 

**Data**

| | |
|---|---|
| speed of light in free space | $c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$ |
| permeability of free space | $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$ |
| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$ |
| | $(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$ |
| elementary charge | $e = 1.60 \times 10^{-19}\,\mathrm{C}$ |
| the Planck constant | $h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$ |
| unified atomic mass unit | $1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$ |
| rest mass of electron | $m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$ |
| rest mass of proton | $m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$ |
| molar gas constant | $R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$ |
| the Avogadro constant | $N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$ |
| the Boltzmann constant | $k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}\,\mathrm{N\,m^{2}\,kg^{-2}}$ |
| acceleration of free fall | $g = 9.81\,\mathrm{m\,s^{-2}}$ |



 

 

**Formulae**

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$<br>$v^2 = u^2 + 2as$ |
| work done on/by a gas | $W = p\Delta V$ |
| gravitational potential | $\phi = -\frac{Gm}{r}$ |
| hydrostatic pressure | $p = \rho gh$ |
| 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. | $v = v_0 \cos \omega t$<br>$v = \pm \omega \sqrt{(x_0^2 - x^2)}$ |
| Doppler effect | $f_o = \frac{f_s v}{v \pm v_s}$ |
| electric potential | $V = \frac{Q}{4\pi\varepsilon_0 r}$ |
| capacitors in series | $1/C = 1/C_1 + 1/C_2 + \ldots$ |
| capacitors in parallel | $C = C_1 + C_2 + \ldots$ |
| energy of charged capacitor | $W = \frac{1}{2}QV$ |
| electric current | $I = Anvq$ |
| resistors in series | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| Hall voltage | $V_H = \frac{BI}{ntq}$ |
| alternating current/voltage | $x = x_0 \sin \omega t$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \frac{0.693}{t_{\frac{1}{2}}}$ |



 

 

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Answer **all** the questions in the spaces provided.

**1** **(a)** **(i)** State what is meant by a *field of force*.

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**(ii)** Define *gravitational field strength*.

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**(b)** An isolated planet may be assumed to be a uniform sphere of radius $3.39 \times 10^6$ m with its mass of $6.42 \times 10^{23}$ kg concentrated at its centre.

Calculate the gravitational field strength at the surface of the planet.



field strength = ............................................ $N\,kg^{-1}$ [3]

**(c)** Calculate the height above the surface of the planet in **(b)** at which the gravitational field strength is 1.0% less than its value at the surface of the planet.

height = .................................................... m [3]

[Total: 9]

 

**2** **(a)** The first law of thermodynamics may be expressed as

$$\Delta U = (+q) + (+w)$$

where $\Delta U$ is the increase in internal energy of the system.

State the meaning of:

$+q$ ..........................................................................................................................

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$+w$. ..........................................................................................................................

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[2]

