



CANDIDATE
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9702/41

May/June 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Data

acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ ($\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$)
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_o = \frac{f_s v}{v \pm v_s}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

gravitational potential	$\phi = -\frac{GM}{r}$
gravitational potential energy	$E_P = -\frac{GMm}{r}$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) (i) Define gravitational field.

.....
 [1]

- (ii) Define electric field.

.....
 [1]

- (iii) State **one** similarity and **one** difference between the gravitational potential due to a point mass and the electric potential due to a point charge.

similarity:

.....

difference:

.....

[2]

- (b) An isolated uniform conducting sphere has mass M and charge Q .

The gravitational field strength at the surface of the sphere is g .

The electric field strength at the surface of the sphere is E .

- (i) Show that

$$\frac{M}{Q} = \alpha \frac{g}{E}$$

where α is a constant.

[3]

- (ii) Show that the numerical value of α is $1.35 \times 10^{20} \text{ kg}^2 \text{ C}^{-2}$.

[1]

- (c) Assume that the Earth is a uniform conducting sphere of mass 5.98×10^{24} kg. The surface of the Earth carries a charge of -4.80×10^5 C that is evenly distributed.
- (i) Use the information in (b) to determine the electric field strength at the surface of the Earth. Give a unit with your answer.

electric field strength = ... unit [2]

- (ii) State how the direction of the electric field at the surface of the Earth compares with the direction of the gravitational field.

..... [1]

[Total: 11]

- 2 A steel sphere of mass 0.29 kg is suspended in equilibrium from a vertical spring. The centre of the sphere is 8.5 cm from the top of the spring, as shown in Fig. 2.1.

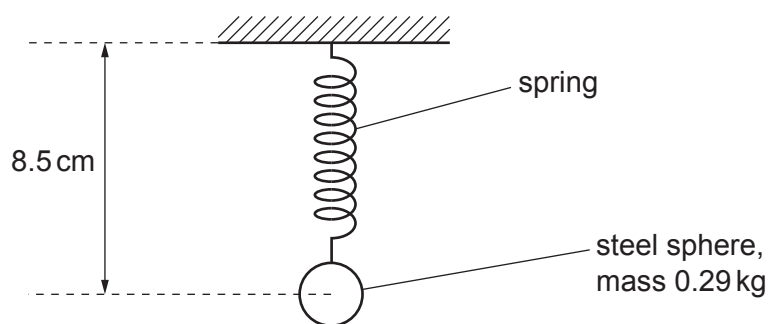


Fig. 2.1

The sphere is now set in motion so that it is moving in a horizontal circle at constant speed, as shown in Fig. 2.2.

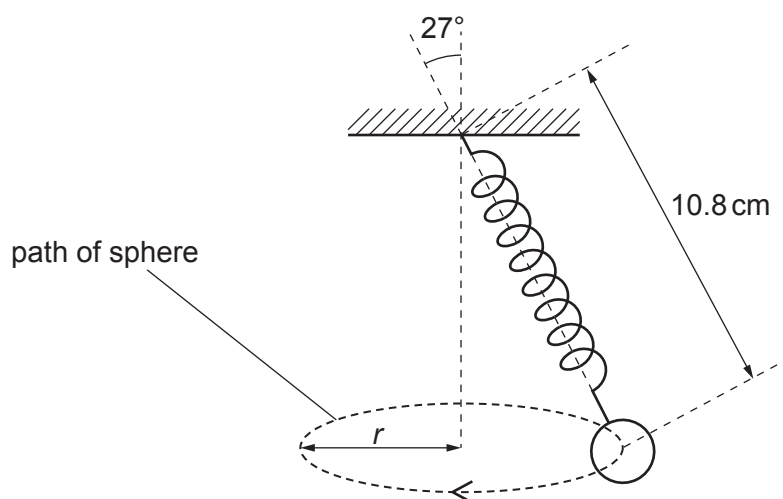


Fig. 2.2

The distance from the centre of the sphere to the top of the spring is now 10.8 cm .

- (a) Explain, with reference to the forces acting on the sphere, why the length of the spring in Fig. 2.2 is greater than in Fig. 2.1.

.....

.....

.....

.....

..... [3]

(b) The angle between the linear axis of the spring and the vertical is 27° .

(i) Show that the radius r of the circle is 4.9 cm.

[1]

(ii) Show that the tension in the spring is 3.2 N.

[2]

(iii) The spring obeys Hooke's law.

Calculate the spring constant, in N cm^{-1} , of the spring.

spring constant = ... N cm^{-1} [2]

(c) (i) Use the information in **(b)** to determine the centripetal acceleration of the sphere.

centripetal acceleration = ... ms^{-2} [2]

(ii) Calculate the period of the circular motion of the sphere.

period = ... s [2]

[Total: 12]

- 3 (a) State the reason why two objects that are at the same temperature are described as being in thermal equilibrium.

.....
 [1]

- (b) Fig. 3.1 shows the variations with temperature of the densities of mercury and of water between 0 °C and 100 °C.

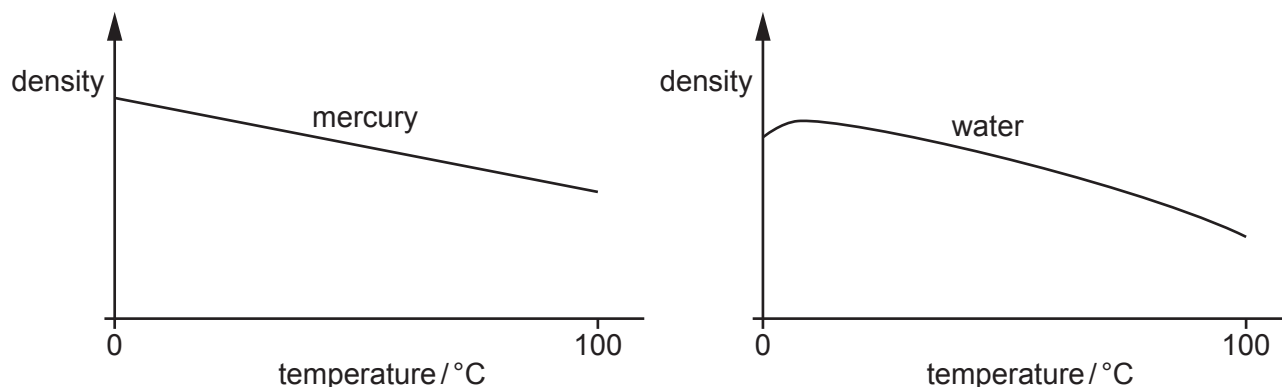


Fig. 3.1

Temperature may be measured using the variation with temperature of the density of a liquid.

Suggest why, for measuring temperature over this temperature range:

- (i) mercury is a suitable liquid

.....
 [1]

- (ii) water is not a suitable liquid.

.....

 [2]

- (c) A beaker contains a liquid of mass 120 g. The liquid is supplied with thermal energy at a rate of 810 W. The beaker has a mass of 42 g and a specific heat capacity of $0.84 \text{ J g}^{-1} \text{ K}^{-1}$. The beaker and the liquid are in thermal equilibrium with each other at all times and are insulated from the surroundings.

Fig. 3.2 shows the variation with time t of the temperature of the liquid.

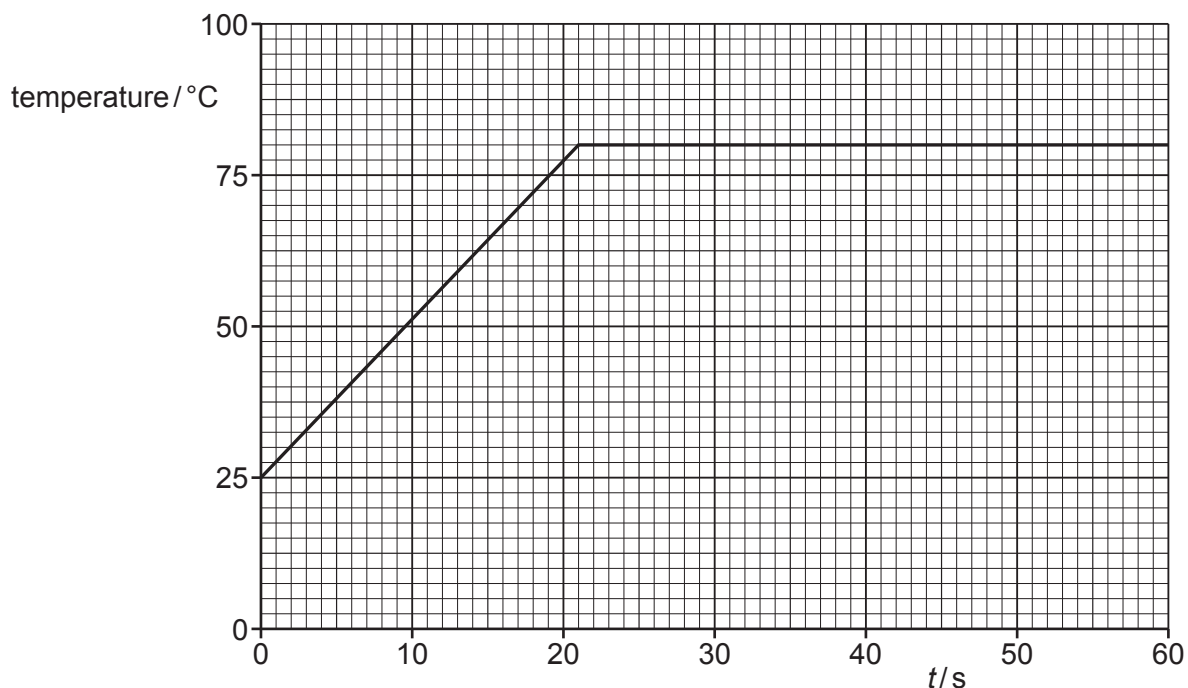


Fig. 3.2

- (i) State the boiling temperature, in °C, of the liquid.

temperature = ... °C [1]

- (ii) Determine the specific heat capacity, in $\text{J g}^{-1} \text{K}^{-1}$, of the liquid.

specific heat capacity = ... $\text{J g}^{-1} \text{K}^{-1}$ [4]

- (d) The experiment in (c) is repeated using water instead of the liquid in (c). The mass of liquid used, the power supplied, and the initial temperature are all unchanged.
The specific heat capacity of water is approximately twice that of the liquid in (c).
The boiling temperature of water is 100 °C.

