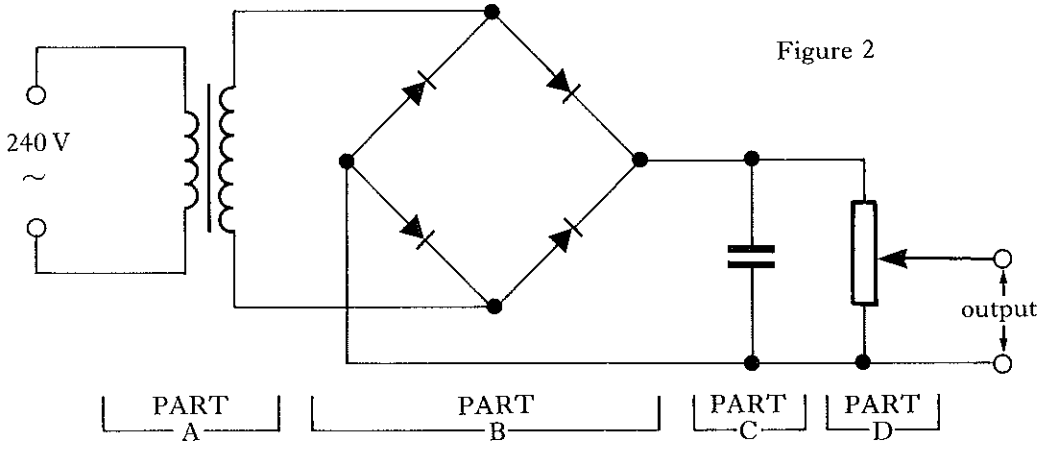



Figure 2

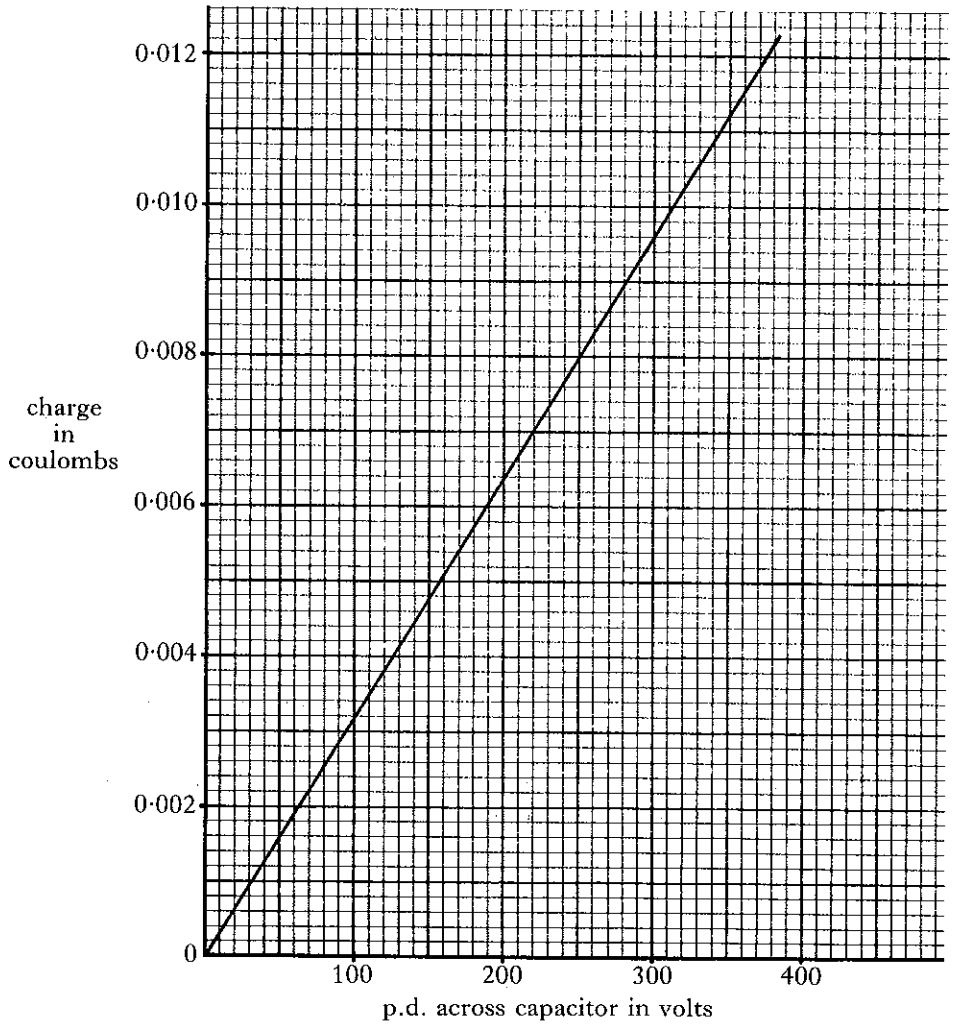
(i) State the function of each of the parts of the circuit labelled A, B, C and D.

