TOPIC 30 Data Analysis

1 The electrical generator in a power station is driven by a steam turbine. The turbine absorbs thermal energy from a boiler and produces useful work. However, thermal energy must also be removed from the turbine by a cooling system as shown in Fig. 1.

The operating efficiency e of the turbine is defined by

$$e = \frac{\text{useful work output}}{\text{thermal energy input}}$$

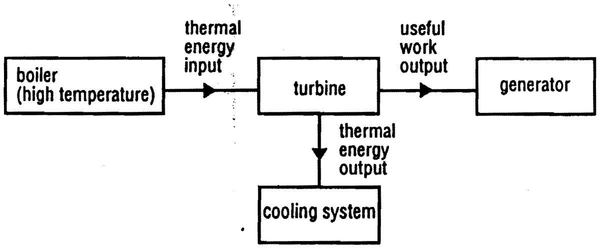


Fig. 1

The efficiency of heat engines, of which the turbine is an example, can never exceed a certain value which is fixed by the temperatures of the boiler and the cooling system. This ideal efficiency e_{max} is given by the equation

$$e_{max} = \frac{T_2 - T_1}{T_2}$$

where T_2 is the thermodynamic temperature of the boiler and T_1 is the thermodynamic temperature of the cooling system.

Further data for a particular power station situated at Newtown are given below.

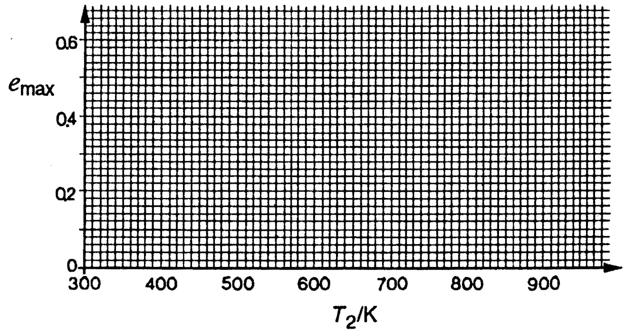
Electrical power output	200 MW
Efficiency of electrical generator	100%
Operating efficiency of turbine	31%
Ideal efficiency of turbine	52%
Effective temperature of the cooling system	330 K
The cooling system uses water which enters at a temperature of 283 K and leaves at 291 K.	
Specific heat capacity of cooling water	4200 J kg^{-1} K^{-1}

(a) Calculate the ideal efficiency if the boiler temperature is 100 °C and the cooling system is at 27 °C. [2]

(b) (i) Plot a graph of e_{max} against T_2 using data from the following table which refers to a constant value of T_1.

T_2/K	e_{max}
333	0.048
373	0.15
450	0.30
600	0.47
750	0.58

[3]



(ii) From your graph deduce the value of T_2 for which $e_{max} = 0$ .... [1]

(iii) Hence deduce the value of T_1 .... [1]

(iv) In principle, the ideal efficiency could be increased by reducing the temperature of the cooling system. Why is this not a practicable method of increasing the efficiency? [1]

(c) For the power station at Newtown, calculate

(i) the effective boiler temperature,

(ii) the rate of input of thermal energy to the turbine,

(iii) the rate at which thermal energy is removed from the turbine,

(iv) the required rate of flow of water through the cooling system. [5]

(d) Suggest two reasons for the discrepancy between the ideal efficiency of the turbine and its operating efficiency. [2]

(e) A significant fraction of the electrical power produced in the U.K. by burning fossil fuels is used for domestic heating. Two suggestions for improvement are as follows.

(i) Burn the fossil fuel in the home instead of at the power station.

(ii) Use the thermal energy output from the turbine for domestic heating.

Comment critically on these suggestions.

Suggest one further way by which consumption of fossil fuel for domestic heating could be reduced. [3]

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2 The table gives the half-lives of four radioactive nuclides together with some of the decay constants. The fourth column lists the significant emissions from the nuclides together with their energies. The total number of each of the emissions as a percentage of the total number of nuclei which decay is also given.

(a) Calculate the decay constant of ^{32}P. [2]

(b) (i) Which of the nuclides would have the greatest activity per unit mass?

(ii) Calculate the activity of a mass of 1.0×10^{-12} kg of the nuclide which you have named in (i). [5]

nuclide	*half-life/s*	*decay constant/s^{-1}*	*type*	*emissions* *energy/$\times 10^{-13}$ J*	*percentage*
Americium ^{341}Am	1.48×10^{10}	4.68×10^{-11}	α	8.78	85
			α	8.70	13
Cobalt ^{60}Co	1.66×10^{8}	4.18×10^{-9}	β	0.496	100
			γ	1.87	100
			γ	2.13	100
Phosphorus ^{32}P	1.24×10^{6}		β	2.74	100
Sodium ^{24}Na	5.42×10^{4}	1.28×10^{-5}	β	9.60	100
			γ	2.19	100
			γ	4.11	100

(c) A laboratory has facilities suitable for the storage of waste radioactive material for periods not exceeding 3 months (7.8×10^{6} s). For which of the nuclides would storage for 3 months before disposal be worthwhile? Give your reasons. [4]

(d) Give an explanation for the figures in the percentage column for the nuclides ^{60}Co and ^{241}Am. [3]

(e) A power source with an output of 1.00 kW is required for use in a space probe. This power is to be derived from the energy of the emitted radiations from the nuclide ^{60}Co. It is known that 2.68×10^{-9} cm^3 of this nuclide has a total activity of 3.00×10^{6} Bq. What volume of cobalt is required? [4] N90/II/8

3 Multi-bladed low-speed wind turbines (windmills) similar to the one shown in Fig. 2 have been used since 1870, particularly for pumping water on farms.

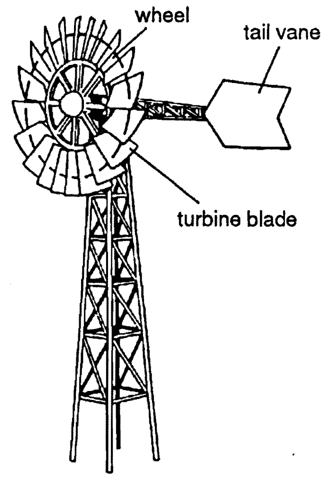

Fig. 2

The turbine blades cover almost the whole surface of the wheel and a tail vane behind the windmill keeps the wheel facing the wind. The diameters of the wheel of windmills of this type vary from about 2 m to a practical maximum of about 12 m. Because of this size limitation, they are not suited to large power outputs. They will start freely with wind speeds as low as 2 m s^{-1} and, at these low speeds, can produce large torques.

Fig. 3 shows how P, the output power of these windmills, varies with the overall diameter of the wheel for different wind speeds, v.

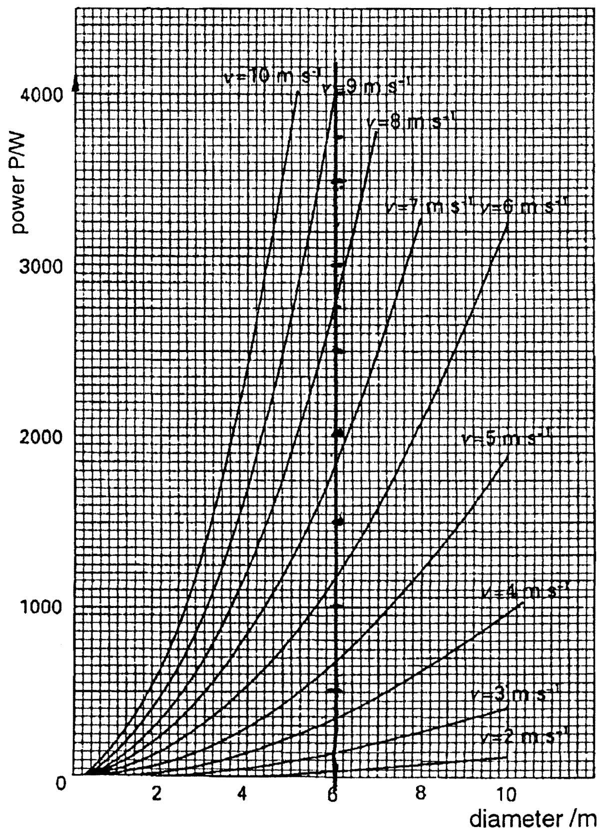

Fig. 3

(a) Use the data supplied in Fig. 3 to tabulate corresponding values of power output and wind speed for a particular multi-bladed low-speed windmill with a wheel of diameter 6.0 m.

wind speed v/m s^{-1}	output power P/W

[2]

(b) For a given diameter, the output power is related to the wind speed by the equation

$$P = kv^n.$$

n and k may be determined by plotting a graph of lg P against lg v. Use your values in *(a)* to tabulate the values of lg P and lg v for the wheel of diameter 6.0 m.

lg (v/m s^{-1})	lg (P/W)

Draw the graph and find the values of n and k. [6]

(c) (i) When the wind speed is 8.0 m s^{-1} what volume of air reaches the 6.0 m diameter wheel of the windmill in one second?

(ii) The density of the air is 1.3 kg m^{-3}. What is the kinetic energy of the volume of moving air in *(c)*(i)? [3]

(d) In *(c)*(ii), you have calculated the power (kinetic energy per second) arriving at the wheel. Use this together with data from Fig. 3 to find the fraction of this power converted into useful output power. [1]

(e) State three factors, other than wind speed and diameter of wheel, that are likely to influence the output power. In each case, give some indication how the power output is likely to be affected. [3]

(f) In practice, it has been found difficult to scale up a windmill such as this, say to a wheel of 30 m diameter, to achieve power outputs of the order of megawatts. Suggest two reasons for this. [3]

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4 This question is about the current through, and the potential difference across, the coils of a transformer. Fig. 4 shows the circuit used.