On Fig. 3.2, sketch the variation with time t of the temperature of the water between $t = 0$ and $t = 60$ s. Numerical calculations are not required. [2]

[Total: 11]

- 4 (a) State **two** of the basic assumptions of the kinetic theory of gases.

1

.....

2

.....

[2]

- (b) An ideal gas has amount of substance n .

The gas is initially in state X, with pressure $2p$ and volume V .

The gas is cooled at constant volume to state Y, with pressure p .

The gas is then heated at constant pressure to state Z, with volume $2V$.

Finally, the gas returns at constant temperature to state X.

- (i) Determine an expression for the temperature T of the gas in state X, in terms of n , p and V .
Identify any other symbols that you use.

[2]

- (ii) On Fig. 4.1, sketch the variation with volume of pressure for the gas as the gas undergoes the three changes. The state X is labelled. Label states Y and Z.

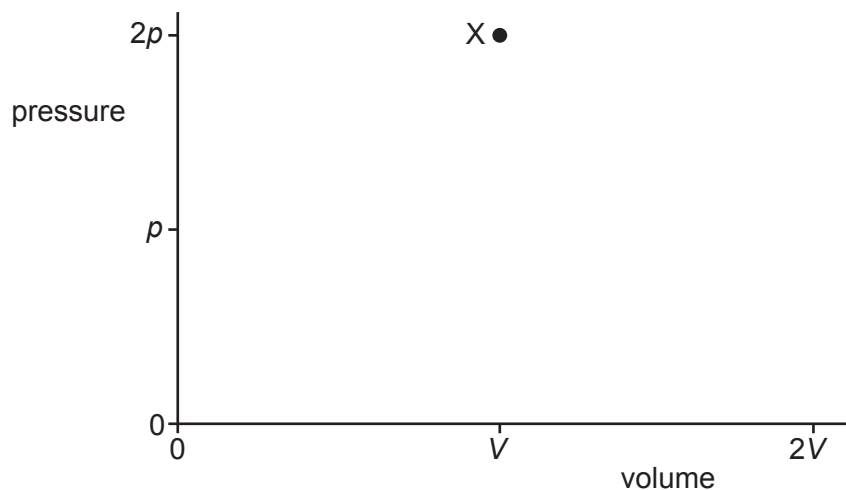


Fig. 4.1

[3]

- (iii) During the change of state from Y to Z, the increase in internal energy of the gas is U .
During the change of state from Z to X, the work done on the gas is W .

Complete Table 4.1 to indicate, for each of the three changes of state, the increase in internal energy of the gas, the thermal energy transferred to the gas and the work done on the gas, in terms of p , V , U and W .

Table 4.1

change	increase in internal energy of gas	thermal energy transferred to gas	work done on gas
X to Y			
Y to Z	$+U$		
Z to X			$+W$

[5]

[Total: 12]

5 Part of an electric circuit is shown in Fig. 5.1.

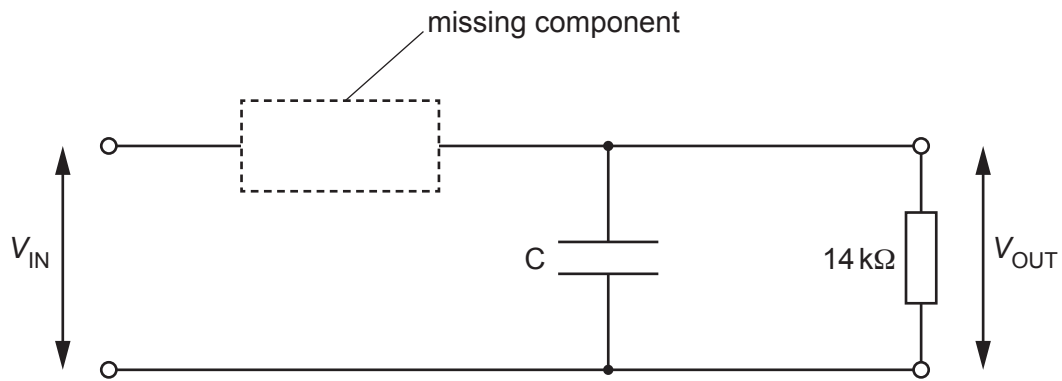


Fig. 5.1

The circuit is used to produce half-wave rectification of an alternating voltage of potential difference (p.d.) V_{IN} .

The output p.d. across the $14\text{ k}\Omega$ resistor is V_{OUT} .

(a) (i) A component is missing from the circuit of Fig. 5.1.

Complete the circuit diagram in Fig. 5.1 by adding the circuit symbol for the missing component, correctly connected. [1]

(ii) A capacitor C is shown in the circuit of Fig. 5.1.

State the effect on V_{OUT} of including the capacitor in the circuit.

..... [1]

(b) Fig. 5.2 shows the variation with time t of V_{IN} .

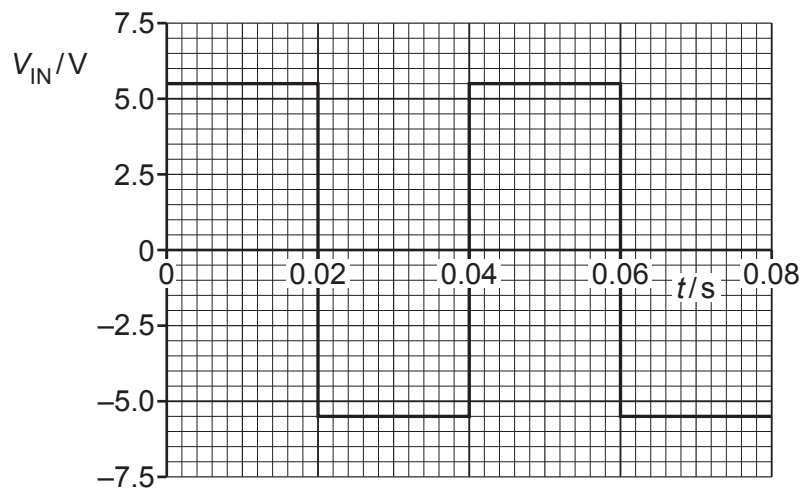


Fig. 5.2

Fig. 5.3 shows the variation with t of V_{OUT} .

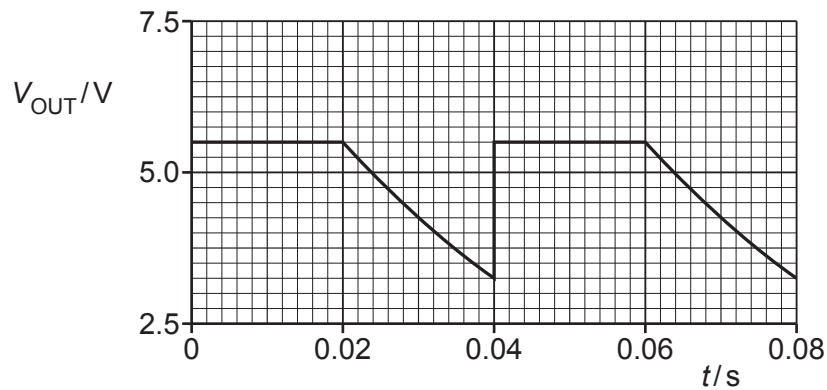


Fig. 5.3

- (i) Determine the frequency of V_{IN} .

frequency = ... Hz [1]

- (ii) Show that the time constant τ for the discharge of the capacitor through the resistor is 0.038 s.

[2]

- (iii) Calculate the capacitance of C. Give a unit with your answer.

capacitance = ... unit [2]

- (c) The circuit of Fig. 5.1 is modified so that it produces full-wave rectification of an input voltage.

Suggest, with a reason, how V_{OUT} now varies with time when V_{IN} is as shown in Fig. 5.2.

.....

 [2]

[Total: 9]

- 6 (a) State what is meant by a magnetic field.

.....

.....

..... [2]

- (b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

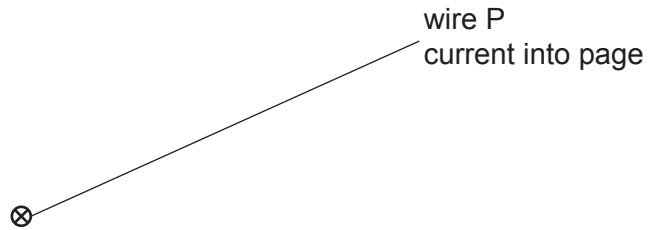


Fig. 6.1

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. [3]

- (c) A second long, straight wire Q, carrying a current of 5.0A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

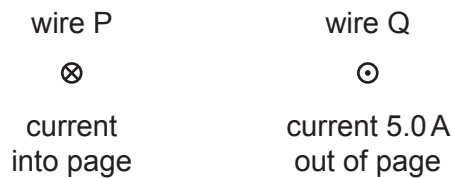


Fig. 6.2

The flux density of the magnetic field at wire Q due to the current in wire P is 2.6 mT.

- (i) Calculate the magnetic force per unit length exerted on wire Q by wire P.

force per unit length = ... N m⁻¹ [2]

- (ii) State the direction of the force exerted on wire Q by wire P.

..... [1]

- (iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning.

current = ... A [2]

[Total: 10]

- 7 (a) State what is meant by the de Broglie wavelength.