**(b)** The variation with pressure $p$ of the volume $V$ of a fixed mass of an ideal gas is shown in Fig. 2.1.

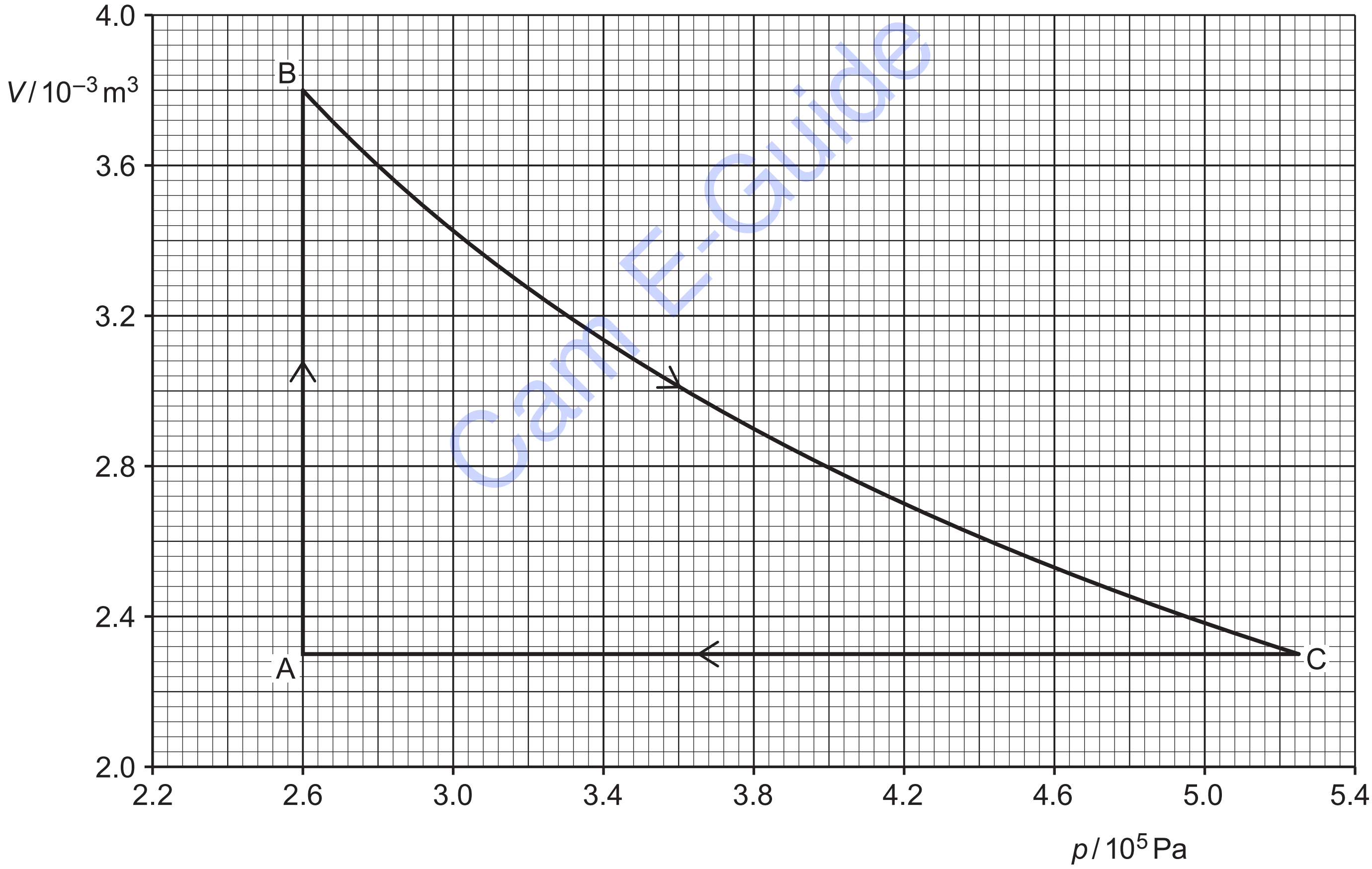


**Fig. 2.1**

The gas undergoes a cycle of changes A to B to C to A.

During the change A to B, the volume of the gas increases from $2.3 \times 10^{-3}\,m^3$ to $3.8 \times 10^{-3}\,m^3$.

 

 

**(i)** Show that the magnitude of the work done during the change A to B is 390 J.

[1]

**(ii)** State and explain the total change, if any, in the internal energy of the gas during one complete cycle.

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**(c)** During the change A to B, 1370 J of thermal energy is transferred to the gas.

During the change B to C, no thermal energy enters or leaves the gas. The work done on the gas during this change is 550 J.

Use these data and the information in **(b)** to complete Table 2.1.



**Table 2.1**

| change | $q$ / J | $w$ / J | $\Delta U$ / J |
|---|---|---|---|
| A to B | .......................... | .......................... | .......................... |
| B to C | .......................... | .......................... | .......................... |
| C to A | .......................... | .......................... | .......................... |

[4]

[Total: 9]

 

 

**3** A pendulum consists of a metal sphere P suspended from a fixed point by means of a thread, as illustrated in Fig. 3.1.