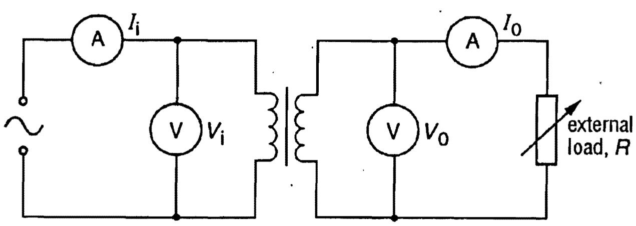

Fig. 4

The resistance of each coil was as follows:

primary coil, 470 ohm,
secondary coil, 2950 ohm.

V_i, the r.m.s. potential difference across the primary coil was maintained at 6.00 V.

The efficiency, ϵ of the transformer is defined as

$$\epsilon = \frac{\text{output power}}{\text{input power}}$$

The ratio $\dfrac{V_0}{V_i}$ is represented by G.

Fig. 5 illustrates the variation of ϵ, and G, with R, the resistance of the external load.

(a) Read off from Fig. 5 a value for the maximum efficiency of the transformer. [1]

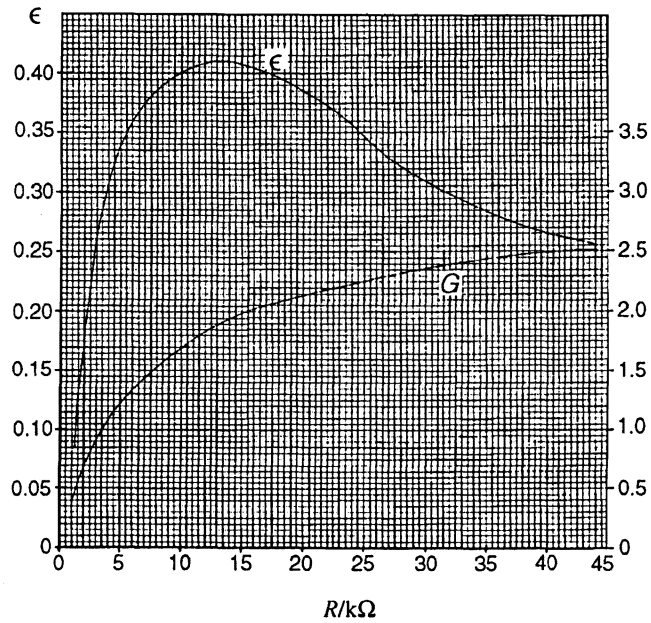

Fig. 5

(b) For the case where the transformer is operating at this maximum efficiency, find

(i) the value of G,

(ii) the value of R,

(iii) the current in R,

(iv) the input current. [5]

(c) Use your answers in *(b)* and any other data, to deduce the following for the transformer when operating at maximum efficiency:

(i) the total power loss in the transformer,

(i) the power loss in the resistance of the primary coil,

(iii) the power loss in the resistance of the secondary coil. [5]

(d) Use your answers in *(c)* to show that there must be some other power loss in the transformer besides power loss in the resistance of the coils. [3]

(e) What would be the effect on the efficiency of using

(i) a very large external load resistance,

(ii) a very small external load resistance? [2]

(f) What would be the practical effect on the transformer of using a very small external load resistance? [2]

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5 Many devices are designed to create a spray of tiny droplets. The effectiveness of these devices usually depends on droplet size. One example is an agricultural pesticide spray in which a few large droplets do not coat the leaves of plants as well as many small droplets. Another example is a fuel injection system for an engine.

Measuring the size of droplets present in a spray is difficult to do by direct means but instruments called *droplet sizers* can be purchased which make droplet sizing a fast, routine operation.

The principle of operation of one such sizer is shown in Fig. 6, in which light from a helium/neon laser is passed through a spray of droplets of uniform diameter and forms a circular diffraction ring of radius x. The diameter, d, of the droplets is related to x by the equation

$$d = k\frac{\lambda}{x}.$$

In this equation λ, the wavelength of the light, is 6.33×10^{-7} m, k is a constant equal to 0.474 m, and d and x are both in metres.

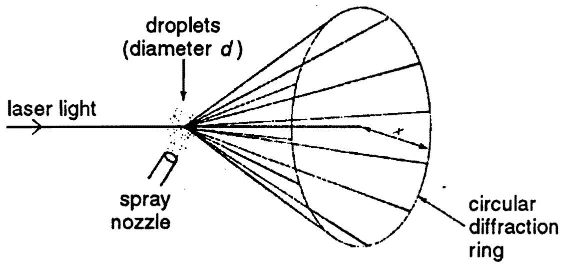

Fig. 6

In practice a spray will consist of droplets of different sizes, so many rings of diffracted light will be caused. The diffraction pattern, Fig. 7, is projected on a flat surface containing many light sensitive detectors. The output from the detectors can be analysed by a computer and be shown in the form of a graph, Fig. 8.

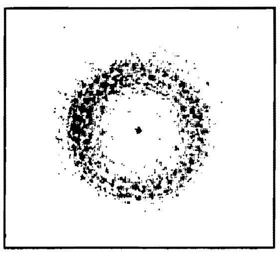

Fig. 7

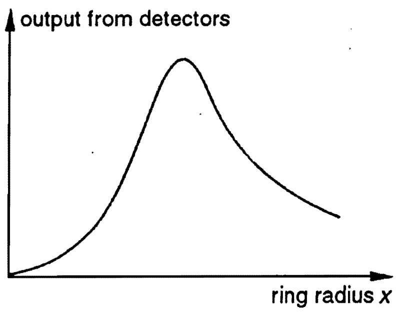

Fig. 8

Answer the questions concerning droplet sizing which follow.

(a) Suggest one device, other than those mentioned in the first paragraph of the passage, where droplet size is important. [1]

(b) Outline a direct method for measuring droplet diameter. [3]

(c) Give two reasons why direct methods are likely to be difficult to use for the measurement of droplets of small diameter. [2]

(d) Calculate the value of x for a droplet of diameter

(i) 10 μm, (ii) 200 μm. [3]

(e) State, with a reason, whether a small value of x corresponds to large or to small droplets. [1]

(f) Sketch on Fig. 9 curves to show the general shape of the graphs which would be obtained if

(i) droplets with a wide range of diameter were used,

(ii) very small droplets with a narrow range of diameters were used.

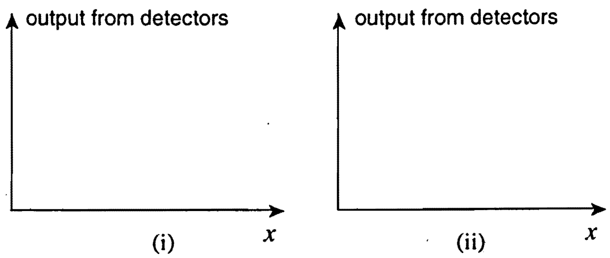

Fig. 9 [2]

(g) Name one other factor, besides droplet diameter, which will affect the intensity of diffracted light. [1]

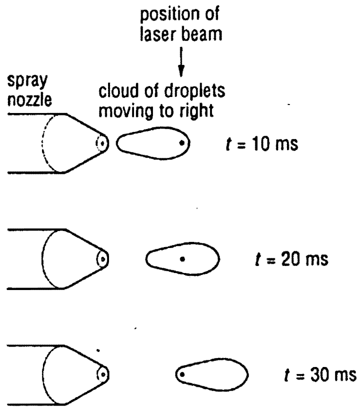

Fig. 10

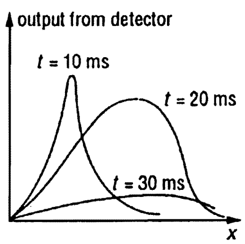

Fig. 11

(h) In practice a cloud of spray droplets moves through the laser beam, as shown at intervals in Fig. 10. The output from the detectors varies with time in the way shown in Fig. 11. Describe the distribution of droplets in the cloud according to their size and concentration. [5]

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6 A photovoltaic cell is a device which converts light energy directly into electrical energy. A potential difference is developed between its two terminals. The magnitude of the p.d. depends on the intensity of the light incident on the surface of the cell and on the current from the cell.

The variation of the potential difference V across the cell with current I can be investigated using the circuit shown in Fig. 12.

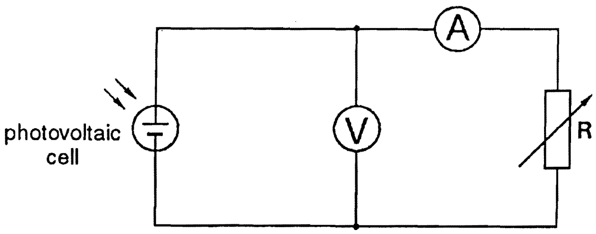

Fig. 12

R is a variable resistor, the voltmeter has infinite resistance and the resistance of the ammeter is negligible.

Fig. 13 shows the variation of V with I for a particular cell of surface area 4.0×10^{-4} m^2 when illuminated normally with light of intensity 1100 Wm^{-2}.

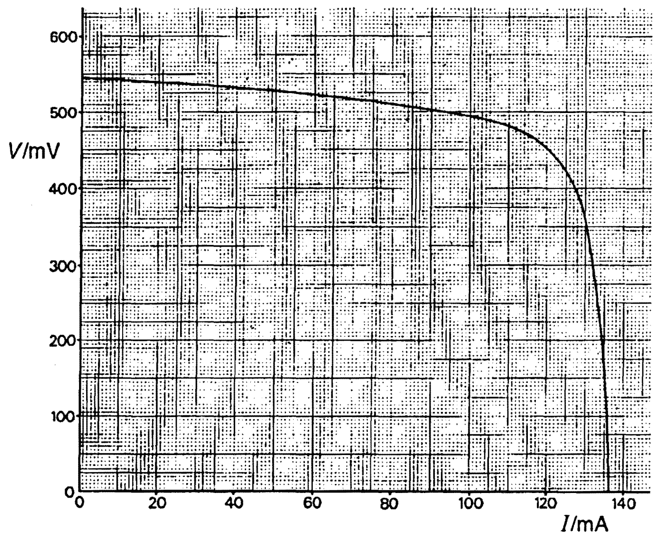

Fig. 13

(a) Use the data supplied in Fig. 13 to tabulate eight corresponding values of p.d. V and current I at the voltage values shown in the table. For each pair of values, calculate P, the power output of the cell. [4]

V/ mV	I/ mA	P/ mW
250		
300		
350		
400		
425		
450		
475		
500		

(b) (i) Draw a graph of P against V on the axes given in Fig. 14.