.....
 [1]

- (b) Fig. 7.1 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

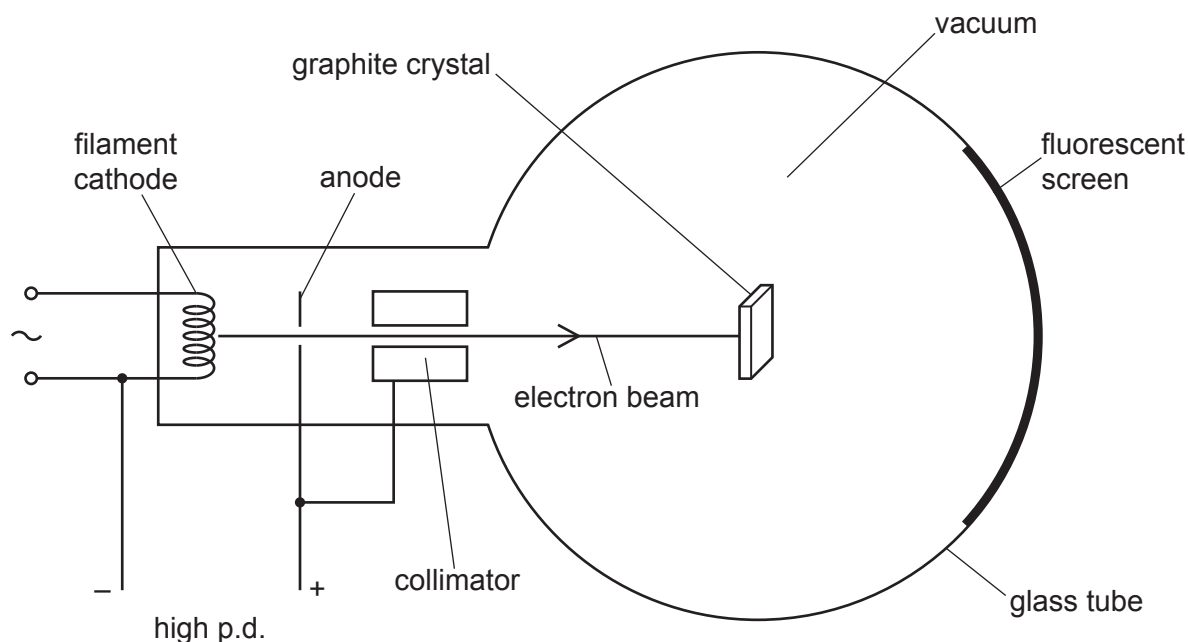


Fig. 7.1 (not to scale)

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 7.2 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 7.1.

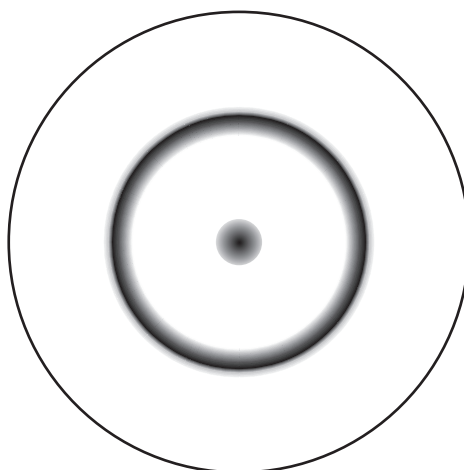


Fig. 7.2

- (i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 7.2.

..... [1]

- (ii) Explain what can be concluded from the pattern in Fig. 7.2 about the nature of electrons.

.....
.....
..... [2]

- (c) The electrons in (b) are now accelerated through a greater potential difference between the cathode and the anode.

- (i) On Fig. 7.3, sketch the pattern that is now seen on the fluorescent screen in Fig. 7.1.

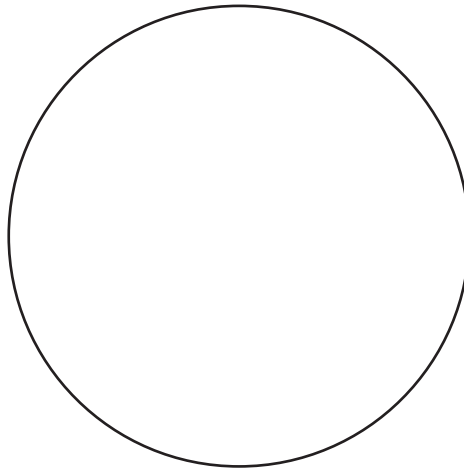


Fig. 7.3

[2]

- (ii) Explain, with reference to de Broglie wavelength, the change in the pattern on the fluorescent screen.

.....
.....
.....
.....
..... [3]

[Total: 9]

- 8 (a) Table 8.1 shows some data relating to the properties of air, gel and body tissue. The data are given to three significant figures.

Table 8.1

material	density / kg m^{-3}	speed of sound / m s^{-1}	specific acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$
air		340	440
gel	1200	1400	
tissue	1090		1.68×10^6

- (i) Show that the specific acoustic impedance of gel is $1.68 \times 10^6 \text{ kg m}^{-2} \text{s}^{-1}$.

[1]

- (ii) Complete Table 8.1 by calculating the missing values to three significant figures. Use the space below for any working that you need.

[2]

- (b) Use the information in (a) to calculate the intensity reflection coefficient for:

- (i) an air–tissue boundary

intensity reflection coefficient = ... [2]

- (ii) a gel–tissue boundary.

intensity reflection coefficient = ... [1]

(c) Use your answers in (b) to explain why gel is applied to the skin during ultrasound scanning.

.....

.....

..... [2]

[Total: 8]

- 9 Carbon-11 is radioactive and decays by β^+ emission to form boron-11. Carbon-11 has a half-life of 20 minutes. Boron-11 is stable.

(a) Define half-life.

.....
 [1]

(b) A sample contains N_0 nuclei of carbon-11 and no other nuclei at time $t = 0$.

On Fig. 9.1, sketch the variation with t of the number of nuclei of **boron-11** in the sample.

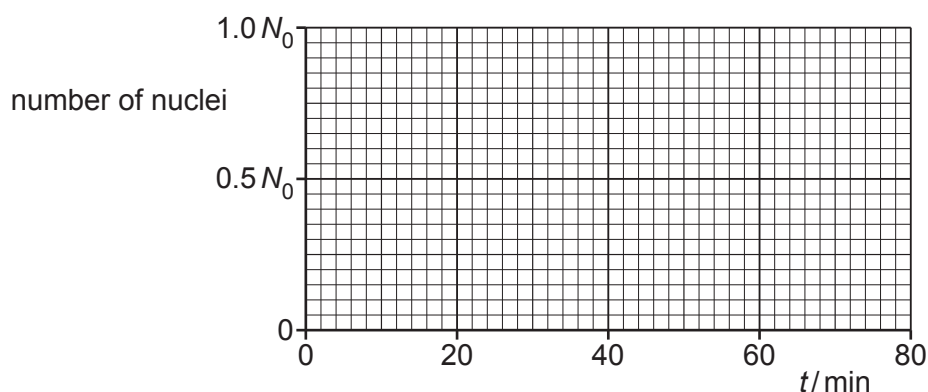


Fig. 9.1

[3]

(c) (i) Explain, with reference to the random nature of radioactive decay, why the activity of the carbon-11 sample in (b) decreases with time.

.....

 [2]

(ii) State, with reasons, whether a radiation detector placed near to the sample of carbon-11 indicates a measured count rate from the sample that is less than, the same as or greater than the activity of the sample.

.....

 [3]

[Total: 9]

- 10 (a) State Hubble's law. Identify any symbols that you use.

.....

.....

.....

..... [2]

- (b) A star of luminosity $3.8 \times 10^{31} \text{ W}$ is a distance of $1.8 \times 10^{24} \text{ m}$ from the Earth.

Calculate the radiant flux intensity at the Earth of the radiation emitted by the star.

radiant flux intensity = ... W m^{-2} [2]

- (c) The star in (b) is in a distant galaxy. A spectral line in the light from this galaxy is known to have a wavelength of 486 nm. This spectral line in the light from the galaxy observed on the Earth has a wavelength of 492 nm.

- (i) Explain why the wavelength observed on the Earth is different from the wavelength that the galaxy is known to have emitted.

.....

.....

..... [2]

- (ii) Determine a value for the Hubble constant H_0 .

$H_0 = \dots\dots\dots \text{s}^{-1}$ [3]

[Total: 9]

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velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
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decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
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Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) State Newton's law of gravitation.

.....

 [2]

- (b) A satellite is in a circular orbit around a planet. The radius of the orbit is R and the period of the orbit is T . The planet is a uniform sphere.

Use Newton's law of gravitation to show that R and T are related by

$$4\pi^2 R^3 = GMT^2$$

where M is the mass of the planet and G is the gravitational constant.

[2]

- (c) The Earth may be considered to be a uniform sphere of mass $5.98 \times 10^{24} \text{ kg}$ and radius $6.37 \times 10^6 \text{ m}$.

A geostationary satellite is in orbit around the Earth.

Use the expression in (b) to determine the height of the satellite above the Earth's surface.

height = ... m [3]

(d) Another satellite is in a circular orbit around the Earth with the same orbital radius and period as the satellite in (c).

(i) Calculate the angular speed of the satellite in this orbit. Give a unit with your answer.

angular speed = ... unit [2]

(ii) Despite having the same orbital period, the orbit of this satellite is not geostationary.

Suggest **two** ways in which the orbit of this satellite could be different from the orbit of the satellite in (c).

1

.....

2

.....

[2]

[Total: 11]

- 2 (a) (i) State what is meant by an ideal gas.

.....

 [2]

- (ii) State the temperature, in degrees Celsius, of absolute zero.

temperature = ... °C [1]

- (b) A sealed vessel contains a mass of 0.0424 kg of an ideal gas at 227 °C.
 The pressure of the gas is 1.37×10^5 Pa and the volume of the gas is 0.640 m³.

Calculate:

- (i) the number of molecules of the gas in the vessel

number of molecules = ... [3]

- (ii) the mass of one molecule of the gas

mass = ... kg [1]

- (iii) the root-mean-square (r.m.s.) speed v of the molecules of the gas.

$v =$ ms⁻¹ [3]

- (c) The gas in (b) is now cooled gradually to absolute zero.

On Fig. 2.1, sketch the variation with thermodynamic temperature T of the r.m.s. speed of the molecules of the gas.