(ii) The capacitor used in the circuit must have a large capacitance. Suggest two ways in which a paper capacitor can be designed to meet this requirement.

(iii) Why does this type of capacitor have a maximum working voltage? **4**

*Marks*

(*c*) The graph of charge against p.d. for a capacitor is shown below.




Calculate

(i) the capacitance of the capacitor;

(ii) the energy stored in the capacitor when the p.d. is 300 V. **4**

**(15)**

**[Turn over**

*Marks*

**13.** (*a*) (i) Figure 1 shows a sketch of the path taken by a ray of monochromatic light when refracted by a prism.

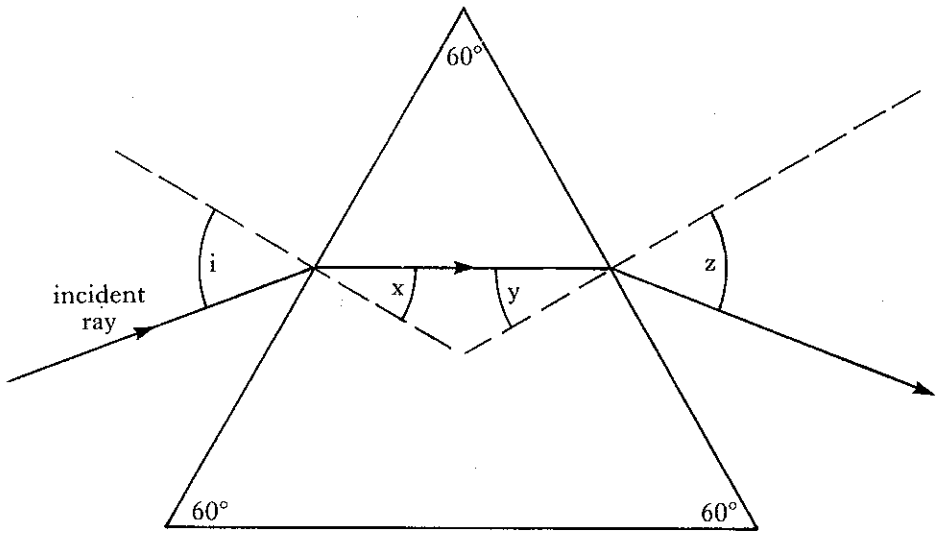



Figure 1

Draw an **accurate** diagram to show this path when the ray is incident at an angle of incidence i = 52° on a prism made from crown glass of refractive index n = 1·53.

On your diagram, mark clearly the values of angles x, y and z.

(ii) Figure 2 is an **accurate** diagram of the path taken by a ray incident at the same angle of 52° on a prism made from glass of high refractive index.

