1 (a) Define gravitational potential at a point.

....

....

.... [2]

(b) A uniform spherical planet has radius R. The gravitational potential at its surface is $-\phi$. P is a point on a line that passes through the centre of the planet, at variable displacement x from the centre, as shown in Figure 1.1.

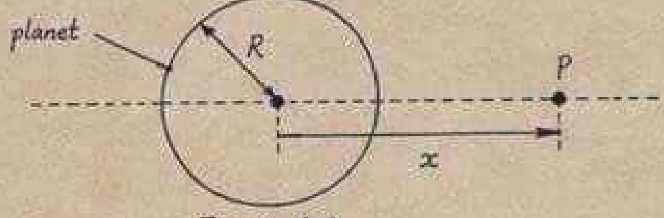


Figure 1.1

Figure 1.2 shows the variation with x of the gravitational potential ϕ due to the planet in the region outside the planet close to its surface.

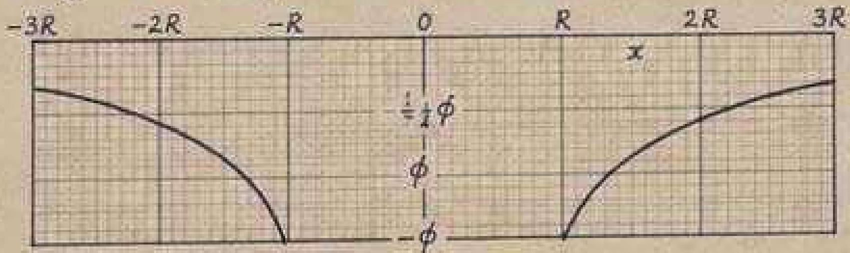


Figure 1.2

(i) Explain why ϕ is negative for all values of x.

....

....

.... [2]

(ii) State an expression, in terms of ϕ and R, for the mass M of the planet. Identify any other symbols that you use.

M = ... [2]

(iii) Determine an expression, in terms of ϕ and R, for the gravitational field strength g_0 at the surface of the planet.

g_0 = ... [1]

(iv) On Figure 1.3, sketch the variation of the gravitational field g with x between $x = -3R$ and $x = 3R$. Do not include the region inside the sphere between $x = -R$ and $x = R$.

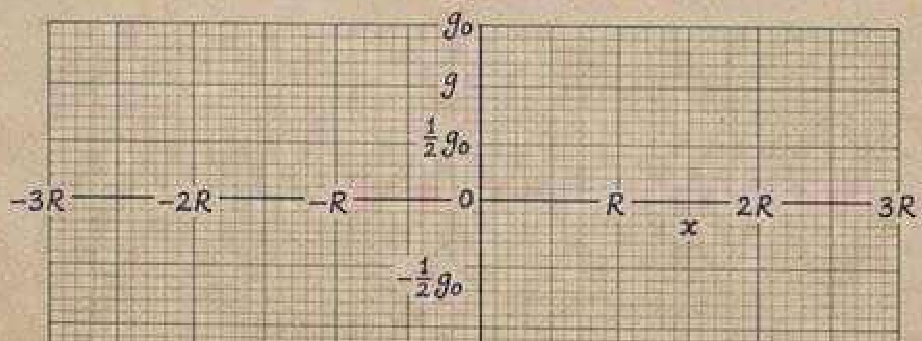


Figure 1.3

[3]

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

....

....

.... [2]

(b) Ideal gases may be used to measure the temperature of the environment in a laboratory experiment. In some situations, however, it is preferable to use a thermocouple thermometer.

(i) Explain how a thermometer that uses an ideal gas can be advantageous compared with a thermometer that uses a liquid in glass.

....

....

.... [1]

(ii) Describe a laboratory situation in which a thermocouple thermometer is preferable to a thermometer that uses an ideal gas.

....

....

.... [1]

(c) A very small sample of an ideal gas consists of five molecules, each of mass 3.34×10^{-27} kg. At a particular instant, the speeds of the molecules are as shown in Figure 2.1.