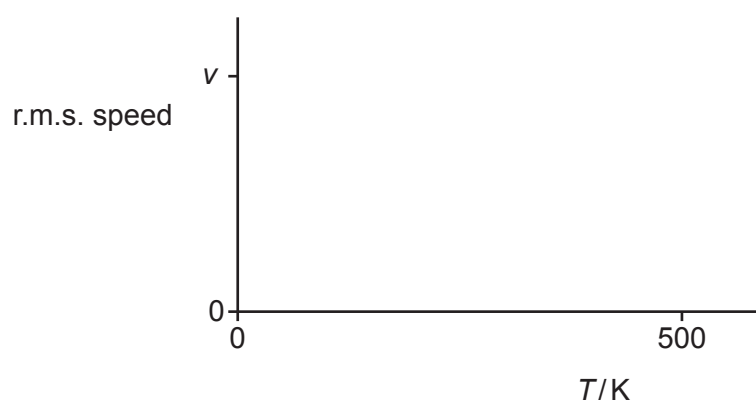


Fig. 2.1

[2]

[Total: 12]

- 3 (a) State the first law of thermodynamics. Identify the meaning of any symbols that you use.

.....

.....

..... [2]

- (b) The state of an ideal gas is continuously changed according to the cycle ABCDA shown in Fig. 3.1.

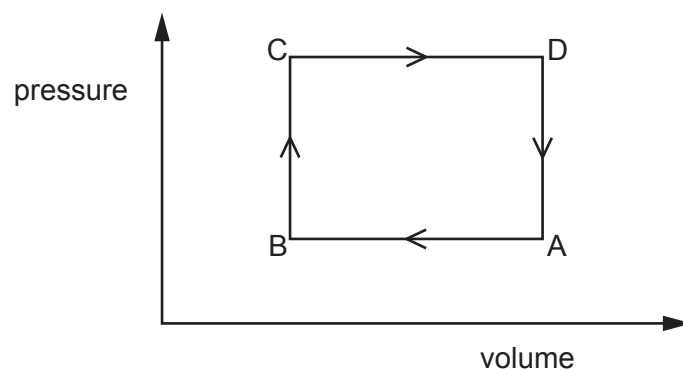


Fig. 3.1

- (i) Complete Table 3.1 for the changes A to B and B to C by placing two ticks (✓) in each row.

Table 3.1

change	change in internal energy			work done on gas		
	decrease	no change	increase	negative	zero	positive
A to B						
B to C						

[4]

- (ii) Use the first law of thermodynamics to describe and explain the energy transfers associated with one complete cycle ABCDA.

.....

.....

.....

.....

..... [3]

[Total: 9]

- 4 A small steel sphere is oscillating vertically on the end of a spring, as shown in Fig. 4.1.

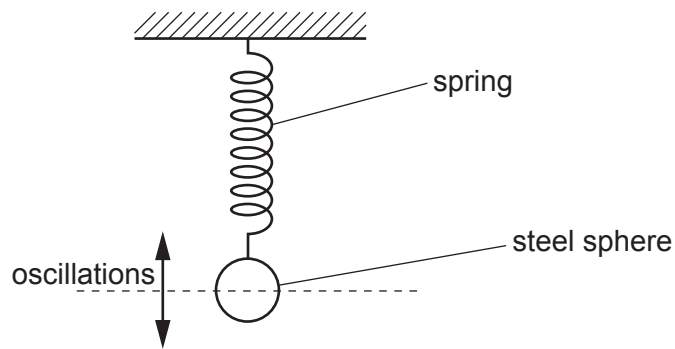


Fig. 4.1

The velocity v of the sphere varies with displacement x from its equilibrium position according to

$$v = \pm 9.7 \sqrt{(11.6 - x^2)}$$

where v is in cm s^{-1} and x is in cm.

- (a) (i) Calculate the frequency of the oscillations.

frequency = ... Hz [2]

- (ii) Show that the amplitude of the oscillations is 3.4 cm.

[1]

- (iii) Calculate the maximum acceleration a_0 of the sphere.

$a_0 = \dots \text{ms}^{-2}$ [2]

- (b) On Fig. 4.2, sketch the variation with x of the acceleration a of the sphere.

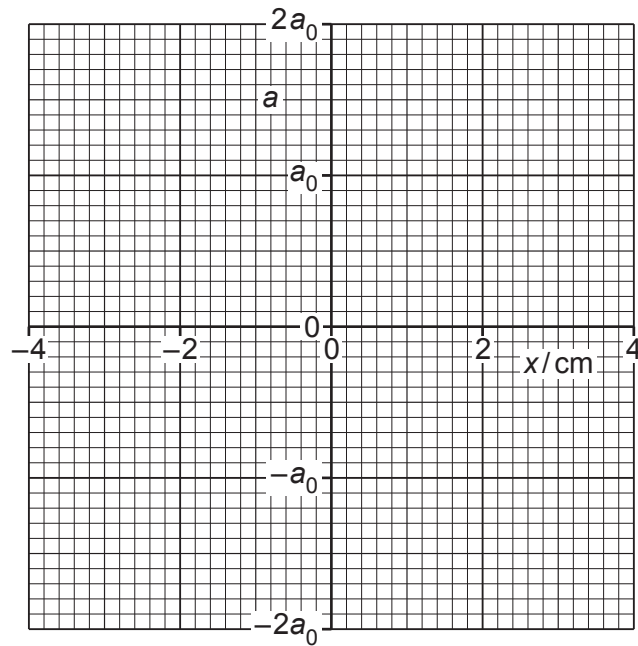


Fig. 4.2

[3]

- (c) Describe, without calculation, the interchange between the potential energy and the kinetic energy of the oscillations.

.....

.....

.....

.....

..... [3]

[Total: 11]

- 5 Two capacitors A and B are connected into the circuit shown in Fig. 5.1.

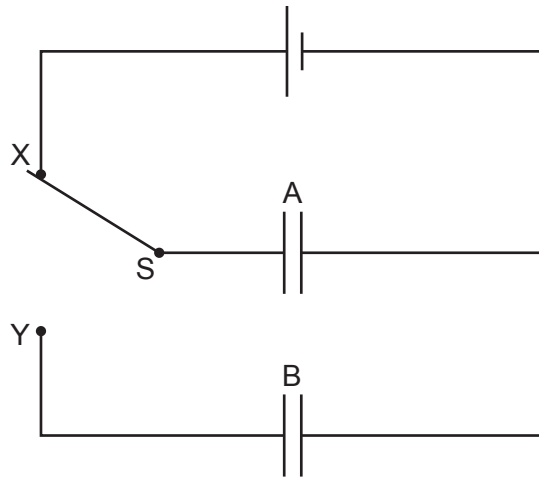


Fig. 5.1

Capacitor A has capacitance C and capacitor B has capacitance $3C$.

The electromotive force (e.m.f.) of the cell is V .

The two-way switch S is initially at position X, and capacitor B is initially uncharged.

- (a) State, in terms of V and C , expressions for:

- (i) the initial charge Q_A on the plates of capacitor A

$$Q_A = \dots\dots\dots [1]$$

- (ii) the initial energy E_A stored in capacitor A.

$$E_A = \dots\dots\dots [1]$$

- (b) The two-way switch S is now moved to position Y.

- (i) State and explain what happens to the charge that was initially on the plates of capacitor A.

.....

 [2]

- (ii) Show that the final potential difference (p.d.) V_B across capacitor B is given by

$$V_B = \frac{V}{4}.$$

Explain your reasoning.

[3]

- (iii) Determine an expression, in terms of V and C , for the decrease ΔE in the total energy that is stored in the capacitors as a result of the change of the position of the switch.

$$\Delta E = \dots\dots\dots [2]$$

[Total: 9]

- 6 A heavy aluminium disc has a radius of 0.36 m. The disc rotates with the wheels of a vehicle and forms part of an electromagnetic braking system on the vehicle.

In order to activate the braking system, a uniform magnetic field of flux density 0.17 T is switched on. This magnetic field is perpendicular to the plane of rotation of the disc, as shown in Fig. 6.1.

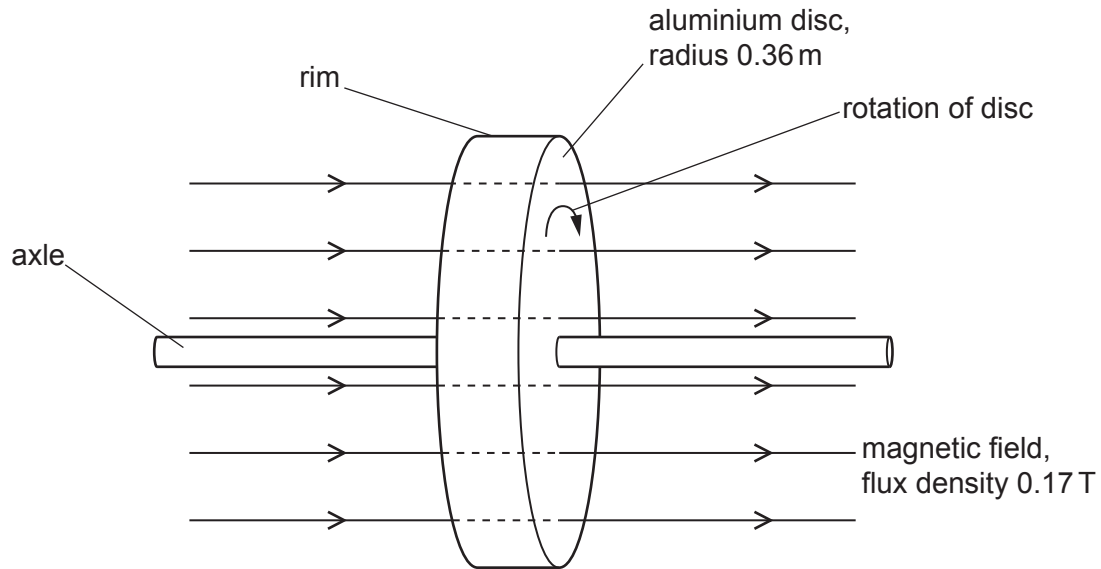


Fig. 6.1

- (a) (i) Define magnetic flux.