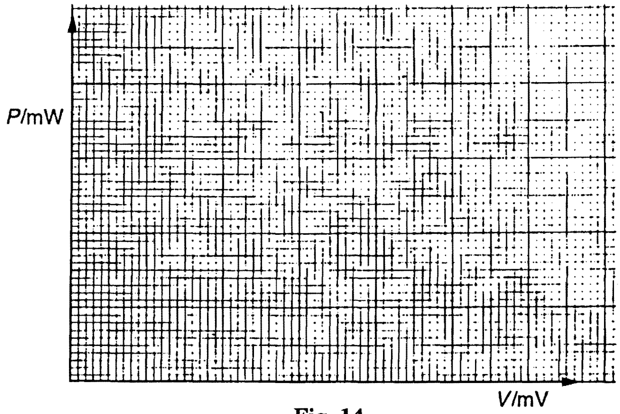

Fig. 14

(ii) From your graph determine the maximum power output P_{MAX} of the cell.

(iii) Find V_{MAX} and calculate I_{MAX} the p.d. and current respectively, which correspond to P_{MAX}.

Plot and label this point on the graph of Fig. 13. [6]

(c) Using your value of P_{MAX} and any other data, calculate the maximum efficiency of conversion of light energy into electrical energy. [3]

(d) A number of photovoltaic cells are connected to a load resistor **L** as shown in Fig. 15.

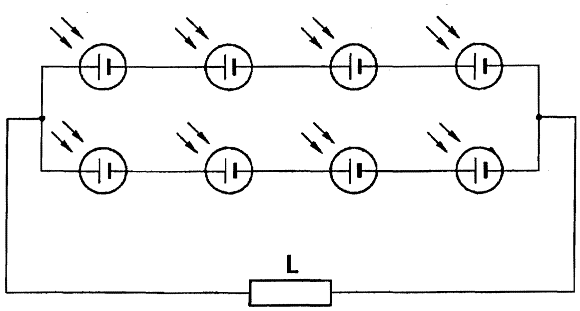

Fig. 15

The resistance of **L** has been adjusted so that each cell gives the value of p.d. and of current that you found in *(b)*(iii). Calculate

(i) the p.d. across **L**,

(ii) the current through L. [2]

(e) Discuss quantitatively how it might be possible to provide a maximum output power of approximately 5 kW at 30 V using a number of these cells in a suitable arrangement. [3]

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7 Read the following passage and answer the questions which follow.

Gamma-ray detectors

In radioactive decay, γ-rays may be emitted. γ-rays emitted from different substances may have different energies.

When γ-rays photons are incident on a sodium iodide crystal, some of the photons may be absorbed by the crystal. When a photon is absorbed, it causes the emission of a small pulse of light known as a scintillation. These scintillations may be detected and converted into electrical pulses by a photo-multiplier tube which, when coupled to a suitable counter, enables γ-ray photons to be counted. This is illustrated in **Fig. 16**.

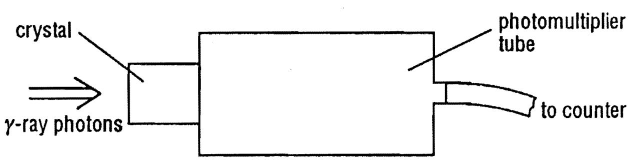


Fig. 16

The crystals used in such detectors may be of various shapes. **Figure 17** shows one particular shape of crystal which is a solid cylinder.

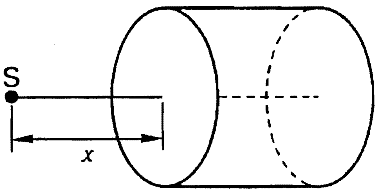


Fig. 17

The γ-ray source S is placed on the axis of the crystal, a distance x in front of one face. The source S is assumed to emit photons uniformly in all directions.

Not all of the γ-ray photons emitted by the source will be absorbed by the crystal. The efficiency Q of a detector is defined by the equation

$$Q = \frac{\text{number of photons producing scintillations in the crystal}}{\text{total number of photons emitted by the source}}.$$

Figure 18 illustrates the variation of the efficiency Q with E, the γ-ray photon energy. Curves are shown for various values of x, the distance of the γ-ray source from the crystal.

(a) By reference to the passage, explain what is meant by a *scintillation*. [1]

(b) The passage refers to γ-ray photons. What is a *photon*? [1]

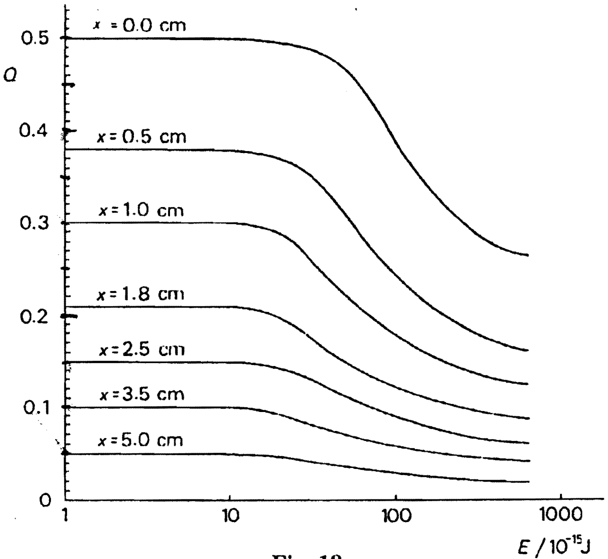
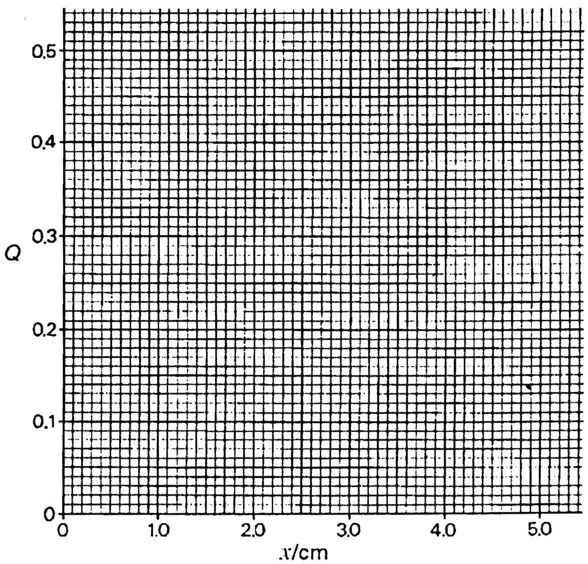


Fig. 18

(c) Look at **Fig. 18.** Consider γ-ray photons of energy 10×10^{-15} J. Tabulate corresponding values of Q and x for γ-ray photons of this energy.

Q	x / cm

[2]



(d) Use your values in *(c)* to draw a graph of Q against x. Hence determine

(i) the value of x for which the efficiency is 0.25,

(ii) the rate of change of Q with x when x = 2.5 cm. [7]

(*e*) (i) By reference to **Fig. 18** or your graph, suggest a maximum possible value of the efficiency Q.

(ii) By reference to **Fig. 17** and the definition of efficiency, give a reason for this maximum value. [3]

(*f*) Look at **Fig. 18.** Suggest why, for any one value of x,

(i) the efficiency is constant at low photon energies,

(ii) the efficiency decreases with increasing photon energy. [4]

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8 Read the following passage and then answer the questions which follow it. (Numbers near to the right-hand margin of the passage indicate the line numbers.)

Lithium solid-state batteries

Lithium solid-state batteries represent a new concept in battery technology. Solid-state means that the liquids and pastes present in ordinary battery systems are replaced by a solid plastic film which cannot leak. This plastic film separates a lithium metal anode (positive electrode) from a composite cathode (negative electrode) which is in contact with aluminium foil. (See Fig. 19.) The resultant cell can be constructed so that it has a large electrode area but is less than 0.2mm thick. It is in many ways similar to a sheet of paper and can be cut and formed into almost any shape. Lithium solid-state cells such as this are rechargeable and can be incorporated into the cases of equipment or into such items as credit cards.

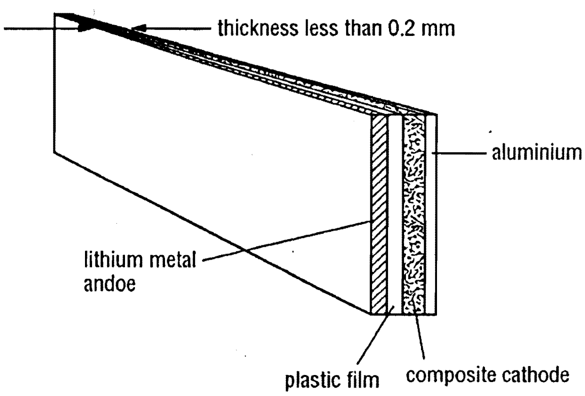

Fig. 19

The initial e.m.f. of the cell at full charge is 3.4 V but it rapidly falls to about 2.8 V on load and thereafter falls as shown in Fig. 20. The cell needs to be recharged when the e.m.f. reaches 2.0 V. In practice, its average e.m.f. is 2.5 V.

The current density, energy density and charge capacity all have to be considered for a particular application.

The recommended maximum value of discharge current density is 0.15 milliamperes per square centimetre of electrode area, the charge capacity is 3.6 coulombs per square centimetre of electrode area, and the energy density is 120 watt-hours per kilogram of cell mass.

Charging one of these cells should be carried out with a constant applied voltage of 3.4V and with a current density limited to 2.5 mA cm^{-2}. A typical charging current against time graph is shown in Fig. 21 for a cell of electrode area 50 cm^2.