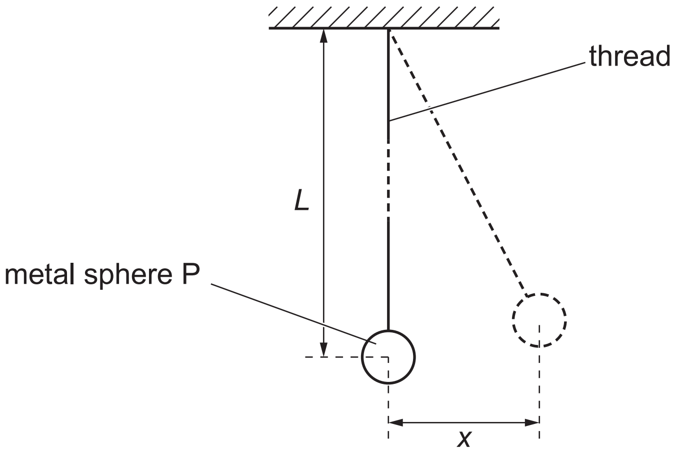


**Fig. 3.1**

The centre of gravity of sphere P is a distance *L* from the fixed point.

The sphere is pulled to one side and then released so that it oscillates. The sphere may be assumed to oscillate with simple harmonic motion.

**(a)** State what is meant by *simple harmonic motion*.

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**(b)** The variation of the velocity *v* of sphere P with the displacement *x* from its mean position is shown in Fig. 3.2.

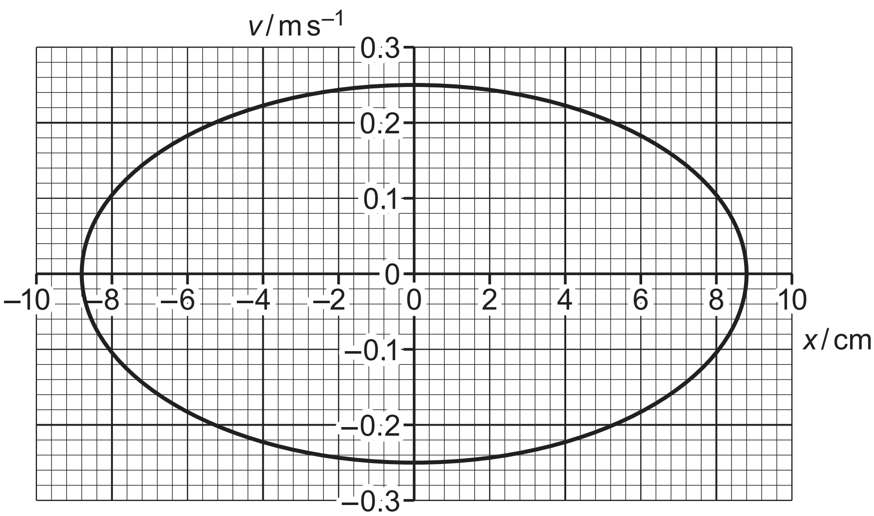


**Fig. 3.2**

 

 

Use Fig. 3.2 to determine the frequency *f* of the oscillations of sphere P.

*f* = .................................................... Hz [3]

**(c)** The period *T* of the oscillations of sphere P is given by the expression

$$T = 2\pi\sqrt{\left(\frac{L}{g}\right)}$$

where *g* is the acceleration of free fall.

Use your answer in **(b)** to determine the length *L*.



*L* = .................................................... m [2]

**(d)** Another pendulum consists of a sphere Q suspended by a thread. Spheres P and Q are identical. The thread attached to sphere Q is longer than the thread attached to sphere P.

Sphere Q is displaced and then released. The oscillations of sphere Q have the same amplitude as the oscillations of sphere P.

On Fig. 3.2, sketch the variation of the velocity *v* with displacement *x* for sphere Q. [2]

[Total: 9]

 

 

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**4** **(a)** Explain the principles of the **generation** of ultrasound waves for use in medical diagnosis.

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**(b)** The linear attenuation (absorption) coefficient for a parallel beam of ultrasound waves in air is $1.2\,\text{cm}^{-1}$.

The parallel beam passes through a layer of air of thickness 3.5 cm.