.....

 [2]

- (ii) Calculate the magnetic flux through the disc. Give a unit with your answer.

magnetic flux = ... unit [2]

- (b) The disc is rotating at a rate of 25 revolutions per second.

Calculate the magnitude of the electromotive force (e.m.f.) induced between the axle and the rim of the disc.

e.m.f. = ... V [3]

- (c) The axle and the rim are connected into an external circuit that enables the energy of the rotation of the disc to be stored for future use. The direction of rotation is shown in Fig. 6.1.

Use Lenz's law of electromagnetic induction to determine whether the current in the disc is from the rim to the axle or from the axle to the rim. Explain your reasoning.

.....

 [3]

[Total: 10]

- 7 Four diodes are used in a bridge rectifier circuit to produce rectification of a sinusoidal a.c. input voltage V_{IN} .
Fig. 7.1 shows part of the circuit, but three of the diodes are missing.

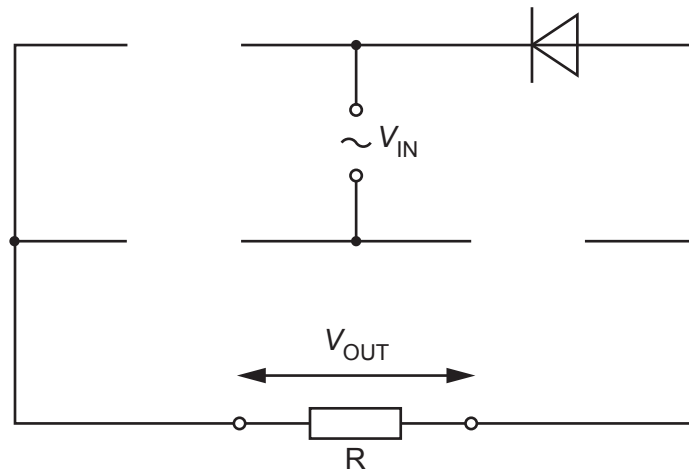


Fig. 7.1

The p.d. across the load resistor R is the output p.d. V_{OUT} of the bridge rectifier.

- (a) (i) State the name of the type of rectification produced by a bridge rectifier.
..... [1]
- (ii) Complete Fig. 7.1 by drawing the three missing diodes, correctly connected. [2]
- (iii) On Fig. 7.1, draw an arrow to indicate the direction of the current in resistor R . [1]
- (b) V_{IN} has amplitude V_0 and period T . Fig. 7.2 shows the variation with time t of V_{IN} .

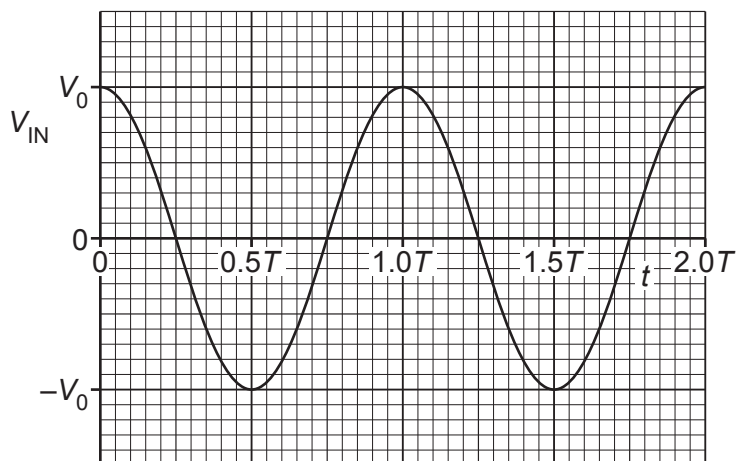


Fig. 7.2

- (i) On Fig. 7.3, sketch the variation of V_{OUT} with t between $t = 0$ and $t = 2.0T$.

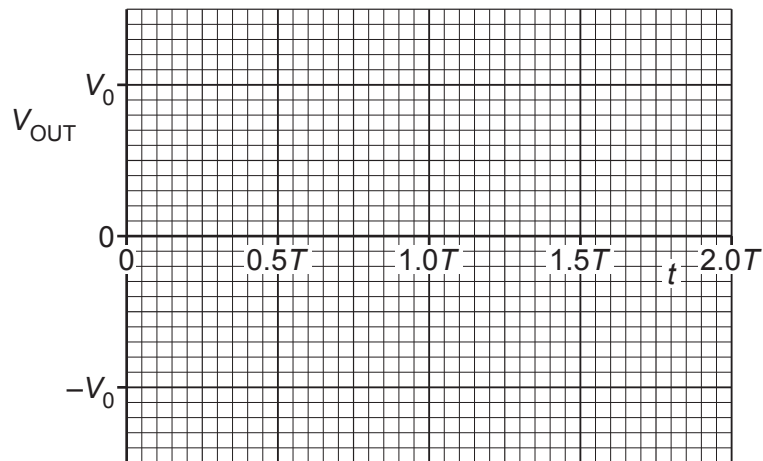


Fig. 7.3

[3]

- (ii) The power dissipated in the resistor is P .

On Fig. 7.4, sketch the variation of P with t between $t = 0$ and $t = 2.0T$.

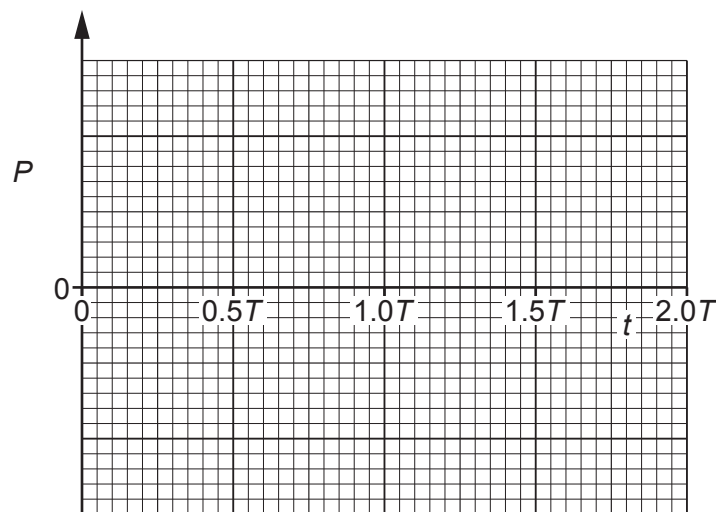


Fig. 7.4

[2]

- (iii) Suggest, with a reason, how the root-mean-square (r.m.s.) value of V_{OUT} compares with the r.m.s. value of V_{IN} .

.....
 [1]

[Total: 10]

- 8 Fig. 8.1 shows the lowest four energy levels of an electron in an isolated atom.

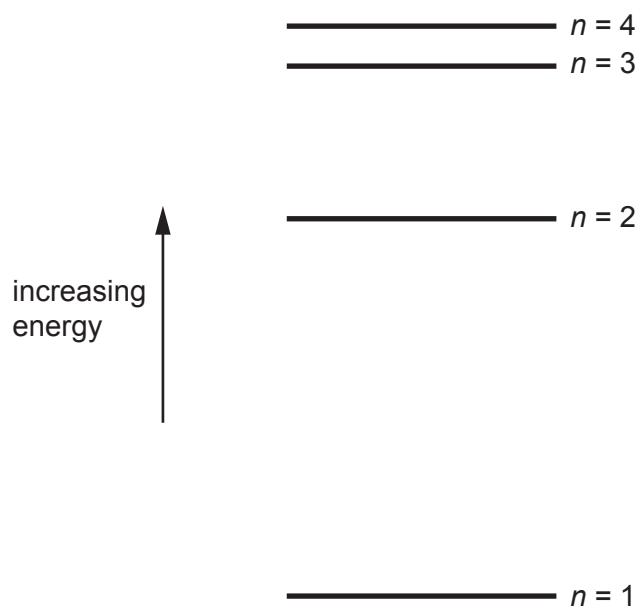


Fig. 8.1

Fig. 8.2 shows the lines in the emission spectrum of the atom that correspond to the transitions of the electron from $n = 3$ to $n = 1$ and from $n = 4$ to $n = 1$.

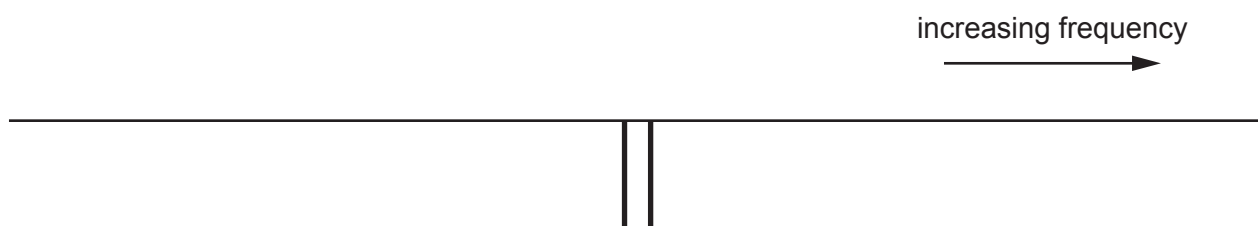


Fig. 8.2

- (a) Explain, with reference to photons, why there is a single frequency of electromagnetic radiation that corresponds to each of these transitions.

..... [2]

.....

.....

- (b) (i) On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 2$ to $n = 1$. Label this line A. [2]
- (ii) On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 3$ to $n = 2$. Label this line B. [2]

- (c) The frequency of radiation represented by line A is f_A .
The frequency of radiation represented by line B is f_B .
The energy of the ground state ($n = 1$) is E_1 .

Determine an expression, in terms of f_A , f_B , E_1 and the Planck constant h , for the energy E_3 of the energy level $n = 3$.

$$E_3 = \dots\dots\dots [2]$$

[Total: 8]

- 9 (a) Define mass defect.