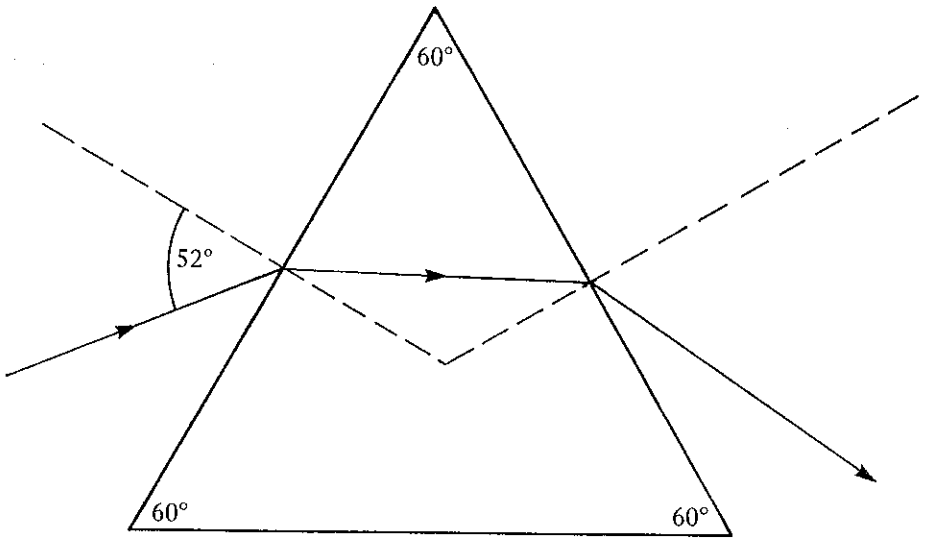



Figure 2

Calculate the refractive index of this glass.

(iii) A person has to wear spectacles with lenses of short focal length. By comparing the diagram you have drawn with Figure 2, suggest the advantage of using glass of high refractive index for the lenses. **7**

*Marks*

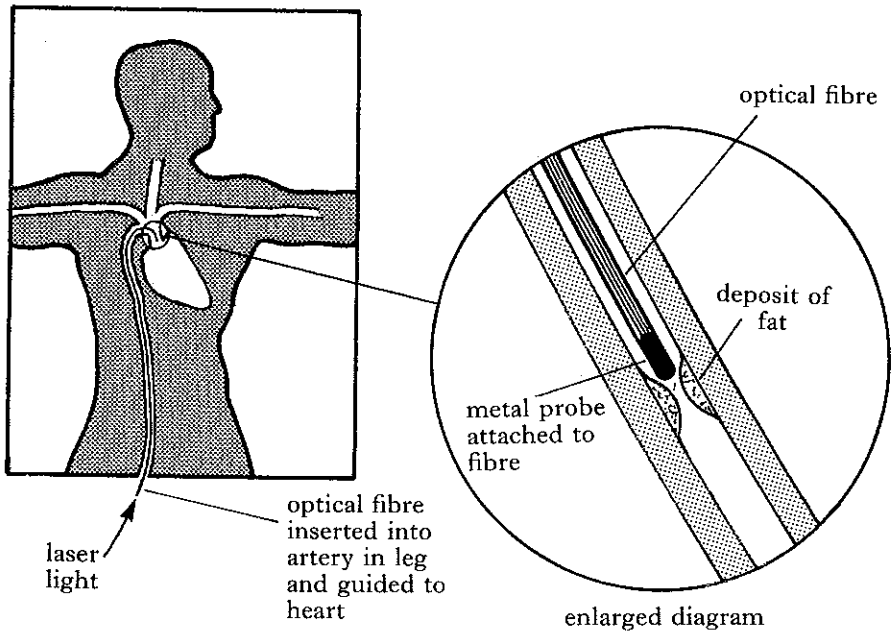
(*b*) (i) What is total internal reflection and under what conditions does it occur?

(ii) Draw a diagram showing the path of a ray of light through a short curved section of optical fibre. **3**

(*c*) The diagram below shows a new technique for removing a deposit of fat blocking an artery leading to the heart.

Laser light is transmitted along an optical fibre inserted into the artery as shown.

The energy of this light heats up a tiny metal probe to a temperature sufficiently high to vaporise the fatty deposit.




The light from the 8 W argon laser used is of 490 nm wavelength.

(i) If the metal probe has a mass of $2{\cdot}5 \times 10^{-4}$ kg and specific heat capacity 441 J kg$^{-1}$ K$^{-1}$, calculate the time required to supply a pulse of energy necessary to raise its temperature from body temperature of 37°C up to 400°C.

(Assume that all the light energy is given as heat to the probe.)

(ii) Calculate how many photons are required to provide this pulse of energy from the 8 W laser.

(energy of a photon, $E = hf$) **5**

**(15)**

**[Turn over**

**[END OF SECTION B]**

## SECTION C—SPECIAL TOPICS

**Answer any ONE question. Each question carries TWENTY marks.**

*Marks*

**14.** *RADIO COMMUNICATION*

(*a*) Similar terms are used to describe the properties of mechanical and electrical oscillating systems.