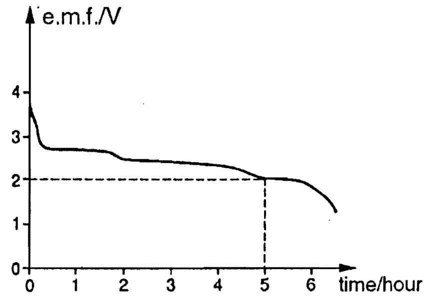

Fig. 20

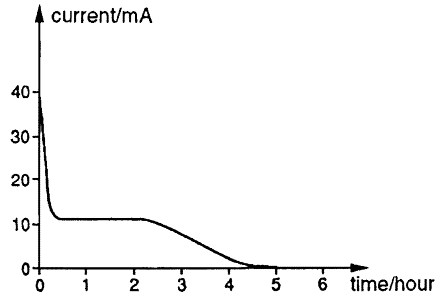

Fig. 21

For safety it is vital that

(1) cells should not be short circuited. (A fuse should be incorporated in any circuit with a cell of charge-storage capacity greater than 3600 coulombs.)

(2) cells should not be used in environments with a temperature above 140 °C.

(3) water or water vapour is kept away from lithium cells.

Questions

(*a*) Give **one** possible use of a lithium solid-state cell. [1]

(*b*) Deduce from the units, and then write down, the meaning of the terms *current density* and *energy density*. (lines 20–26) [2]

(*c*) By reference to lines 15–31 of the passage, answer the following questions for a cell of electrode area 50 cm^2.

(i) Calculate the charge-storage capacity of this cell.

(ii) Calculate the recommended maximum value of the discharge current.

(iii) For how long can this cell supply this maximum current?

(iv) Calculate the energy it supplies in this time, assuming that the e.m.f. has a constant value of 2.5 V. [6]

(d) Figure 21 shows the charging graph for a cell of the same electrode area as in *(c)*.

(i) From the graph, estimate the average charging current over the 5-hour charging time.

(ii) Calculate the energy used in charging the cell. [3]

(e) Using your answers to *(c)*(iv) and *(d)*(ii), deduce the electrical efficiency of the charge/discharge cycle. [2]

(f) Suggest reasons for **two** of the safety considerations. (lines 32–38) [2]

(g) Draw a diagram, using circuit symbols, to illustrate how you would connect a battery of cells which could produce a current of up to 300 mA at a voltage of approximately 10 V. In your answer, specify the electrode area of the individual cells. [2]

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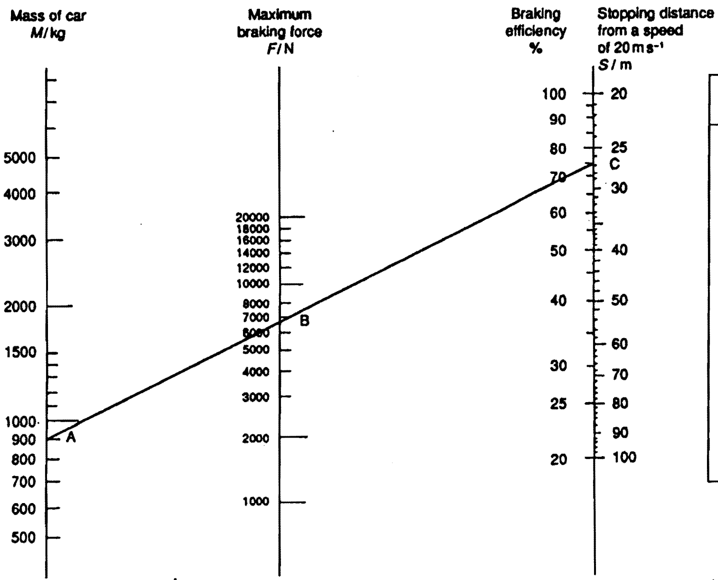
9 When a car has a brake test, two sets of measurements are made:

1. the maximum braking force on the wheels produced by operating the foot brake,
2. the maximum braking force produced by operating the hand brake.

Typical data for a car of mass 900 kg are as follows.

	Maximum braking force /N
1. Foot brake	6700
2. Hand brake	2000

In order to determine whether or not the brakes are satisfactory, the data are applied to a chart (called a nomogram) like the one shown in Fig. 22. This chart has three vertical lines, marked with scales.



Brake efficiency and stopping distance from 20 m s^{-1}

Fig. 22

The central vertical line is for the maximum braking force. The left line is for the mass of the car. The right hand line is for the braking efficiency and also for the stopping distance from an initial speed of 20 m s^{-1}. The braking efficiency E is defined by the equation

$$E = \frac{\text{deceleration of car}}{\text{acceleration of free fall}} \times 100.$$

As an example of the use of this chart for the car of mass 900 kg, the figures in the table show a maximum braking force for the foot brake of 6700 N. The point A corresponding to the mass and the point B corresponding to the braking force are joined to give a straight, sloping line. This line is extended to cut the braking efficiency scale at the point C, and shows that in this particular case the stopping distance S from a speed of 20 m s^{-1} is about 27 m.

(a) Read from the chart the braking efficiency corresponding to point C. [1]

(b) Using the definition of braking efficiency given above, find the deceleration corresponding to this value of braking efficiency. Give your answer in m s^{-2}. [2]

(c) Show, by calculation from the equations of motion, that the deceleration you obtained in *(b)* gives a stopping distance of 27 m to 2 sig. fig. from an initial speed of 20 m s^{-1}. [3]

(d) (i) Draw a line on the chart to represent the results of the hand brake test on the car of mass 900 kg. [1]

(ii) Using the hand brake alone,

1. what would be the stopping distance from a speed of 20 m s^{-1}, [1]
2. what is the braking efficiency? [1]

(e) Now consider a car of mass 1300 kg. Read from the chart in Fig. 22 corresponding pairs of values of the maximum braking force and stopping distance from 20 m s^{-1}, and tabulate them below.

Maximum braking force/N	*Stopping distances from 20 m s^{-1}/m*
....	....
....	....
....	....
....	....
....	....
....	....
....	....

[3]

Plot a graph of these values on the grid . [3]

(f) Use the chart to estimate the braking efficiency for the car of mass 1300 kg if the maximum braking force were 14000 N. Comment on your answer. [3]

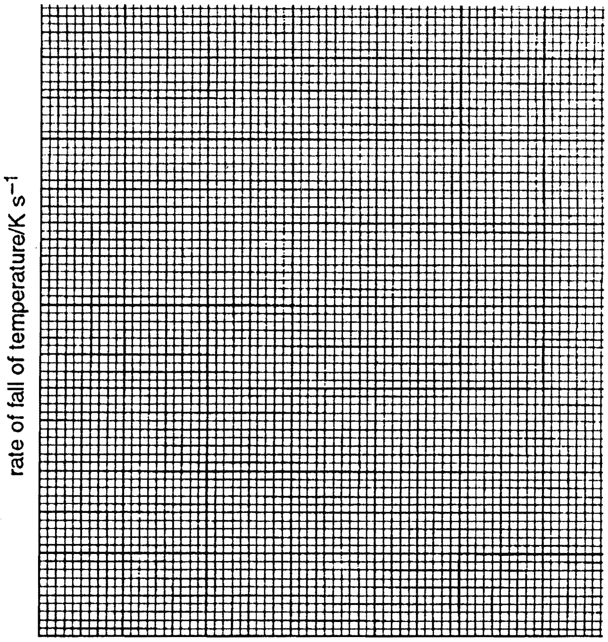


Fig. 26

(d) The experiment was repeated with similar apparatus but using oil near to its boiling point so that larger excess temperatures could be obtained. Suggest why, at these much higher excess temperatures, the container cooled at a rate greater than that which was expected from the conclusion in *(c)* (iii) (2). [2]

(e) A motor cycle is fitted with an engine which cools in a similar way to the one used in the experiment described. The rider adjusts the engine so that it maintains a constant output power, independent of the speed of the cycle. Suggest why the engine is more likely to overheat when travelling uphill than when on level ground. [2] N94/II/8

11 Ultrasonic sound waves (ultrasound) have frequencies outside the audible range of the human ear, that is, greater than about 20 kHz.

As ultrasound passes through a medium, wave energy is absorbed. The rate at which energy is absorbed by unit mass of the medium is known as *dose-rate*. The dose-rate is measured in W kg^{-1}. The total energy absorbed by unit mass of the medium is known as the *absorbed dose*. This is measured in J kg^{-1} or, as in this question, kJ kg^{-1}.

Under certain circumstances, biological cells may be destroyed by ultrasound. The effect on a group of cells is measured in terms of the survival fraction (*SF*),

$$SF = \frac{\text{number of cells surviving after exposure}}{\text{number of cells before exposure}}.$$

For any particular absorbed dose, it is found that the survival fraction changes as the dose-rate increases. Fig. 27 shows the variation with dose-rate of the survival fraction for samples of cells in a liquid. The absorbed dose for each sample of cells was 240 kJ kg^{-1}.

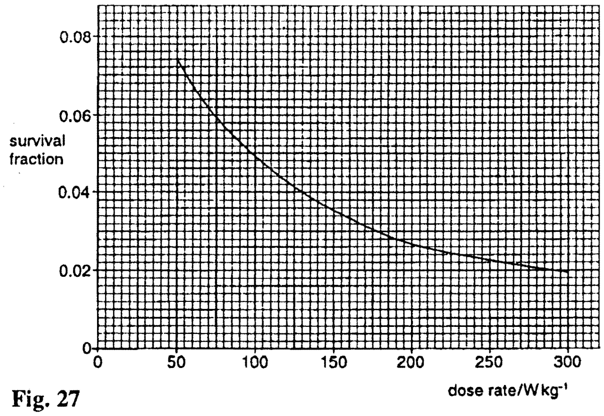


Fig. 27

(a) (i) Read off from Fig. 27 the survival fraction for a dose-rate of 200 W kg^{-1}.

(ii) Calculate the exposure time for an absorbed dose of 240 kJ kg^{-1} and at a dose-rate of 200 W kg^{-1}. [3]

(b) Survival fraction depends not only on dose-rate but also on absorbed dose. Fig. 28 shows the variation with dose-rate of $\log_{10}(SF)$ for different values of absorbed dose.