.....

.....

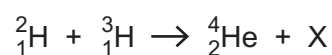
..... [2]

- (b) Table 9.1 shows the mass defects of three nuclei.

Table 9.1

nucleus	mass defect / u
${}^2_1\text{H}$	0.002 388
${}^3_1\text{H}$	0.009 105
${}^4_2\text{He}$	0.030 377

The nuclear fusion process in a particular star is described by



where X is a particle that has no mass defect.

- (i) State the name of particle X.

..... [1]

- (ii) Show that the energy released when one nucleus of ${}^4_2\text{He}$ is formed in this fusion reaction is $2.8 \times 10^{-12} \text{ J}$.

[3]

- (c) The star in (b) has a radius of $2.3 \times 10^9 \text{ m}$ and a luminosity of $1.4 \times 10^{28} \text{ W}$.
 All the energy released from the formation of ${}^4_2\text{He}$ is radiated away from the star.
 All the energy that is radiated from the star has been released in the formation of ${}^4_2\text{He}$.

Determine:

- (i) the mass of ${}^4_2\text{He}$ produced per unit time by the fusion process

mass per unit time = ... kg s^{-1} [3]

- (ii) the surface temperature of the star.

temperature = ... K [2]

[Total: 11]

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- 10 (a) X-rays for use in medical diagnosis are produced in an X-ray tube. In the X-ray tube, charged particles are accelerated towards a metal target by an applied potential difference (p.d.).

(i) State the name of the charged particles that are accelerated by the applied p.d.

..... [1]

(ii) Explain how X-rays are produced at the metal target.

.....

.....

.....

..... [2]

(iii) Calculate the minimum wavelength of X-rays produced when the applied p.d. is 5.80 kV.

wavelength = ... m [3]

(b) X-rays pass through a medium that has an attenuation coefficient of 1.4 cm^{-1} .

Calculate the percentage of the X-ray energy that is **absorbed** by a 2.8 cm thickness of this medium.

percentage absorbed = ... % [3]

[Total: 9]

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9702/43

May/June 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Data

acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ ($\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$)
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_o = \frac{f_s v}{v \pm v_s}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

gravitational potential	$\phi = -\frac{GM}{r}$
gravitational potential energy	$E_P = -\frac{GMm}{r}$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) (i) Define gravitational field.

.....
 [1]

- (ii) Define electric field.

.....
 [1]

- (iii) State **one** similarity and **one** difference between the gravitational potential due to a point mass and the electric potential due to a point charge.

similarity:

.....

difference:

.....

[2]

- (b) An isolated uniform conducting sphere has mass M and charge Q .
 The gravitational field strength at the surface of the sphere is g .
 The electric field strength at the surface of the sphere is E .

- (i) Show that

$$\frac{M}{Q} = \alpha \frac{g}{E}$$

where α is a constant.

[3]

- (ii) Show that the numerical value of α is $1.35 \times 10^{20} \text{ kg}^2 \text{ C}^{-2}$.

[1]

- (c) Assume that the Earth is a uniform conducting sphere of mass 5.98×10^{24} kg. The surface of the Earth carries a charge of -4.80×10^5 C that is evenly distributed.
- (i) Use the information in (b) to determine the electric field strength at the surface of the Earth. Give a unit with your answer.

electric field strength = ... unit [2]

- (ii) State how the direction of the electric field at the surface of the Earth compares with the direction of the gravitational field.

..... [1]

[Total: 11]

- 2 A steel sphere of mass 0.29 kg is suspended in equilibrium from a vertical spring. The centre of the sphere is 8.5 cm from the top of the spring, as shown in Fig. 2.1.

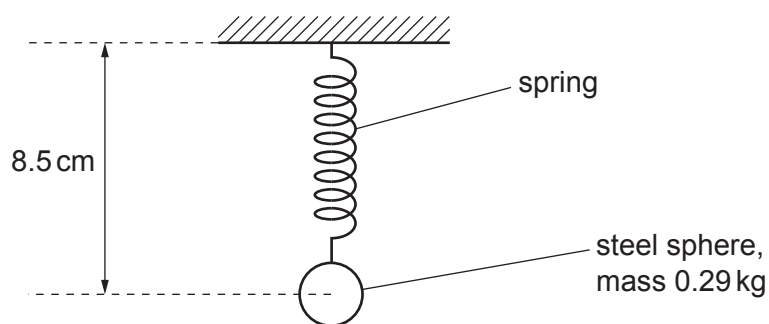


Fig. 2.1

The sphere is now set in motion so that it is moving in a horizontal circle at constant speed, as shown in Fig. 2.2.

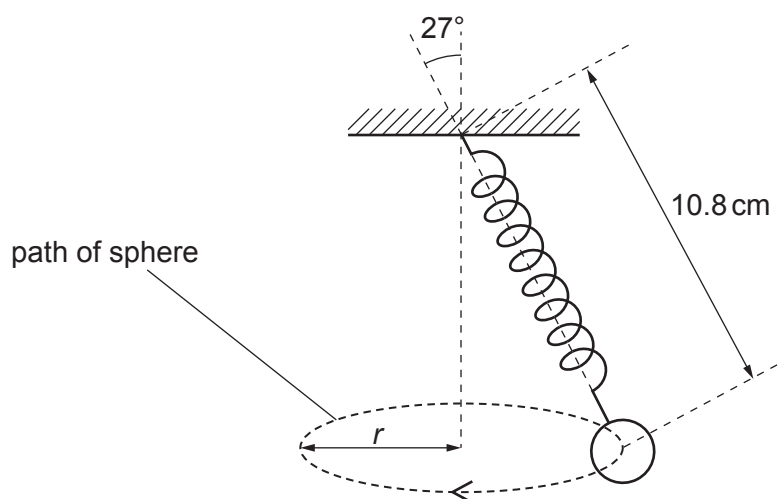


Fig. 2.2

The distance from the centre of the sphere to the top of the spring is now 10.8 cm .

- (a) Explain, with reference to the forces acting on the sphere, why the length of the spring in Fig. 2.2 is greater than in Fig. 2.1.

.....

.....

.....

.....

..... [3]

(b) The angle between the linear axis of the spring and the vertical is 27° .

(i) Show that the radius r of the circle is 4.9 cm.

[1]

(ii) Show that the tension in the spring is 3.2 N.

[2]

(iii) The spring obeys Hooke's law.

Calculate the spring constant, in N cm^{-1} , of the spring.

spring constant = ... N cm^{-1} [2]

(c) (i) Use the information in (b) to determine the centripetal acceleration of the sphere.

centripetal acceleration = ... ms^{-2} [2]

(ii) Calculate the period of the circular motion of the sphere.

period = ... s [2]

[Total: 12]

- 3 (a) State the reason why two objects that are at the same temperature are described as being in thermal equilibrium.

.....
 [1]

- (b) Fig. 3.1 shows the variations with temperature of the densities of mercury and of water between 0 °C and 100 °C.

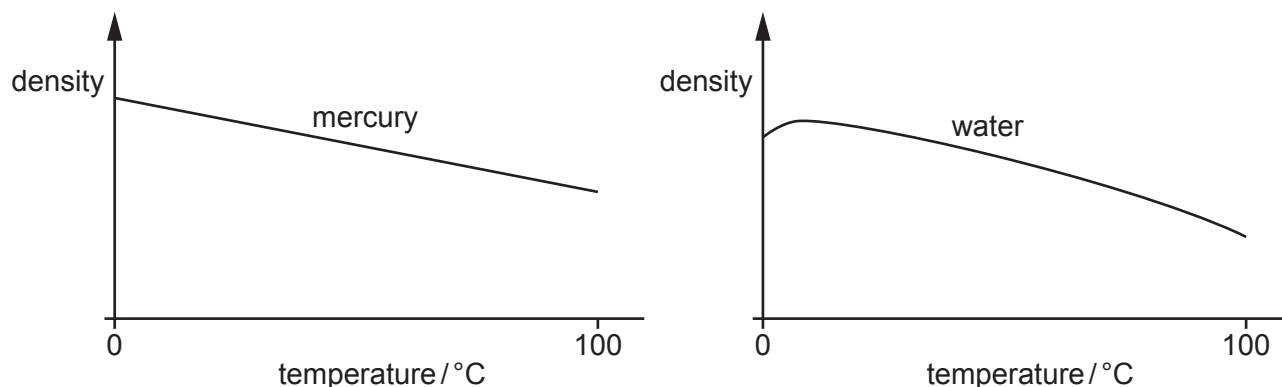


Fig. 3.1

Temperature may be measured using the variation with temperature of the density of a liquid.

Suggest why, for measuring temperature over this temperature range:

- (i) mercury is a suitable liquid

.....
 [1]

- (ii) water is not a suitable liquid.

.....

 [2]

- (c) A beaker contains a liquid of mass 120 g. The liquid is supplied with thermal energy at a rate of 810 W. The beaker has a mass of 42 g and a specific heat capacity of $0.84 \text{ J g}^{-1} \text{ K}^{-1}$. The beaker and the liquid are in thermal equilibrium with each other at all times and are insulated from the surroundings.

Fig. 3.2 shows the variation with time t of the temperature of the liquid.