Figures 1 and 2 show an example of each system. Damped oscillations are observed in each case.

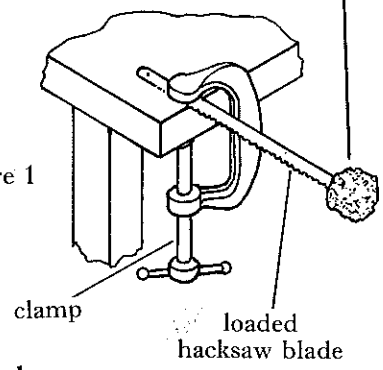



Figure 1

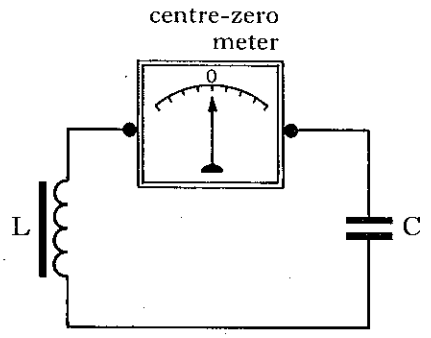



Figure 2

(i) In **each** system,

(A) state what factors control the *natural frequency* of oscillation;

(B) give **two** ways by which the natural frequency can be increased;

(C) explain clearly what causes the damping.

(ii) For the system shown in Figure 2, describe briefly how its oscillations could be maintained at the resonant frequency. **8**

(*b*) Figure 3 shows part of the circuit of a simple short-range AM radio transmitter.

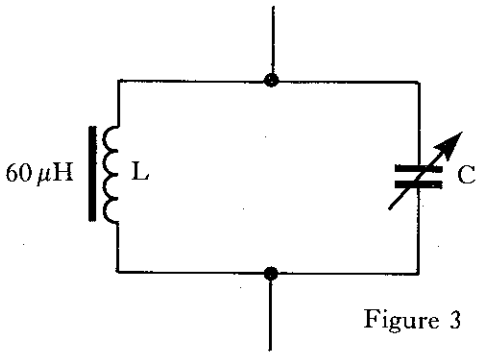



Figure 3

The inductor has an inductance of 60 $\mu$H.

(i) Use the relationship $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ to calculate the resonant frequency when the variable capacitor is set to a capacitance of 300 pF.

(ii) Calculate the inductive reactance at $f_0$.

(iii) State the value of the capacitive reactance at $f_0$.

(iv) If a commercial transmitter broadcast signals with this frequency, into what radio wave band would its transmission fall? **6**

*Marks*

(*c*) Radio frequency (r.f.) waves are modulated in order to carry audio frequency (a.f.) information.

Sketch a waveform to illustrate

(i) amplitude modulation;

(ii) frequency modulation. **2**

(*d*) Stations which transmit in the medium waveband operate on a restricted a.f. bandwidth.

Why is this restriction on bandwidth necessary? **1**

(*e*) Draw a block diagram of the systems contained within a simple radio transmitter to include the following:

microphone; a.f. amplifier; master r.f. oscillator; r.f. amplifier; modulator; r.f. power amplifier; aerial. **3**

**(20)**

**15.** *OPTICAL INSTRUMENTS*

(*a*) By means of a ray diagram, show that the magnitude of the linear magnification $M$ of a **diverging** lens is given by

$$M = \frac{v}{u}$$

where $u$ and $v$ are the object distance and image distance respectively. **3**

(*b*) (i) By means of ray diagrams, illustrate the following eye defects:

(A) short sight;

(B) long sight.

(ii) What causes astigmatism in the human eye?

(iii) For what type of eye defect would spectacles with diverging lenses be prescribed? **6**

(*c*) (i) One way of reducing the amount of light falling on the film of a camera is to "stop down" the lens. Explain why a change of two stops, from f/8 to f/16, will reduce the image brightness by a factor of four.

(ii) A photograph taken with an aperture setting of f/4 and an exposure time of 1/250 seconds is found to have too small a depth of field. Give one possible aperture setting and the corresponding exposure time to produce a photograph with a greater depth of field (given the same lighting conditions). **6**

(*d*) The human eye can be compared to a camera, the pupil taking the place of the aperture and the retina taking the place of the film.