$357\ m\,s^{-1}$	$424\ m\,s^{-1}$	$509\ m\,s^{-1}$	$286\ m\,s^{-1}$	$435\ m\,s^{-1}$

Figure 2.1

Determine, to three significant figures, the root-mean-square (r.m.s.) speed c_0 of the molecules.

c_0 = ... $m\,s^{-1}$ [2]

(d) A larger sample of the gas in 2(c) consists of 5.0×10^{23} molecules. These molecules have the same r.m.s. speed as the molecules of the gas in 2(c).

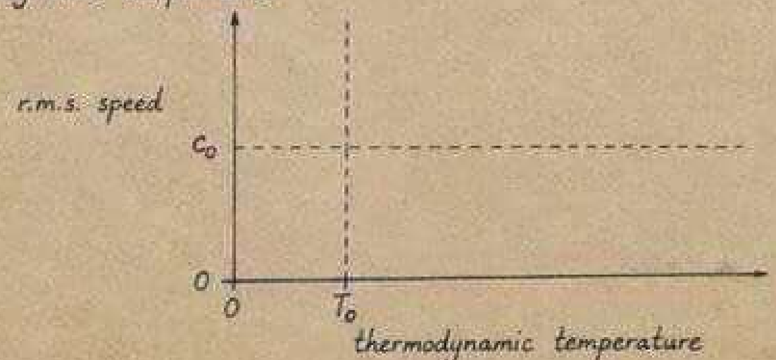
(i) Calculate the amount of gas.

amount of gas = ... mol [2]

(ii) Determine the thermodynamic temperature T_0 of the gas.

T_0 = ... K [2]

(iii) The temperature of the gas is now gradually increased.
On Figure 2.2, sketch the variation of the r.m.s. speed of the molecules of the gas with thermodynamic temperature.

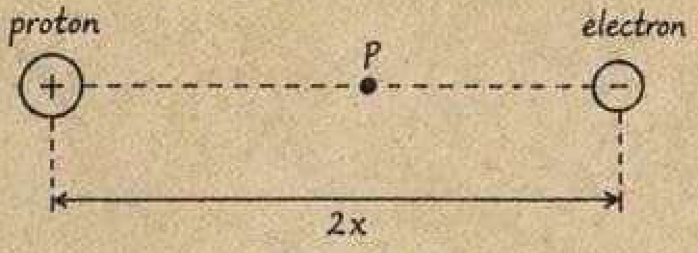


[3]

Figure 2.2

[Total: 13]

4 A hydrogen atom consists of a proton and an electron separated by distance $2x$, as shown in Figure 4.1.



not to scale

Figure 4.1

Point P is at the midpoint of the line joining the centres of the proton and the electron.

(a) (i) For point P, compare the electric field due to the proton with the electric field due to the electron.

....

....

....

....

.... [3]

(ii) For point P, compare the electric potential due to the proton with the electric potential due to the electron.

....

....

....

....

.... [3]

(b) (i) The elementary charge is e and the permittivity of free space is ε_0.

State an expression, in terms of x, e and ε_0, for the magnitude of the electric force F between the proton and the electron.

$F =$ .... [2]

(ii) Determine an expression, in terms of F and x, for the electric potential energy E_p of the proton and the electron.

$E_p =$ .... [1]

[Total: 9]

5 (a) Define the capacitance of a parallel plate capacitor.

....

....

.... [2]

(b) Two capacitors X and Y have capacitances C_X and C_Y respectively. The capacitors are connected in parallel to a supply that has electromotive force (e.m.f.) E, as shown in Figure 5.1.

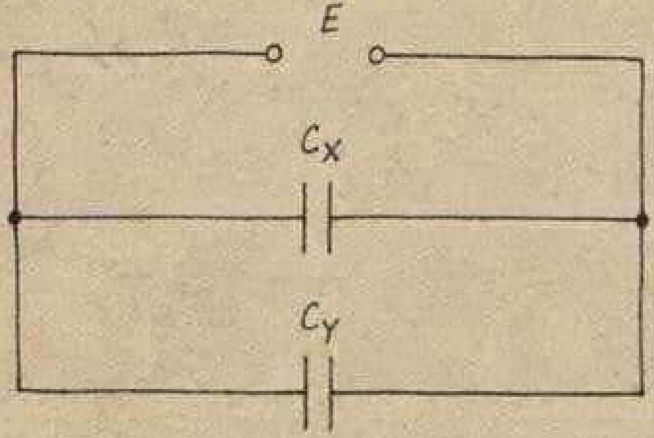


Figure 5.1

Derive the expression for the relationship between C_X, C_Y and the combined capacitance C_T of the circuit.