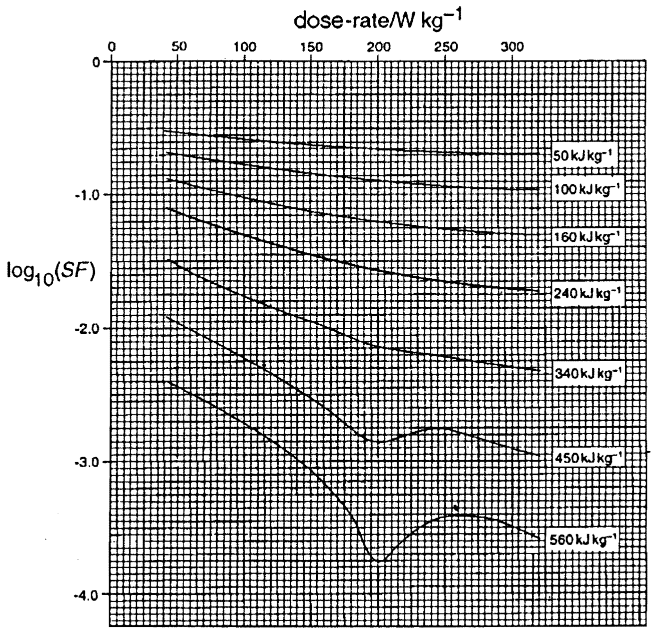


Fig. 28

The bold line represents the data given in Fig. 27, but with survival fraction plotted on a logarithmic scale.

(i) Suggest a reason for plotting survival fraction on a *logarithmic* scale.

(ii) By reference to Fig. 28, complete the table of Fig. 29 for a dose-rate of 200 W kg^{-1}.

absorbed dose /kJ kg^{-1}	$\log_{10}(SF)$
50	
100	
160	
240	
340	
450	
560	

Fig. 29

(iii) Using the relevant value of $\log_{10}(SF)$ from Fig. 29, calculate the survival fraction for an absorbed dose of 160 kJ kg^{-1} at a dose-rate of 200 W kg^{-1}. [5]

(c) Use your values in the table of Fig. 29 to plot, on the axes of Fig. 30, a graph to show the variation with absorbed dose of $\log_{10}(SF)$ for the dose-rate of 200 W kg^{-1}. [3]

(d) Theory suggests that at a dose-rate of 200 W kg^{-1}, two separate effects may give rise to cell destruction. According to this theory, one of the effects becomes apparent only at higher absorbed doses. What evidence is provided for this theory by

(i) Fig. 28,

(ii) Fig. 30? [3]

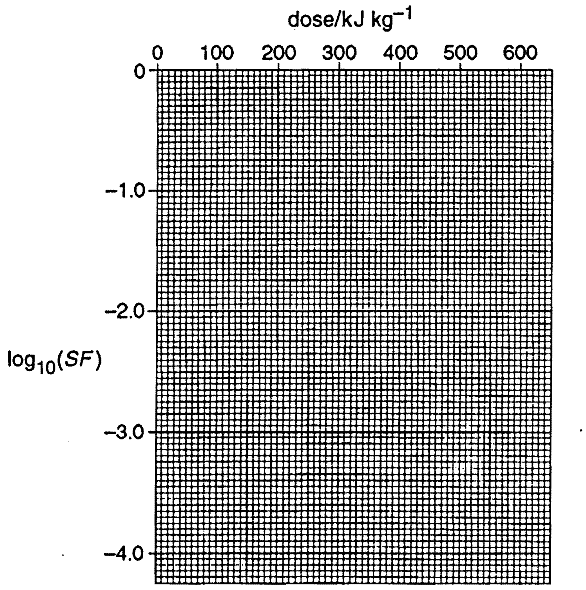


Fig. 30

(e) The theory outlined in *(d)* suggests that the resultant survival fraction $(SF)_R$ due to the two independent effects which have survival fractions $(SF)_1$ and $(SF)_2$ is given by the expression

$$(SF)_R = (SF)_1 \times (SF)_2.$$

(i) Give the corresponding expression of $\log_{10}(SF)_R$ in terms of $\log_{10}(SF)_1$ and $\log_{10}(SF)_2$.

You may wish to use an equation of the form $\log_{10}(ab) = \log_{10}(a) + \log_{10}(b)$.

(ii) State how the graph of Fig. 30 may be used to determine $(SF)_R$ for an absorbed dose of 560 kJ kg^{-1}.

(iii) Discuss whether it is possible, by reference to your graph of Fig. 30, to determine separate values of $(SF)_1$ and $(SF)_2$ for the absorbed dose of 560 kJ kg^{-1}. [4] J95/II/8

12 A wire-wound resistor is manufactured by winding resistance wire on an insulating former. A commonly used material for the wire is an alloy of nickel and chromium called nichrome. The wire is produced by pulling the nichrome through a suitably sized hole. Nichrome is sufficiently ductile to be drawn into a wire without danger of it cracking or breaking after winding. It resists corrosion and has a fairly high resistivity. The wire itself must be uniform and thin, and is covered with an insulating material.

A manufacturer of resistors of this type supplies information concerning them in the form of a family of lines shown in the graph of Fig. 31. Resistors of different resistance R_1, R_2 .... R_5 are shown by the separate lines.

(a) Why is it important that the material chosen to make the wire for these wire-wound resistors is ductile? [1]

(b) Define *resistivity*. [2]

(c) Using your answer to *(b)*, explain why the wire must be thin and the material must have a fairly high resistivity. [2]

(d) By choosing some values of potential difference and current from Fig. 31, complete the table showing the resistances R_1, R_2 ... R_5. [2]

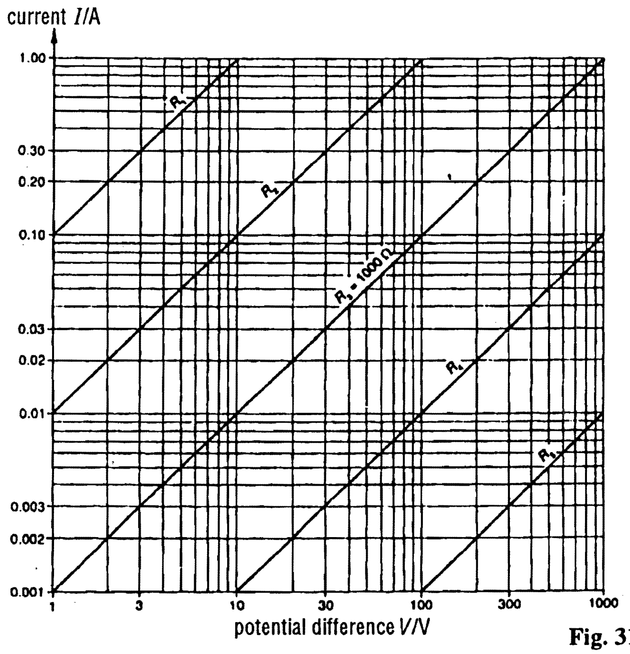


Fig. 31

14 For thousands of years, Man has studied the night sky and some ancient buildings provide evidence of careful and patient astronomical observations by people of many different cultures. As instrumentation has improved, so has the precision with which astronomical observations could be made. Between 1576 and 1597, Brahé made comprehensive observations of planetary positions and, on his death, these records became available to Kepler.

Kepler was able to interpret the observations and deduced three laws, one of which had a great impact on later discoveries. He deduced that, for a circular orbit of a planet around the Sun, if T is the period of rotation and r is the radius of the orbit, then

$$T^2 \propto r^3.$$

As a result of Kepler's work, Newton formulated the law of gravitation.

(a) (i) State an equation representing Newton's law of gravitation, explaining the symbols used.

(ii) By relating the gravitational force on a planet to the centripetal acceleration it causes, show that, for a circular orbit,

$$T^2 = \frac{4\pi^2 r^3}{GM}.$$ [4]

(b) The planet Jupiter has a number of moons. Data for some of these are given in Fig. 32.

moon	*period T/days*	*mean distance from centre of Jupiter r/10^9 m*	*$\log_{10}$ (T/days)*	*$\log_{10}$(r/m)*
Sinope	758	23.7	2.88	10.37
Leda	239	11.1		
Callisto	16.7	1.88		
Io	1.77	0.422		
Metis	0.295	0.128	–0.53	8.11

Fig. 32

(i) Complete Fig. 32 by calculating values for $\log_{10}$ (T/days) and $\log_{10}$ (r/m).

(ii) On the axes of Fig. 33, plot a graph of $\log_{10}$ (T/days) against $\log_{10}$ (r/m). [4]

(c) (i) Determine the gradient of the graph in Fig. 33.

(ii) Hence discuss whether the data in Fig. 32 support the relation given in *(a)*(ii). [4]

(d) Observation shows that the moon Ganymede orbits Jupiter with a period of 7.16 days. Use the graph of Fig. 33 to estimate the orbital radius of Ganymede. [2]

(e) It was reported in a newspaper that the moon Thebe had been discovered which orbited Jupiter every 16.2 hours at a height of 222 thousand kilometres above its surface. Comment on the accuracy of this statement. [2]

(f) Suggest whether the graph of Fig. 33 could be used to check data on the orbital radii and periods of the moons of another planet (e.g. Saturn). [2]

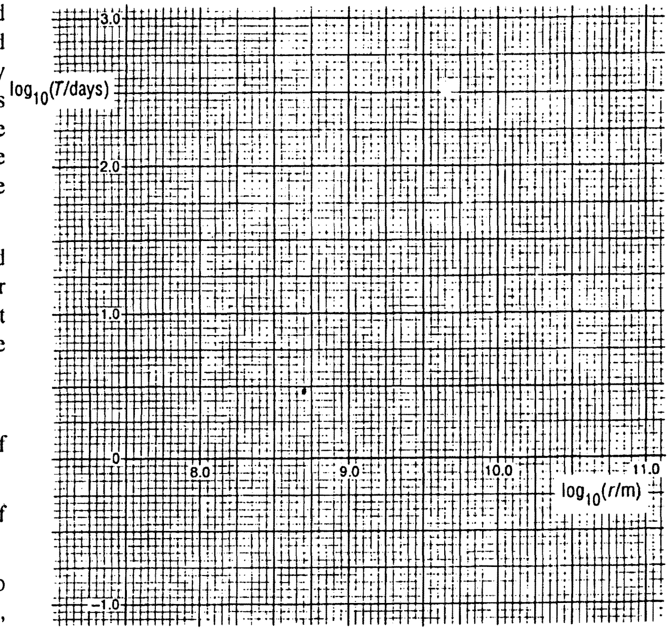


Fig. 33

N96/II/8

15 With increasing levels of noise in the environment, it is recognised that measures need to be taken to reduce noise, particularly in the home and working environment. Noise near busy roads or airports is of great concern, and the level of noise insulation provided by windows must be considered.