(i) Estimate the distance between the curved front surface of the eye and the retina.

(ii) Estimate the diameter of the pupil in bright light conditions.

(iii) Hence calculate the f-number of the human eye when it is viewing a brightly-lit, distant object. **5**

**(20)**

**[Turn over**

*Marks*

**16.** *ANALOGUE ELECTRONICS*

(*a*) Draw the circuit diagram for an operational amplifier connected in the inverting mode. **4**

(*b*) You are asked to design an amplifier using an op. amp. connected in the inverting mode.

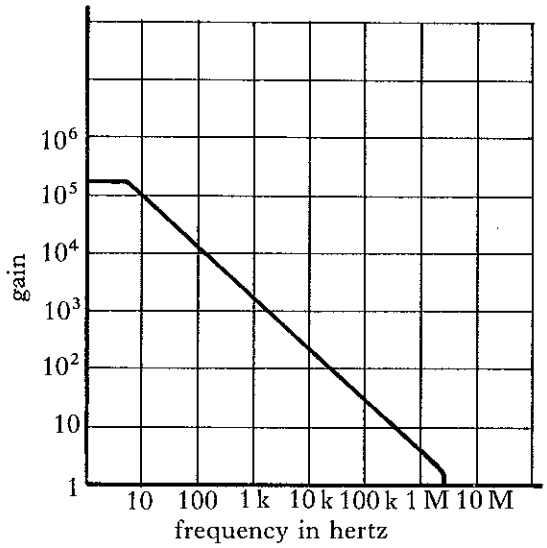
The following two design points should be taken into account:

the input impedance of the op. amp. in this mode is approximately the same as the value of the input resistor;

the input impedance of the amplifier should be at least 100 times the output impedance of the device feeding into it.

Give suitable values for the input and feedback resistors of a single-stage inverting amplifier taking its input from a microphone of impedance 600 Ω and having a gain of 1 000. **3**

(*c*) The microphone amplifier is required to have a bandwidth of at least 10 kHz. The diagram shows a graph of gain against frequency for a 741 op. amp. without feedback.



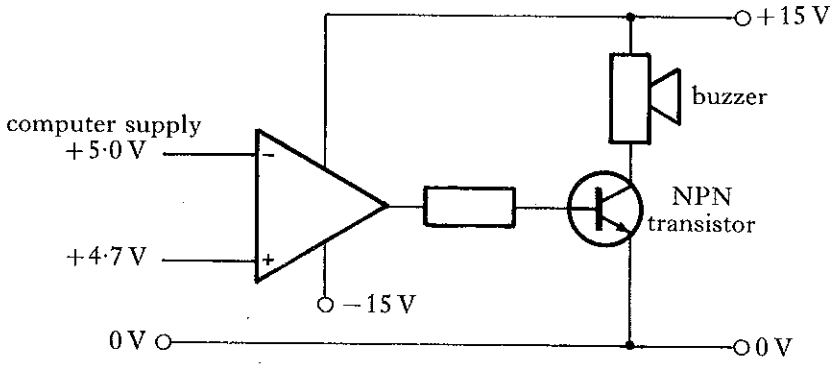

(i) Explain what is meant by the term "bandwidth".

(ii) By referring to the diagram, explain why it is not possible to produce a single-stage amplifier with a gain of 1 000 and a bandwidth of 10 kHz using a 741 op. amp.

(iii) Suggest how you would use **two** 741 op. amps. to produce an amplifier with an overall gain of 1 000 and a bandwidth of at least 10 kHz. You need not give component values but you should indicate the gain of each op. amp. **7**

*Marks*

(*d*) An op. amp. is connected as a comparator in the circuit shown. The voltage at the non-inverting input is fixed at +4·7 V, while the inverting input is connected to a computer power supply of voltage +5·0 V.




The circuit is powered from an independent supply and is designed to give an audible warning when the computer power supply voltage fails. The fixed +4·7 V at the non-inverting input of the op. amp. is also obtained from the independent power supply.

(i) How does the output of an op. amp. used as a comparator differ from its output when it is used as an inverting amplifier?

(ii) What is the polarity of the output of the op. amp. when the computer supply voltage is +5·0 V?