[3]

(c) Two capacitors are connected in series to a supply that has e.m.f. 6.00 V.

One of the capacitors has capacitance C and the other has capacitance 2C.

The total energy stored by the two capacitors is 1.30 mJ.

Calculate C in μF.

C = ... μF [3]

[Total: 8]

6 (a) Define magnetic flux density.

....

....

.... [2]

(b) Figure 6.1 shows a beam of charged particles in a device known as a mass spectrometer.

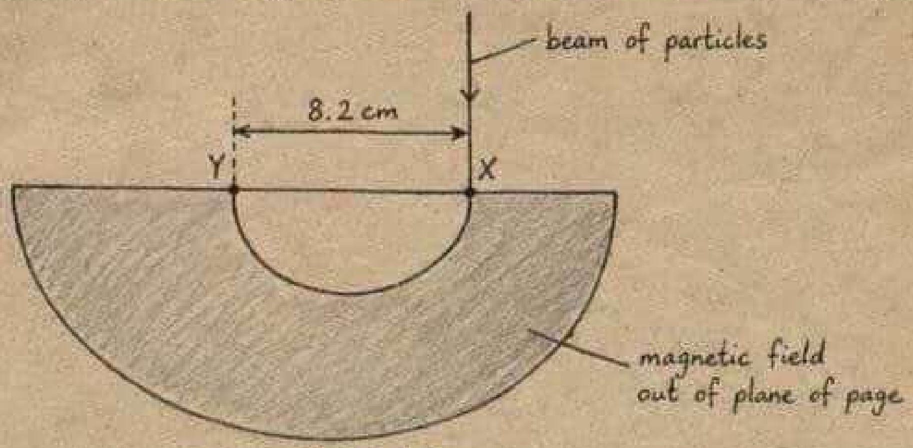


Figure 6.1

The shaded region contains a uniform magnetic field that is out of the plane of the page. The particles enter the region of the magnetic field at point X and strike a detector at point Y.

(i) Explain whether the sign of the charge on the particles is positive or negative.

....

....

.... [2]

(ii) Explain why the path followed by the beam of particles inside the magnetic field is circular.

....

....

.... [2]

(c) Each of the particles in 6(b) has a mass of 2.0×10^{-26} kg and a charge of magnitude 3.2×10^{-19} C. All of the particles have a speed of 7.3×10^{4} m s^{-1}.

The distance XY is 8.2 cm.

(i) Show that the centripetal acceleration of one of the particles is 1.3×10^{11} m s^{-2}.

[2]

(ii) Use the information in 6(c)(i) to determine the flux density B of the uniform magnetic field. Give a unit with your answer.

B = ... unit .... [2]

(d) The particles in 6(b) are replaced with particles that have half of the charge and a quarter of the mass of the particles in 6(b). The sign of the charge and the speed of the particles are both unchanged.

On Figure 6.1, draw the path of this beam of particles. [2]

[Total: 12]

7 (a) (i) State what is meant by half-wave rectification of an alternating current.

....

....

.... [2]

(ii) Figure 7.1 shows an incomplete diagram of the circuit used to achieve half-wave rectification of an alternating input voltage V_{IN} to produce output voltage V_{OUT}.

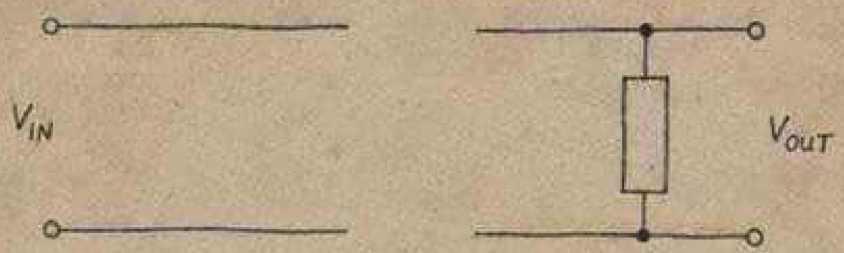


Figure 7.1

Complete the circuit diagram in Figure 7.1. [2]

(b) Two alternating voltages V_1 and V_2 have the same peak voltage V_0 and the same period T. One is sinusoidal and the other is a square wave, as shown by the variations with time t in Figure 7.2 and Figure 7.3.