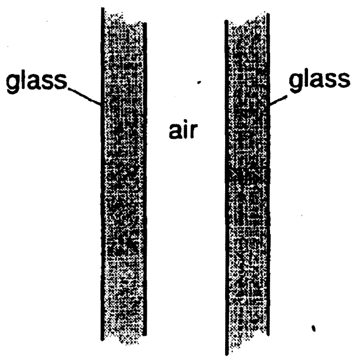


Fig. 34

Double-glazed windows consist of two glass sheets separated by a layer of air as illustrated in Fig. 34.

For glass of thickness 6.0 mm and an air-gap of 12 mm, the window would be specified as 6-12-6 double glazing. The table of Fig. 35 shows how sound insulation varies with frequency for two double-glazed windows and also for a single sheet of glass of thickness 6.0 mm. Higher values of sound insulation represent more noise reduction. A change of less than 3 units is not detectable by the human ear.

	sound insulation/arbitrary units		
frequency/ Hz	6-12-6	6-200-6	6 mm
100	21	32	22
125	27	35	22
160	27	38	23
200	23	40	24
250	25	42	25
315	28	43	26
400	29	45	27
500	31	46	29
630	32	47	30
800	33	48	31
1000	34	49	31

Fig. 35

(a) On Fig. 36, plot a graph to show how sound insulation varies with frequency for 6-200-6 double glazing. [3]

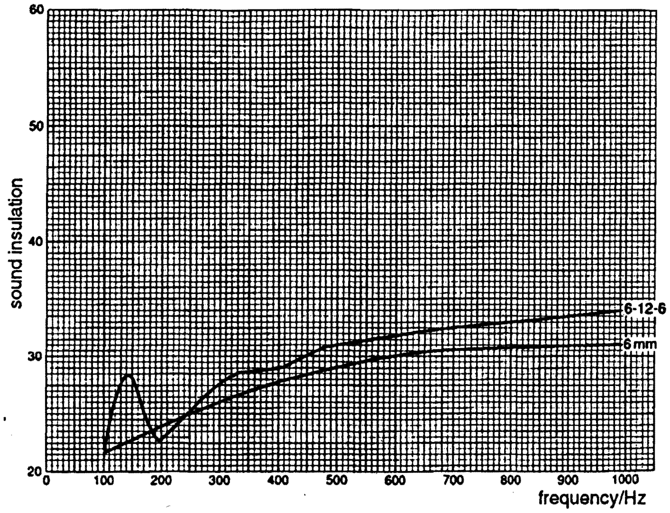


Fig. 36

(b) 6-12-6 double glazing is sometimes sold for thermal insulation. A salesman claims that it is also effective for sound insulation.

(i) State and explain two reasons why 6-12-6 double glazing is more effective as a thermal insulator than a single sheet of 6 mm glass.

(ii) 6-200-6 double glazing is not as effective as 6-12-6 double glazing for thermal insulation. Suggest a reason for this difference.

(iii) Use Fig. 36 to comment on whether the salesman's claim is justified. [9]

(c) In a television advertisement for double glazing, the effectiveness of the sound insulation of windows was demonstrated by using machinery which produced noise at about 1 kHz. Comment on whether the demonstration could be misleading for a potential customer who wishes to insulate against the low-frequency rumbling noise of traffic. [3]

(d) The noise insulation provided by a window may be measured by comparing the sound intensity I_0 incident on the window with the sound intensity I_T which has been transmitted (see Fig. 37).

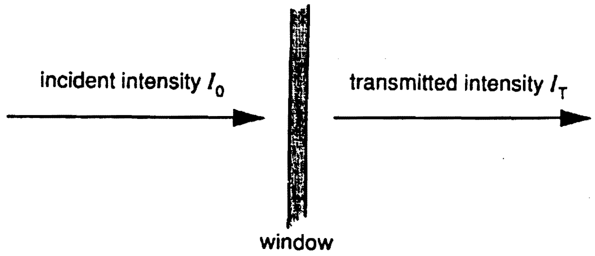


Fig. 37

The sound insulation, measured in decibels (dB), is given by

$$\text{sound insulation} = -10 \lg(I_T/I_0) \text{ dB}.$$

Fig. 38 shows the variation with frequency of the sound insulation provided by a sheet of glass of thickness 6 mm.

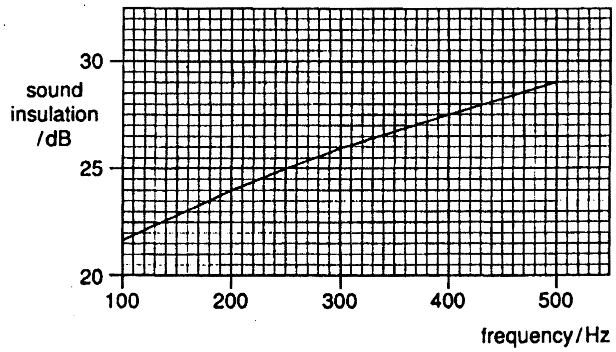


Fig. 38

(i) State whether the glass sheet provides better sound insulation at high or at low frequencies.

(ii) From Fig. 38, read off the value of sound insulation for a frequency of 350 Hz.

value = ... dB

(iii) Calculate the ratio I_T/I_0 at a frequency of 350 Hz.

ratio = ... [5]

J97/II/9

16 The Normandy Bridge over the mouth of the Seine is constructed in the way shown in Fig. 39. Two towers were sunk into the river bed and the roadway, which is supported by many cables, was made in stages. One end of each cable is attached to the roadway, passes over a tower and its other end is also attached to the roadway. Each cable is therefore an inverted V. As you pass over the bridge there are cables on both your right hand side and your left hand side. Having many cables is a much better system than that of a traditional suspension bridge which relies on the immense tensile strength of one pair of cables taking the entire load. Simplified data concerning the bridge are given below.

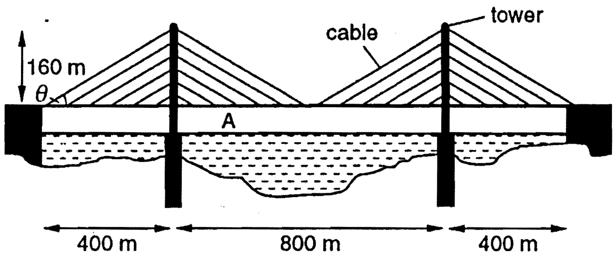


Fig. 39

Length of bridge supported by the towers	= 1600 m
Height of tower above roadway	= 160 m
Total mass of all the cables	= 1.4×10^6 kg
Mass of roadway	= 8.5×10^6 kg
Maximum mass of load of traffic (assume uniform distribution)	= 11.5×10^6 kg
Horizontal distance between cables	= 20 m
Vertical distance between cables	= 8 m
Number of cables	= 80

(a) What reason does the paragraph give for the construction with many inverted V cables? [2]

(b) Calculate the maximum total mass which each of the two towers may need to support.

mass =.......................... kg [2]

(c) Calculate the mass of 20 m of roadway and the traffic which those 20 m of roadway may have to support.

mass =.......................... kg [2]

(d) Calculate the angle, θ, between a cable and the horizontal.

angle to horizontal = ... [2]

(e) Draw a force diagram for a fully laden 20 m section of road at A. Explain how this road section is in equilibrium. [4]

(f) Calculate the tension in a cable when the bridge is fully laden. (The tension in all cables is assumed to be the same.)

tension = ... N [4]

(g) Where is there likely to be a tension in the roadway? Explain your answer. [2]

(h) Describe qualitatively what will happen to the tension in the cables on an extremely cold day. [2]

N97/II/9

17 Most countries have building regulations which contain instructions about limiting heat transfer. In countries which are cold in the winter, these instructions are designed to reduce the amount of heating required. In tropical countries, the same principles can be used to reduce the need for air conditioning. The instructions apply to domestic and public buildings and are enforced in order to reduce the amount of energy required to keep buildings at a comfortable temperature. This has the effect of reducing the amount of fossil fuel which needs to be burnt and, hence, of reducing the emission of greenhouse gases into the atmosphere.

In order to calculate heat gains or losses, a thermal transmittance coefficient or U-value is measured for each type of building material. The U-value is the rate of heat transfer, in watts, through one square metre of a structure when the air temperatures on each side of the structure differ by 1 kelvin. The following U-values will be needed in answering this question.

U-value for bricks 100 mm thick	= $8.2\ \mathrm{W\,m^{-2}\,K^{-1}}$
U-value for thermal insulation 50 mm thick	= $1.4\ \mathrm{W\,m^{-2}\,K^{-1}}$

Answer the following questions using the information given.

(a) What is stated in the passage as an advantage of enforcing regulations which limit heat transfer to and from buildings? [1]

(b) Explain why it is that the same physical theory can be applied to a situation where a house is to be kept warm in cold weather and to one where a house is to be kept cool in hot weather. [3]

(c) Using the definition given in the passage, write down an equation relating the rate R of heat transfer to the difference in temperature ΔT between the two surfaces of the material, the surface area A of the material and the U-value U of the material. [1]

(d) Calculate the rate of heat transfer flow through a brick wall 100 mm thick and of dimensions 3.0 m × 5.0 m when the temperature on the inside is 20 °C and on the outside is 0 °C.

rate of heat transfer = ... W [2]

(e) A composite wall is constructed from two 100 mm brick walls separated from one another by 50 mm of thermal insulation, as shown in Fig. 40.