(iii) Explain what happens in the circuit if the computer supply voltage falls below +4·7 V. **6**

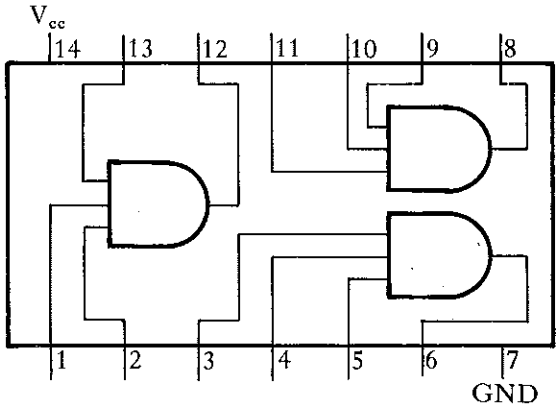
**(20)**

**[Turn over**

*Marks*

**17.** *DIGITAL ELECTRONICS*

(*a*) A manufacturer's data sheet gives the following diagram for a 74LS11 integrated circuit.




(i) Name the type of gate in this integrated circuit.

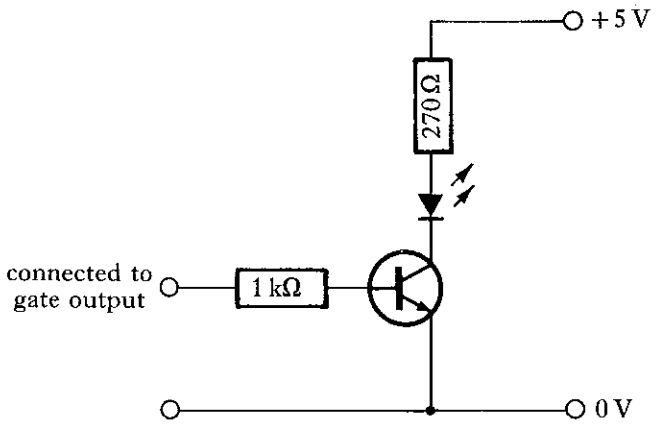
(ii) For **one** of these gates, give:

(A) the pin numbers corresponding to each of its inputs;

(B) the pin number corresponding to its output.

(iii) Write down the truth table for a gate of this type. **7**

(*b*) The circuit shown can be used to indicate the state of the output of a logic gate.




(i) State the function of:

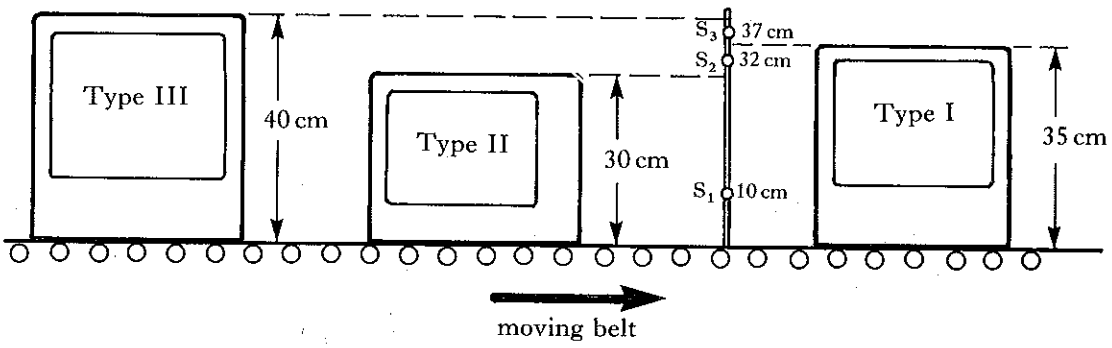
(A) the transistor;

(B) the 270 ohm resistor.

(ii) Explain why the light emitting diode lights when the gate output is high. **4**

*Marks*

(*c*) Each production line worker in a factory assembles a complete television set of one of three types as shown.




Sets are put on to a moving belt randomly as they are completed. Three sensors, S1, S2 and S3, are placed vertically above one another close to the production line at heights of 10, 32 and 37 cm.

(i) Suggest a suitable type of sensor and explain how it would be switched by the passing television sets.