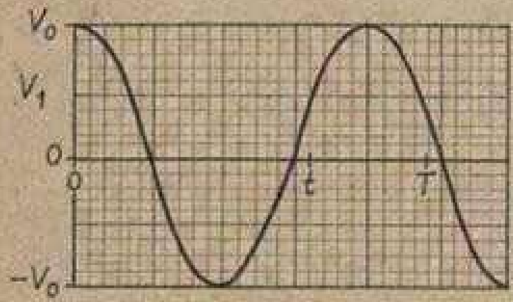


Figure 7.2

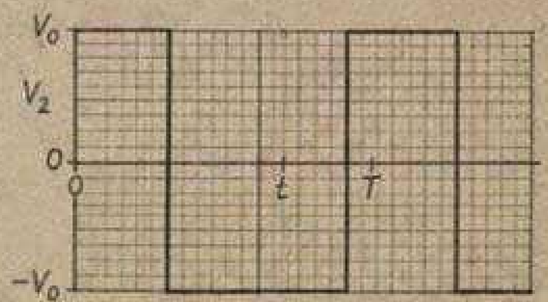


Figure 7.3

The alternating voltages are applied in turn to the input terminals in the completed circuit of Figure 7.1.

Complete Table 7.1 to show, in terms of V_0, expressions for the root-mean-square (r.m.s.) values of the two unrectified and the two half-wave rectified voltages.

Table 7.1

	r.m.s. value	
	V_1	V_2
unrectified		
half-wave rectified		

[4]

[Total: 8]

8 (a) State what is meant by a photon.

....

....

.... [2]

(b) X-rays for use in medical diagnosis are produced by accelerating charged particles towards a metal target.

(i) State the name of the charged particles.

.... [1]

(ii) Describe how X-rays are formed at the target.

....

....

.... [2]

(iii) For any given accelerating voltage, there is a range of wavelengths of X-rays produced that has a minimum value.

Explain, with reference to photons, why there is a range of wavelengths and why this range has a minimum value.

....

....

....

....

.... [3]

(iv) Calculate the minimum wavelength of X-rays produced when the accelerating voltage is 52.0kV.

minimum wavelength = ... m [3]

(c) X-rays are used to create an image of the internal structure of an object that is made from two types of material of similar thickness.

Describe and explain how a property of the materials determines whether or not the image produced has good contrast.

....

....

.... [2]

[Total: 13]

9 (a) Define the mass defect of a nucleus.

....

....

.... [2]

(b) Thorium-228 ($^{228}_{90}Th$) is radioactive.

Table 9.1 shows the mass defects of thorium-228 and some other nuclides.

Table 9.1

nuclide	mass defect / u
$^{4}_{2}He$	0.030377
$^{224}_{88}Ra$	1.846840
$^{228}_{89}Ac$	1.869820
$^{228}_{90}Th$	1.871290
$^{228}_{91}Pa$	1.866129

(i) Use the data in Table 9.1 to explain why thorium-228 is an α-emitter and not a β^- emitter or a β^+ emitter.

....

....

.... [4]

(ii) Calculate the energy, in MeV, released by the α-decay of one thorium-228 nucleus. Give your answer to three significant figures.

energy = ... MeV [3]

[Total: 9]

Turn over

10 (a) State Wien's displacement law.

....

....

.... [2]

(b) The Sun has a radius of 6.96×10^8 m and a surface temperature of 5770 K.

The Earth is at a distance of 1.52×10^{11} m from the Sun.

(i) Calculate the luminosity of the Sun.

luminosity = ... W [2]

(ii) Determine the radiant flux intensity at the Earth of radiation emitted by the Sun. Give a unit with your answer.

radiant flux intensity = ... unit .... [3]

(iii) Star X has a wavelength of maximum emission of $0.581\lambda_s$, where λ_s is the wavelength of maximum emission from the Sun.

Calculate the surface temperature of star X.

surface temperature = ... K [1]

[Total: 8]