In order to calculate the rate of heat transfer through such a wall, a composite U-value, U_C, has to be used. U_C is given in terms of the U-values of the individual materials by the equation

$$\frac{1}{U_C} = \frac{1}{U_1} + \frac{1}{U_2} + \ldots\ldots$$

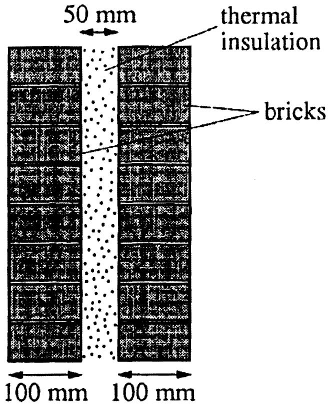


Fig. 40

Use the equation to find

(i) U_C for the composite wall shown in Fig. 40,

(ii) the rate of heat transfer through a wall of dimensions 3.0 m × 5.0 m when the temperature on the inside is 20 °C and on the outside is 0 °C.

rate of heat transfer = ... W [5]

(f) On Fig. 41, sketch a graph to show how the rate of heat transfer through a wall, such as that shown in Fig. 40, varies with the thickness of the insulation. Label the vertical axis with suitable values. [4]

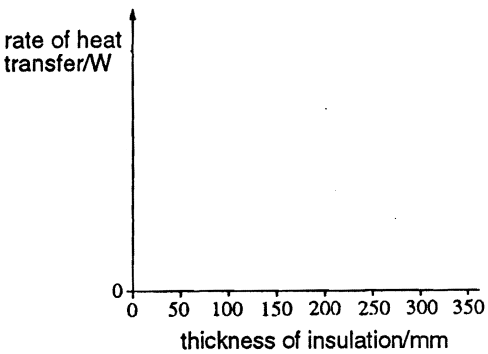


Fig. 41

(g) Suggest a factor which will also affect heat losses from a room, in addition to loss by conduction which has already been considered. Indicate how the effect of this factor may be minimised. [2]

Quality of Language [4]
J98/II/8

18 Dangers associated with exposure to radiation have been recognised for many years. As a result of these hazards, measures have been adopted to reduce exposure to radiation to as low a level as possible. One such measure is to shield individuals from radioactive sources using radiation absorbing materials.

Experiments have been carried out to investigate the effectiveness of materials as absorbers of γ-ray photons. One possible experiment is illustrated in Fig. 42.

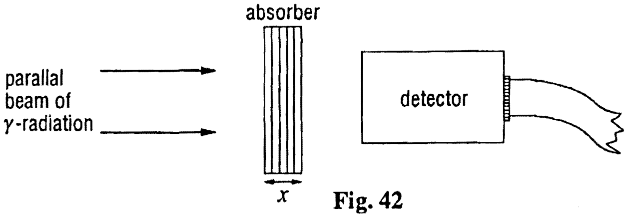


Fig. 42

The count-rate C_X of γ-ray photons is measured for various thicknesses x of the absorber, together with the count-rate C_0 for no absorber. Fig. 43 shows the variation with thickness x of the ratio C_X/C_0 for lead.

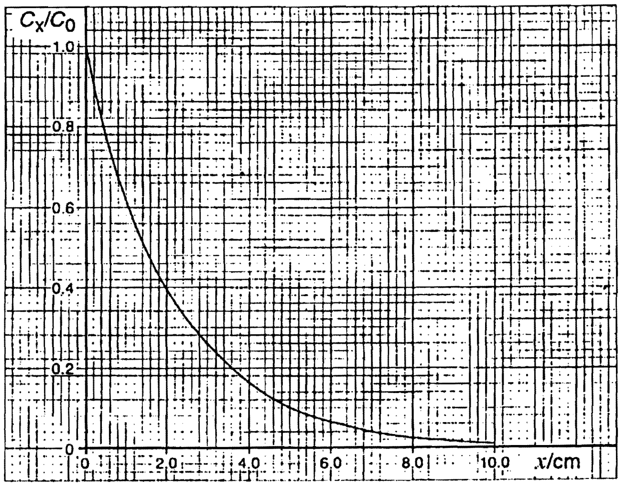


Fig. 43

(a) (i) What is a photon?

(ii) In the experiment, suggest why it is necessary to have a parallel beam of γ-radiation.

(iii) What evidence is provided in Fig. 43 for the fact that, theoretically, complete shielding is not possible? [4]

(b) Fig. 43 indicates that there may be an exponential decrease of the ratio C_X/C_0 with thickness x. In order to test this suggestion, a graph of $\ln(C_X/C_0)$ against x is plotted. This is shown in Fig. 44.

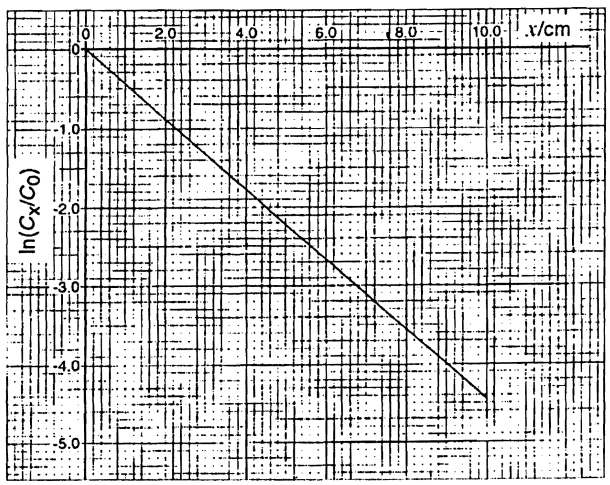


Fig. 44

(i) Explain the following.

1. PQ on the graph corresponds mainly to the decay of cobalt.
2. RS on the graph corresponds mainly to the decay of nickel.
3. The shape of QR is a curve.

(ii) Determine the following gradients.

1. the gradient of PQ
2. the gradient of RS

gradient of PQ = ...

gradient of RS = ...

(iii) Given that the general decay law is of the form $x = x_0 \exp(-\lambda t)$, use the gradients found in (ii) to *estimate* values of the decay constants for the cobalt and the nickel nuclides.

decay constant of cobalt = ...

decay constant of nickel = ...

(iv) Use your answer to (iii) to calculate the half-life of the cobalt.

half-life = ... year [10]

(d) Suggest whether these two nuclides, with these activities, would pose any hazard if found when de-commissioning a nuclear reactor. [2]

(e) In an actual reactor, activities of radioactive materials can often be 10^{12} times larger than those given in Fig. 46. Explain when and why each of these two nuclides would pose the greater hazard. [4]

Quality of language [4]

J99/II/8

20 Read the following passage.

Liquids, vapours and gases

When a small mass of water is introduced into a large evacuated vessel, the water evaporates completely to form what is called an unsaturated vapour. If the unsaturated vapour is then compressed slowly, the volume of the vapour decreases. During this change, the temperature is kept constant. This is known as an isothermal change and is shown by the line AB in Fig. 48.

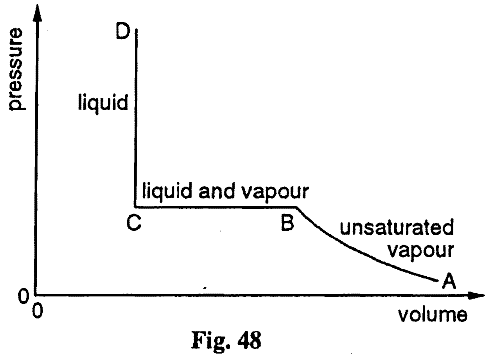


Fig. 48

On reducing the volume further at constant temperature, the vapour condenses and the pressure remains constant. In the region BC on Fig. 48, liquid and vapour are present and the vapour is said to be saturated. At C, all the vapour has condensed and only liquid is present. Any further reduction in volume is achieved only by applying very large pressures.

When values of the volume and the corresponding pressure are obtained at a number of different temperatures, a series of lines known as isotherms may be drawn as shown in Fig. 49. Each isotherm is drawn for the same mass of water.

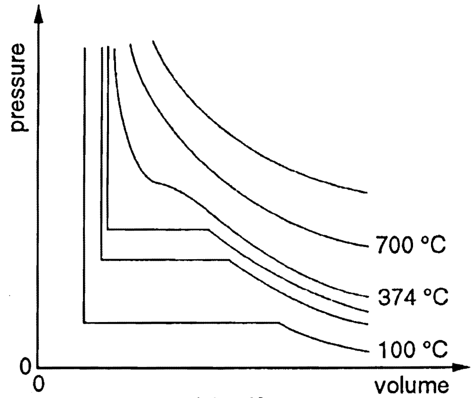


Fig. 49

Answer the following questions.

(a) By reference to the passage,

(i) state what is meant by

1. 'an isothermal change',
2. 'the vapour condenses'. [3]

(ii) distinguish between an *unsaturated* vapour and a *saturated* vapour. [2]

(iii) distinguish between the behaviour of an unsaturated vapour and a saturated vapour when the volume is reduced at constant temperature. [2]

(b) State the feature of the line on Fig. 48 which indicates that large changes in pressure are required to produce small changes in volume of a liquid. [1]

(c) In order to produce liquid by increasing the pressure alone, the vapour must be below a particular temperature which is different for different substances. This temperature is known as the critical temperature T_C of the substance. Fig. 50 lists some substances and the corresponding critical temperatures, measured in kelvin.

substance	T_C/K
hydrogen	33
nitrogen	126
oxygen	154
carbon dioxide	304
ammonia	406
sulphur dioxide	431
water	....

Fig. 50

Use Fig. 49 to complete Fig. 50 for water. [1]

(d) In early experiments to try to liquefy gases, increase in pressure alone was used. Gases which could not be liquefied at room temperature by pressure alone were known as *permanent gases*.

(i) List the substances in Fig. 50 which would have been known as permanent gases.

(ii) Suggest, with a reason, which substance listed in Fig. 50 proved to be most useful in early experimental work on the behaviour of a vapour near to its critical temperature. [4]

(e) Scientists investigating the behaviour of gases first used atmospheric air. As a result of their investigations, the gas laws were developed.