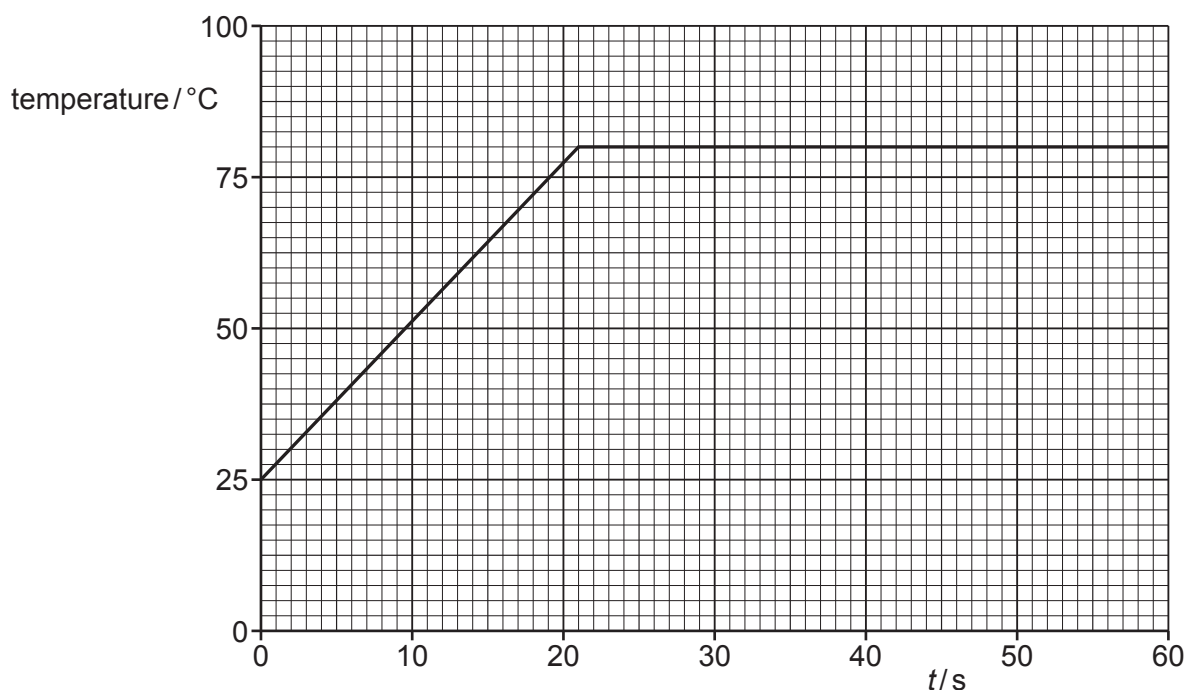


Fig. 3.2

- (i) State the boiling temperature, in °C, of the liquid.

temperature = ... °C [1]

- (ii) Determine the specific heat capacity, in $\text{J g}^{-1} \text{K}^{-1}$, of the liquid.

specific heat capacity = ... $\text{J g}^{-1} \text{K}^{-1}$ [4]

- (d) The experiment in (c) is repeated using water instead of the liquid in (c). The mass of liquid used, the power supplied, and the initial temperature are all unchanged.
The specific heat capacity of water is approximately twice that of the liquid in (c).
The boiling temperature of water is 100 °C.

On Fig. 3.2, sketch the variation with time t of the temperature of the water between $t = 0$ and $t = 60$ s. Numerical calculations are not required. [2]

[Total: 11]

- 4 (a) State **two** of the basic assumptions of the kinetic theory of gases.

1

.....

2

.....

[2]

- (b) An ideal gas has amount of substance n .

The gas is initially in state X, with pressure $2p$ and volume V .

The gas is cooled at constant volume to state Y, with pressure p .

The gas is then heated at constant pressure to state Z, with volume $2V$.

Finally, the gas returns at constant temperature to state X.

- (i) Determine an expression for the temperature T of the gas in state X, in terms of n , p and V .
Identify any other symbols that you use.

[2]

- (ii) On Fig. 4.1, sketch the variation with volume of pressure for the gas as the gas undergoes the three changes. The state X is labelled. Label states Y and Z.

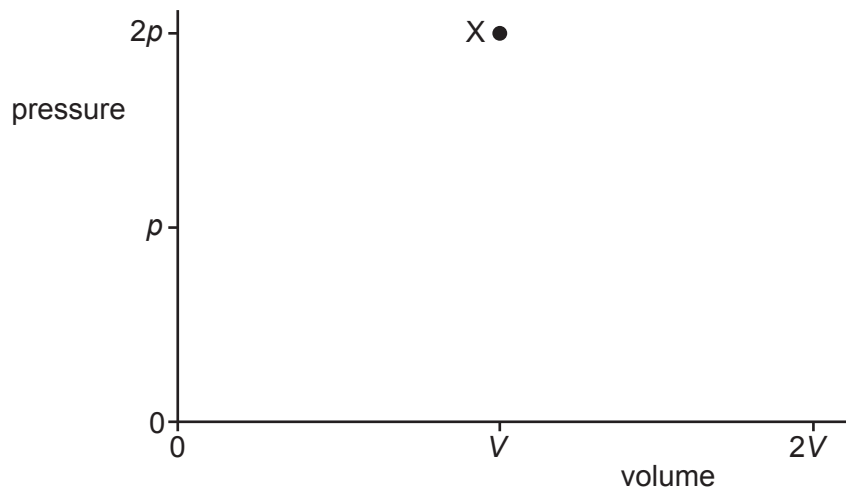


Fig. 4.1

[3]

- (iii) During the change of state from Y to Z, the increase in internal energy of the gas is U .
During the change of state from Z to X, the work done on the gas is W .

Complete Table 4.1 to indicate, for each of the three changes of state, the increase in internal energy of the gas, the thermal energy transferred to the gas and the work done on the gas, in terms of p , V , U and W .

Table 4.1

change	increase in internal energy of gas	thermal energy transferred to gas	work done on gas
X to Y			
Y to Z	$+U$		
Z to X			$+W$

[5]

[Total: 12]

5 Part of an electric circuit is shown in Fig. 5.1.

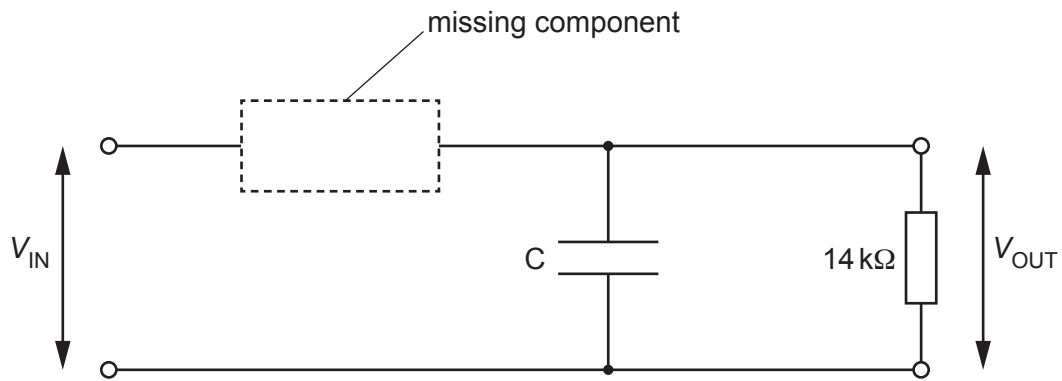


Fig. 5.1

The circuit is used to produce half-wave rectification of an alternating voltage of potential difference (p.d.) V_{IN} .

The output p.d. across the $14\text{ k}\Omega$ resistor is V_{OUT} .

(a) (i) A component is missing from the circuit of Fig. 5.1.

Complete the circuit diagram in Fig. 5.1 by adding the circuit symbol for the missing component, correctly connected. [1]

(ii) A capacitor C is shown in the circuit of Fig. 5.1.

State the effect on V_{OUT} of including the capacitor in the circuit.

..... [1]

(b) Fig. 5.2 shows the variation with time t of V_{IN} .

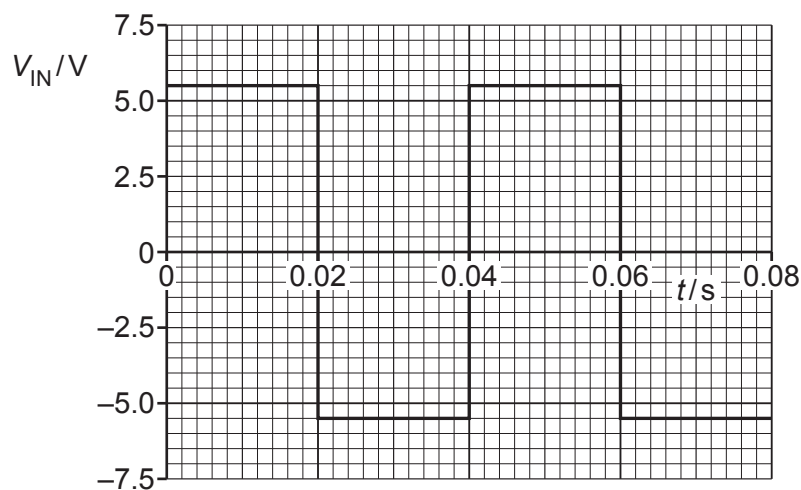


Fig. 5.2

Fig. 5.3 shows the variation with t of V_{OUT} .

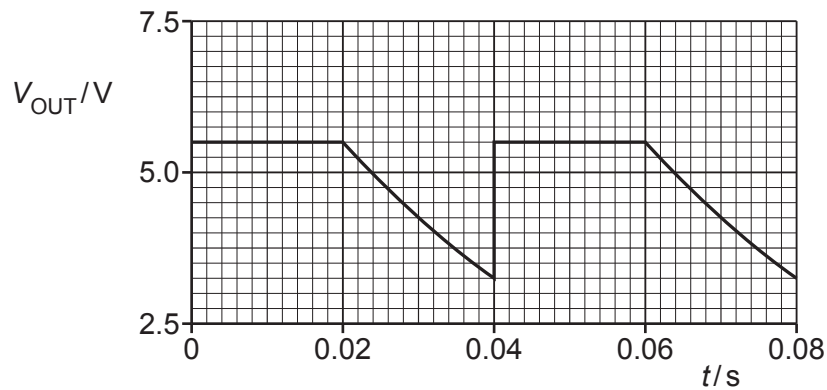


Fig. 5.3

- (i) Determine the frequency of V_{IN} .

frequency = ... Hz [1]

- (ii) Show that the time constant τ for the discharge of the capacitor through the resistor is 0.038 s.

[2]

- (iii) Calculate the capacitance of C. Give a unit with your answer.

capacitance = ... unit [2]

- (c) The circuit of Fig. 5.1 is modified so that it produces full-wave rectification of an input voltage.