(ii) The first row of the table shows the state of each sensor output as a set of type I passes the line of sensors. Copy and complete the table.

| | *Sensor output* | | |
|---|---|---|---|
| *Type* | *S1* | *S2* | *S3* |
| I | high | high | low |
| II | high | | |
| III | high | | |

**5**

(*d*) The number of a particular type of set being produced is monitored by an electronic counter that counts each time its input goes from low to high.

(i) What logic gate could be connected between the sensors and the counter to produce an output that goes high only when all three sensor outputs go high?

(ii) Sketch a logic circuit with three inputs (one from each sensor) and one output (for a counter of the type described).

The output of this circuit should go high only when a type I set is passing the line of sensors. You may use either two or three gates but no more. **4**

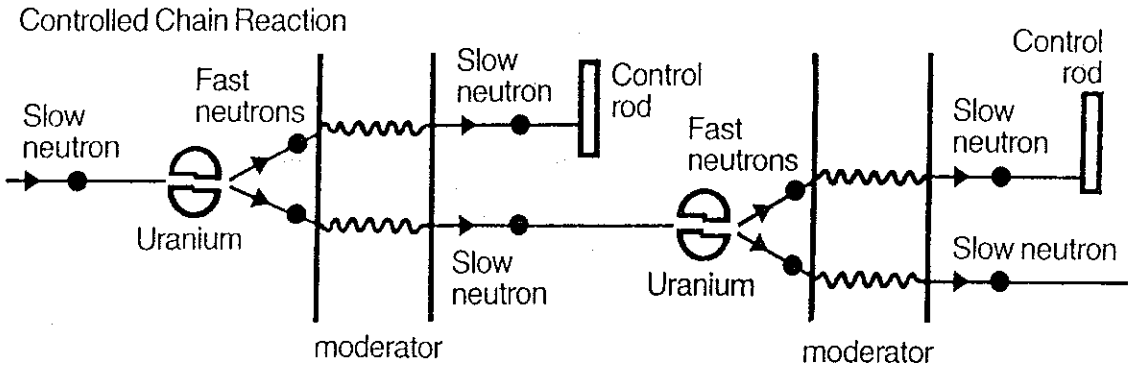
**(20)**

**[Turn over**

*Marks*

**18.** *NUCLEAR REACTORS*

(*a*) The simplified diagram below is taken from an information booklet on the Advanced Gas Cooled Reactor.




(i) Explain clearly, by making reference to multiplication factor, why the reaction is described as *controlled*.

(ii) Name a material commonly used for the control rods.

(iii) Fast neutrons are released in the fission reaction. Why are these moderated to become slow (thermal) neutrons?

(iv) Give **two** features required of the material used as moderator and name the material commonly used. **6**

(*b*) A reactor at Torness has 332 fuel channels each containing 8 fuel elements. The mass of uranium per element is 43 kg.

(i) If only 2·3% of the mass of the fuel consists of the $^{235}U$ isotope, calculate the mass of $^{235}U$ initially present in the reactor.

(ii) A kilogram of $^{235}U$ contains $2{\cdot}56 \times 10^{24}$ nuclei.

On average, in each fission reaction, $3{\cdot}2 \times 10^{-11}$ J of energy are released.

Calculate the total energy available from fission of the $^{235}U$ nuclei in the reactor.

(iii) The reactor is designed to have a heat output of 1650 MW. Estimate for how many days the reactor could operate at maximum output before the fuel would be exhausted.

(iv) With the heat output stated in part (iii), the net electrical output of the reactor is 645 MW.

Calculate the thermal efficiency of the reactor. **8**

*Marks*

(*c*) 97·7% of the enriched fuel used in the fuel elements is of the form $^{238}_{92}U$. This isotope absorbs slow neutrons without fission taking place.

(i) Copy and complete the equation below to show this absorption process and its products.

$$^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{?}_{93}Np + {}^{0}_{-1}e \rightarrow {}^{239}_{?}? + {}^{0}_{-1}e + {}^{0}_{-1}e$$

(ii) State briefly what is done during reprocessing with the final nuclide produced in this reaction.

(iii) State **one** use for this nuclide. **4**

(*d*) Radioisotopes are formed when non-radioactive isotopes absorb neutrons in a reactor.

State and explain an example of the use of a radioisotope in medicine. **2**

**(20)**

*[END OF QUESTION PAPER]*