Calculate the ratio, in dB,

$$\frac{\text{intensity of beam after passing through the layer of air}}{\text{intensity of beam entering the layer of air}}.$$



ratio = .................................................... dB [4]

[Total: 8]

 

**5** **(a)** Define *electric potential* at a point.

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**(b)** Two point charges A and B are separated by a distance of 12.0 cm in a vacuum, as illustrated in Fig. 5.1.

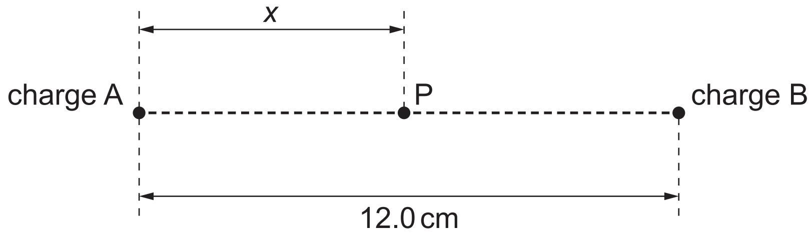


**Fig. 5.1**

The charge of A is $+2.0 \times 10^{-9}$ C.

A point P lies on the line joining charges A and B. Its distance from charge A is $x$.

The variation with distance $x$ of the electric potential $V$ at point P is shown in Fig. 5.2.

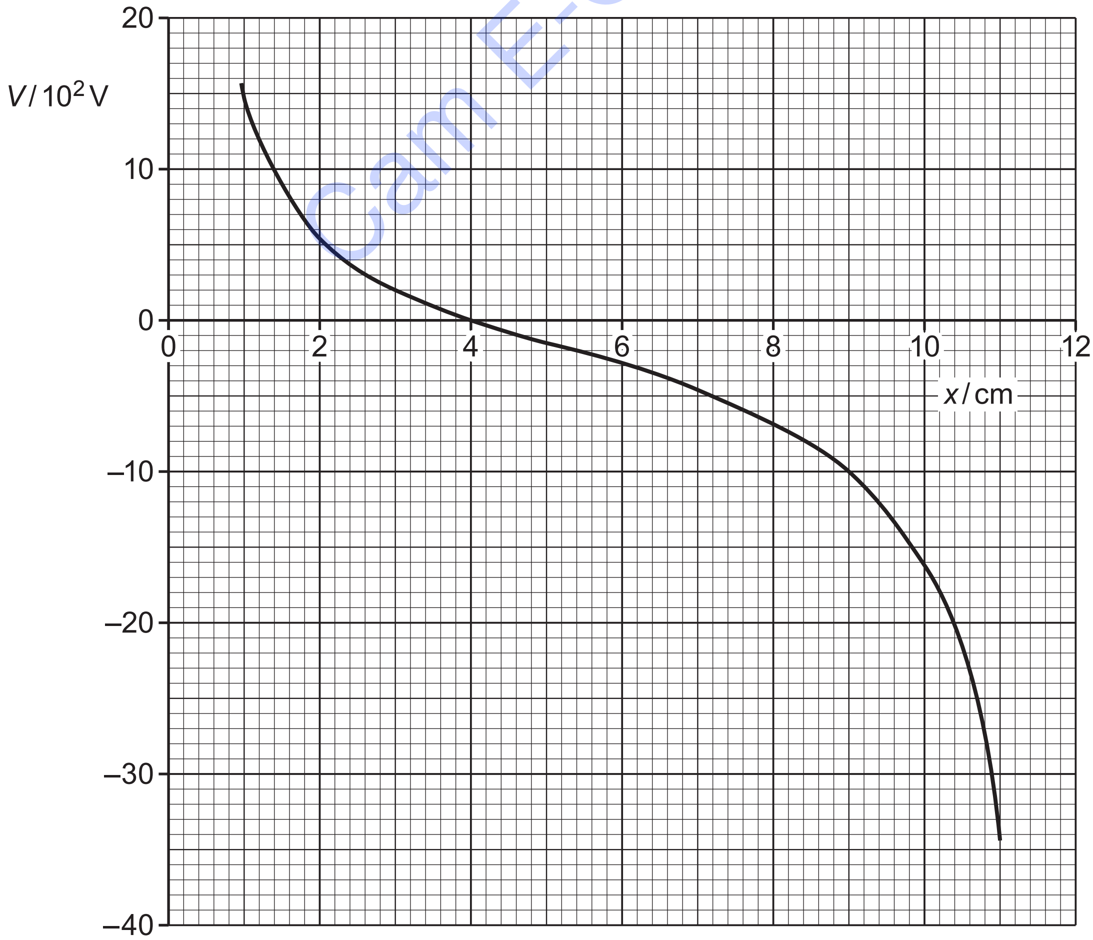


**Fig. 5.2**

 