Suggest, with a reason, how V_{OUT} now varies with time when V_{IN} is as shown in Fig. 5.2.

.....

 [2]

[Total: 9]

- 6 (a) State what is meant by a magnetic field.

.....

.....

..... [2]

- (b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

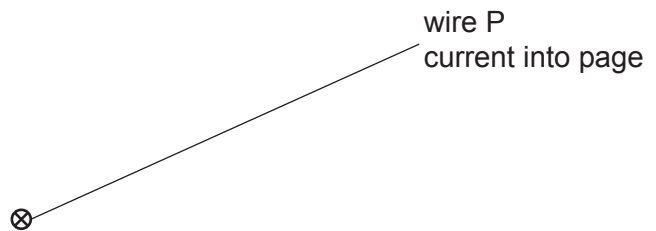


Fig. 6.1

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. [3]

- (c) A second long, straight wire Q, carrying a current of 5.0A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

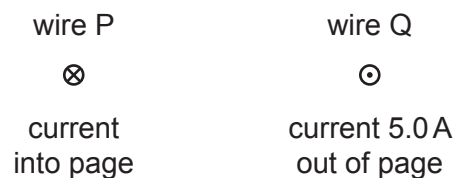


Fig. 6.2

The flux density of the magnetic field at wire Q due to the current in wire P is 2.6 mT.

- (i) Calculate the magnetic force per unit length exerted on wire Q by wire P.

force per unit length = ... Nm^{-1} [2]

- (ii) State the direction of the force exerted on wire Q by wire P.

..... [1]

- (iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning.

current = ... A [2]

[Total: 10]

- 7 (a) State what is meant by the de Broglie wavelength.

.....
 [1]

- (b) Fig. 7.1 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

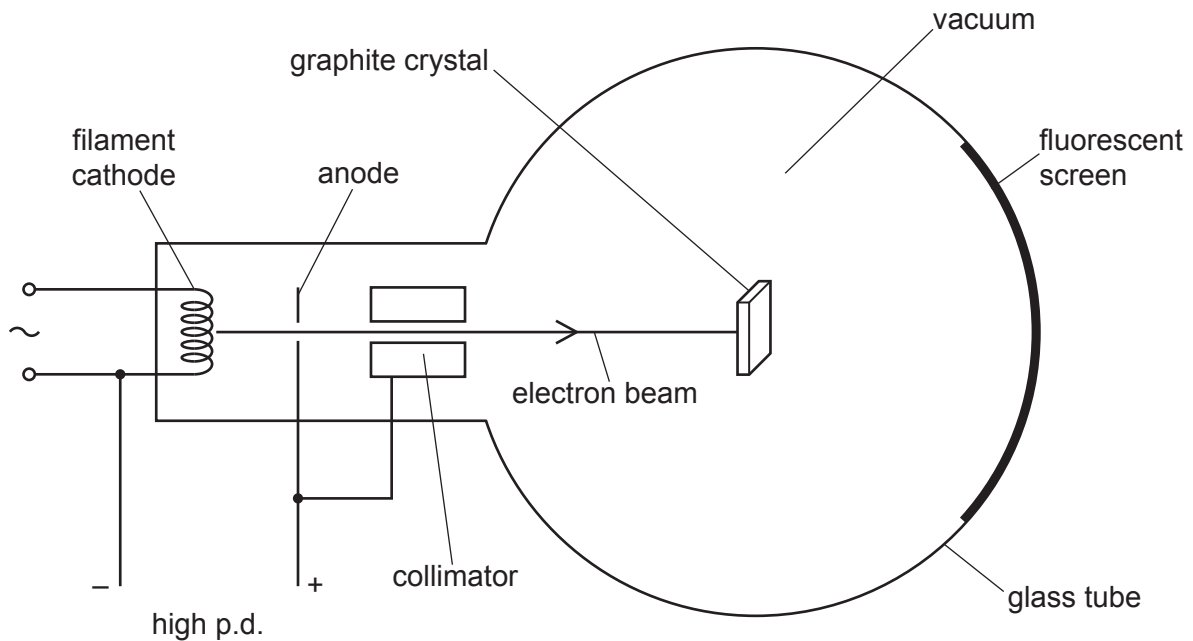


Fig. 7.1 (not to scale)

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 7.2 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 7.1.

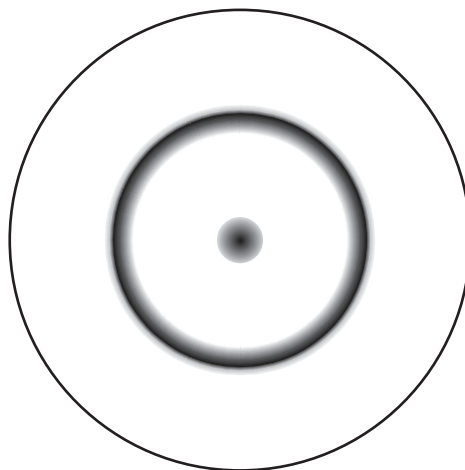


Fig. 7.2

- (i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 7.2.

..... [1]

- (ii) Explain what can be concluded from the pattern in Fig. 7.2 about the nature of electrons.

.....

.....

..... [2]

- (c) The electrons in (b) are now accelerated through a greater potential difference between the cathode and the anode.

- (i) On Fig. 7.3, sketch the pattern that is now seen on the fluorescent screen in Fig. 7.1.

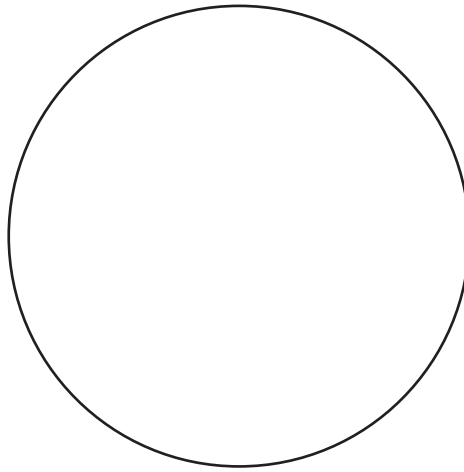


Fig. 7.3

[2]

- (ii) Explain, with reference to de Broglie wavelength, the change in the pattern on the fluorescent screen.

.....

.....

.....

.....

..... [3]

[Total: 9]

- 8 (a) Table 8.1 shows some data relating to the properties of air, gel and body tissue. The data are given to three significant figures.

Table 8.1

material	density / kg m^{-3}	speed of sound / m s^{-1}	specific acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$
air		340	440
gel	1200	1400	
tissue	1090		1.68×10^6

- (i) Show that the specific acoustic impedance of gel is $1.68 \times 10^6 \text{ kg m}^{-2} \text{s}^{-1}$.

[1]

- (ii) Complete Table 8.1 by calculating the missing values to three significant figures. Use the space below for any working that you need.

[2]

- (b) Use the information in (a) to calculate the intensity reflection coefficient for:

- (i) an air–tissue boundary

intensity reflection coefficient = ... [2]

- (ii) a gel–tissue boundary.

intensity reflection coefficient = ... [1]

(c) Use your answers in (b) to explain why gel is applied to the skin during ultrasound scanning.

.....

.....

..... [2]

[Total: 8]

- 9 Carbon-11 is radioactive and decays by β^+ emission to form boron-11. Carbon-11 has a half-life of 20 minutes. Boron-11 is stable.

(a) Define half-life.

.....
 [1]

(b) A sample contains N_0 nuclei of carbon-11 and no other nuclei at time $t = 0$.

On Fig. 9.1, sketch the variation with t of the number of nuclei of **boron-11** in the sample.

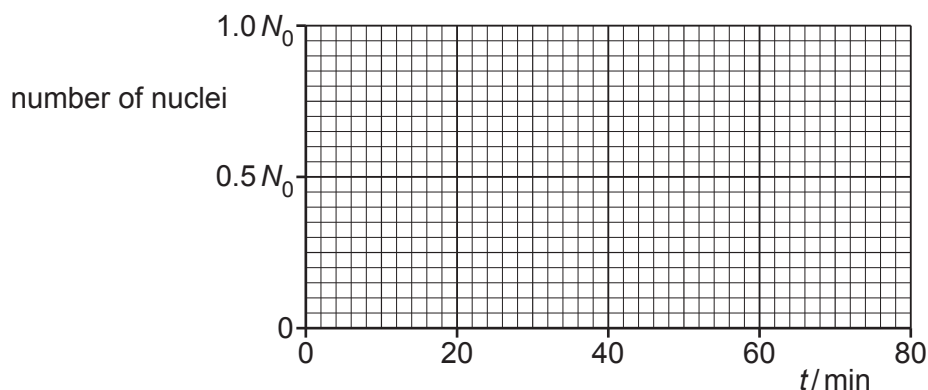


Fig. 9.1

[3]

(c) (i) Explain, with reference to the random nature of radioactive decay, why the activity of the carbon-11 sample in (b) decreases with time.

.....

 [2]

(ii) State, with reasons, whether a radiation detector placed near to the sample of carbon-11 indicates a measured count rate from the sample that is less than, the same as or greater than the activity of the sample.

.....

 [3]

[Total: 9]

- 10 (a) State Hubble's law. Identify any symbols that you use.

.....

.....

.....

..... [2]

- (b) A star of luminosity $3.8 \times 10^{31} \text{ W}$ is a distance of $1.8 \times 10^{24} \text{ m}$ from the Earth.

Calculate the radiant flux intensity at the Earth of the radiation emitted by the star.

radiant flux intensity = ... W m^{-2} [2]

- (c) The star in (b) is in a distant galaxy. A spectral line in the light from this galaxy is known to have a wavelength of 486 nm. This spectral line in the light from the galaxy observed on the Earth has a wavelength of 492 nm.

- (i) Explain why the wavelength observed on the Earth is different from the wavelength that the galaxy is known to have emitted.

.....

.....

..... [2]

- (ii) Determine a value for the Hubble constant H_0 .

$H_0 = \dots\dots\dots \text{ s}^{-1}$ [3]

[Total: 9]

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