(i) State the ideal gas equation.

(ii) By reference to Figs 49 and 50, suggest why

1. it was fortunate for the early investigators of gas laws that atmospheric air is composed mainly of nitrogen and oxygen,
2. when verifying the gas laws in a school laboratory, water vapour should be removed from the sample of air. [5]

Quality of language [4]

N99/II/8

21 Read the passage below and then answer the questions that follow.

When a structural engineer is designing a building there will be occasions when a beam has to be used to bridge a gap. The width of the gap is called the span. The engineer makes calculations to ensure that the beam is strong enough to withstand any forces applied to it, and to ensure that there is not too much sag in the beam. This question concerns how the choice of beam is made.

Sometimes, when the loading is small, a plain wooden beam is sufficient, as shown in Fig. 51. A beam such as this, loaded at its centre, will undergo a maximum depression x given by

$$x = \frac{WL^3}{kab^3}$$

where W is the load at the centre, a is the width and b is the depth of the beam and k is a constant.

When greater loads or greater spans are required, a steel beam may be used. In order to minimise the amount of steel required the shape of the beam used is as shown in Fig. 52.

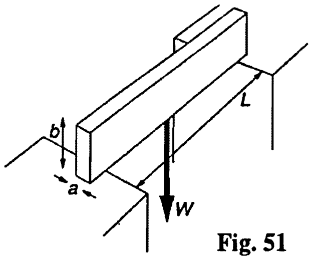


Fig. 51

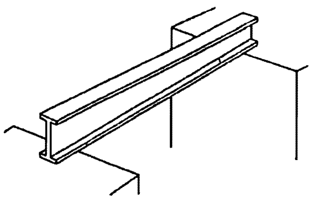


Fig. 52

Sometimes, the loading of the beam is uniform, along its length, as shown in Fig. 53.

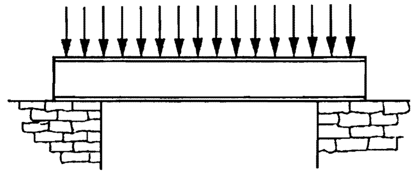


Fig. 53

Sometimes, with complex loading (Fig. 54), the moments of the forces have to be calculated.

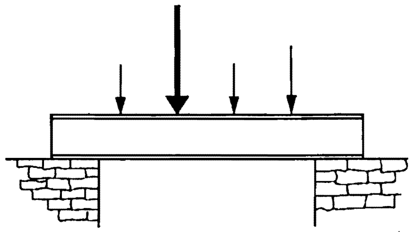


Fig. 54

(a) (i) State **two** reasons why the structural engineer has to make calculations when using a beam to bridge a gap.

(ii) Write down the reason given in the passage for making the steel beam the shape shown in Fig. 52.

(iii) The cross-sectional area of the beams shown in Fig. 55 are the same.

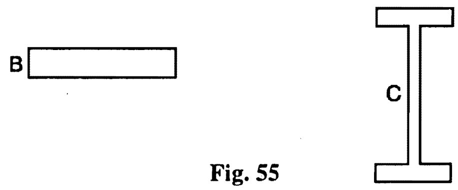


Fig. 55

Suggest why, for beams of the same length, one would sag more than the other. [5]

(b) A wooden beam has width 0.050 m, depth 0.10 m and spans 3.0 m. Calculate the maximum load which it can support at its centre for a maximum depression of 0.010 m. Take k to be 3.6×10^{10} Pa for this wood. [3]

(c) A steel beam, loaded uniformly as in Fig. 56, is allowed to sag by a maximum of 1/360 of the gap it is spanning. A particular beam is used to carry a load of 33 000 N and to span a gap of 4.20 m. A quantity B, known as the bending moment for this loading pattern is given by

$B = \frac{WL}{8}$ and the depression x at the centre is given by

$x = \frac{BL^3}{c}$ where c has the value 3.35×10^8 Nm^3.

Calculate

(i) the amount x_{max} by which the beam is allowed to sag,

(ii) the bending moment B,

(iii) the actual amount x of sag. [5]

(d) A beam across a gap is shown in Fig. 56, together with values of the forces acting and their distances from X.

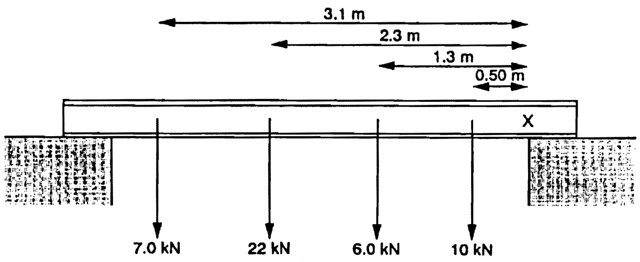


Fig. 56

Calculate the total moment of the forces shown about point X. [4]

(e) The final check on the suitability of any beam is to ensure that it is strong enough. This is done, using a table of values, to find the allowable bending stress.

(i) For the beam in *(c)*, two constants P and Q, without units, are found from the dimensions of the beam and the gap it is spanning. For this beam P = 21 and Q = 170. Use Fig. 57 to find the allowable bending stress.

allowable bending stress/MPa				
	P			
Q	15	20	25	30
160	111	96	88	82
170	106	93	83	77
180	102	89	80	73

Fig. 57

(ii) The beam is safe to use if

$$\frac{\text{bending moment}}{\text{allowable bending stress}} < 2.0 \times 10^{-4}\ \text{m}^3$$

Use this relationship to determine whether the beam is safe under these conditions.

$$\frac{\text{bending moment}}{\text{allowable bending stress}} =$$

Is the beam safe?...................................... [3]

Quality of language [4]

J2000/II/8

22 Radioactive Decay Series

The decay of the nuclei of a radioactive isotope is said to be random and spontaneous. The nuclei may emit particles and, in so doing, become nuclei of a different element. When radioactive decay occurs, the original nucleus is known as the parent nucleus and the nucleus resulting from the decay is the daughter nucleus.

(a) Explain what is meant by radioactive decay being a *spontaneous* process. [1]

(b) Thorium-231 ($^{231}_{90}$Th) decays with a half-life of 25 hours to form the daughter product Protactinium-231 ($^{231}_{91}$Pa) which has a half-life of 3.4×10^4 years.

(i) State the change in the composition of a nucleus of Thorium-231 when it decays to become Protactinium-231.

(ii) A fresh sample of radioactive material contains N_0 nuclei of Thorium-231 and no Protactinium-231 at time t = 0. Assume that Protactinium-231 is stable. On Fig. 58, sketch graphs to show the variation with time t of the number N of nuclei in the sample which are

1. thorium nuclei (label this line T),
2. protactinium nuclei (label this line P).

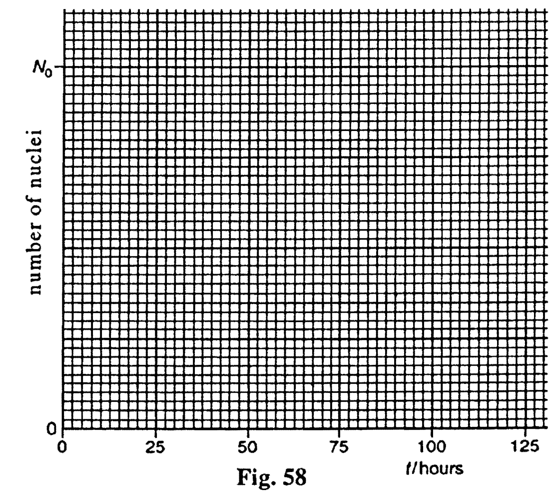


Fig. 58

(iii) Using Fig. 58, or otherwise, deduce the age of the sample of radioactive material when

$$\frac{\text{number of Thorium-231 nuclei in sample}}{\text{number of Protactinium-231 nuclei in sample}} = 1/3\ .$$

age = ... hours [6]

(c) For many unstable parent nuclei, the daughter product is itself radioactive. This may give rise to a radioactive series where there may be ten or more different radioactive daughter products. The variation with time t of the percentage number P of different nuclei in a radioactive sample is illustrated in Fig. 59. The parent nucleus has a daughter nucleus and, in turn, this daughter produces a further daughter.

Initially, there are 1.2×10^{15} nuclei of the parent isotope in the sample and the daughter products are not present. The parent isotope has a half-life of 3.0 years and the daughter product D has a half-life of 15 years, decaying to form the further daughter S which is stable.

(i) On Fig. 59, label with the letter S the line representing the variation with t of the number of nuclei of the stable further daughter S. Give an explanation for your choice. [1]

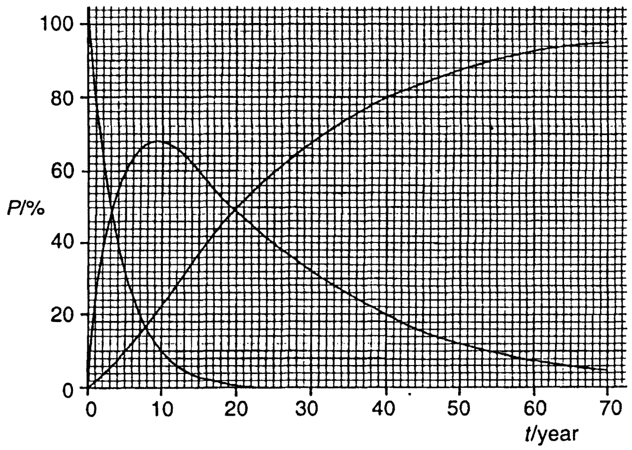


Fig. 59

(ii) 1. State the time after which the daughter product D will have its maximum activity.

time = ... years

2. Calculate the maximum activity, in microcuries (μCi), of the daughter product D given that 1.0 μCi = 3.7×10^4 Bq.

activity = ... μCi [4]

(iii) Suggest why the number of nuclei of the daughter product D increases to a maximum and then decreases. [4]

(iv) The relative activities of the parent isotope and the daughter products may be used as a means of determining the age of the sample. Suggest why this technique may provide reliable results for ages up to about 30 years but for an age of about 100 years, the method would be far less reliable. [2]

Quality of language [4]

N2000/II/8