 

Use Fig. 5.2 to determine:

**(i)** the charge of B

charge = .................................................... C [3]

**(ii)** the change in electric potential when point P moves from the position where $x$ = 9.0 cm to the position where $x$ = 3.0 cm.

change = .................................................... V [1]

**(c)** An $\alpha$-particle moves along the line joining point charges A and B in Fig. 5.1.

The $\alpha$-particle moves from the position where $x$ = 9.0 cm and just reaches the position where $x$ = 3.0 cm.

Use your answer in **(b)(ii)** to calculate the speed $v$ of the $\alpha$-particle at the position where $x$ = 9.0 cm.

$v$ = ............................................... $\mathrm{m\,s^{-1}}$ [3]

[Total: 9]



 

 

**6** **(a)** **(i)** Define the *capacitance* of a parallel plate capacitor.

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**(ii)** State **three** functions of capacitors in electrical circuits.

1. ..............................................................................................................................

2. ..............................................................................................................................

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

**(b)** A student has available four capacitors, each of capacitance 24 μF.

The capacitors are connected as shown in Fig. 6.1.

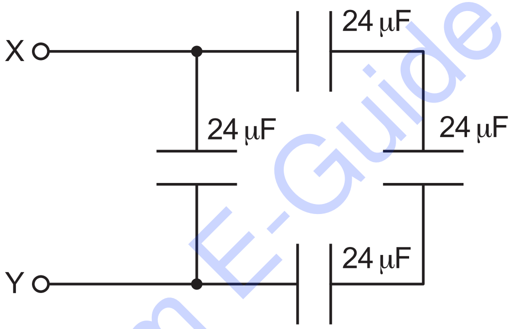


**Fig. 6.1**

Calculate the combined capacitance between the terminals X and Y.

capacitance = ................................................... μF [2]

[Total: 7]

 

 

**7** An ideal operational amplifier (op-amp) is to be used in a comparator circuit.
Part of the comparator circuit is shown in Fig. 7.1.

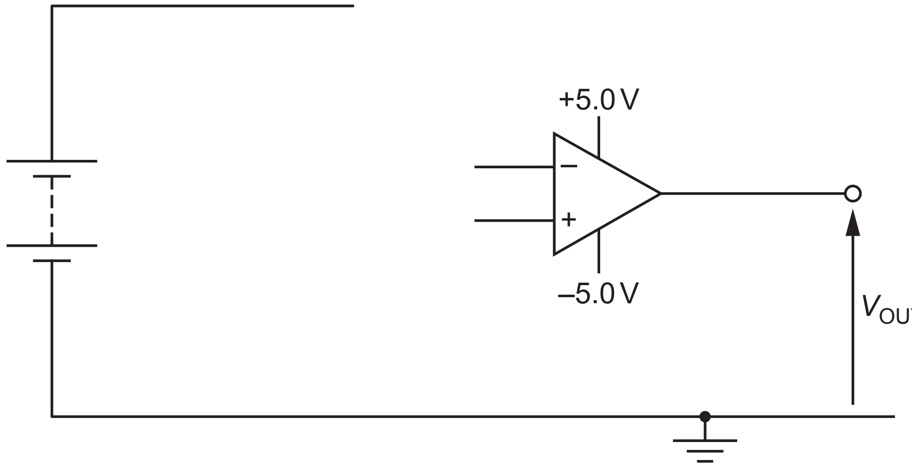


**Fig. 7.1**

Three resistors, each of resistance 1000 Ω, and a negative temperature coefficient thermistor are available to complete the circuit.

The circuit is to be designed so that, at low temperatures, the output $V_{OUT}$ is –5.0 V and at higher temperatures, the output $V_{OUT}$ is to be +5.0 V.

**(a)** On Fig. 7.1, draw the input circuit to the inverting and non-inverting inputs of the op-amp. [4]

**(b)** State a suitable value for the thermistor resistance when the thermistor is at:

**(i)** low temperature where $V_{OUT}$ is –5.0 V

.............................................................................................................................. [1]

**(ii)** a higher temperature where $V_{OUT}$ is +5.0 V.

.............................................................................................................................. [1]

[Total: 6]



 

 

**8** A slice of a conducting material has its face QRLK normal to a uniform magnetic field of flux density *B*, as illustrated in Fig. 8.1.

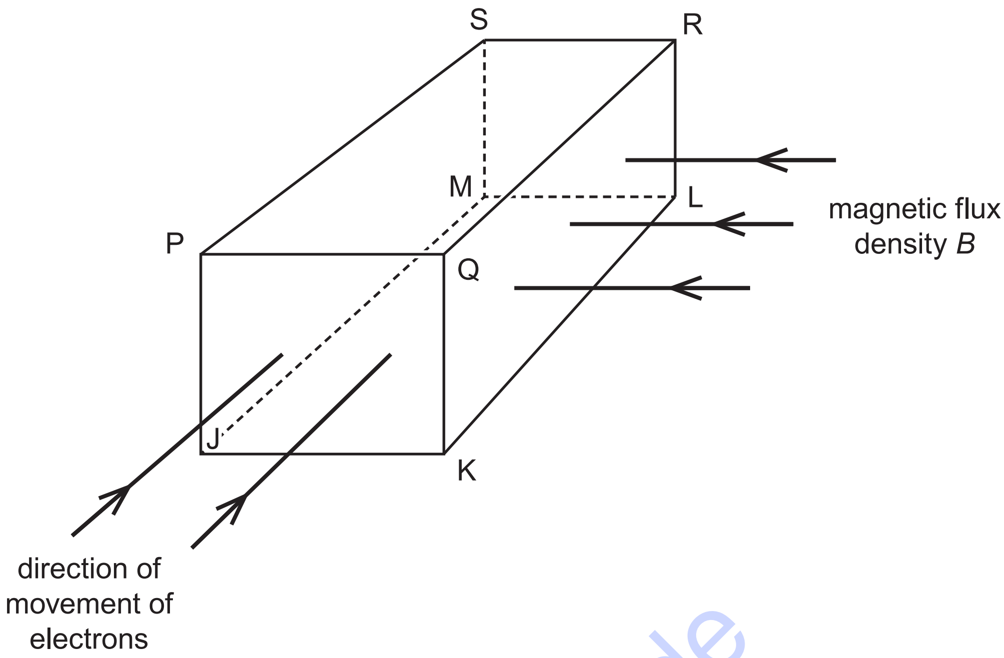


**Fig. 8.1**



Electrons enter the slice travelling perpendicular to face PQKJ.

**(a)** For the free electrons moving in the slice:

**(i)** state the direction of the force on an electron due to movement of the electron in the magnetic field

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**(ii)** identify the faces, using the letters on Fig. 8.1, between which a potential difference is developed.

face ................................ and face ................................ [1]

**(b)** Explain why the potential difference in **(a)(ii)** reaches a maximum value.

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**(c)** The number of free electrons per unit volume in the slice of material is $1.3 \times 10^{29}\,m^{-3}$.
The thickness PQ of the slice is 0.10 mm.
The magnetic flux density $B$ is $4.6 \times 10^{-3}\,T$.

Calculate the potential difference across the slice for a current of $6.3 \times 10^{-4}\,A$.

potential difference = .................................................... V [2]

**(d)** The slice in **(c)** is a metal.

By reference to your answer in **(c)**, suggest why Hall probes are usually made using semiconductors rather than metals.

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[Total: 8]



 

**9** **(a)** Define *magnetic flux*.

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**(b)** A simple transformer consists of two coils of wire wound on a soft-iron core, as illustrated in Fig. 9.1.

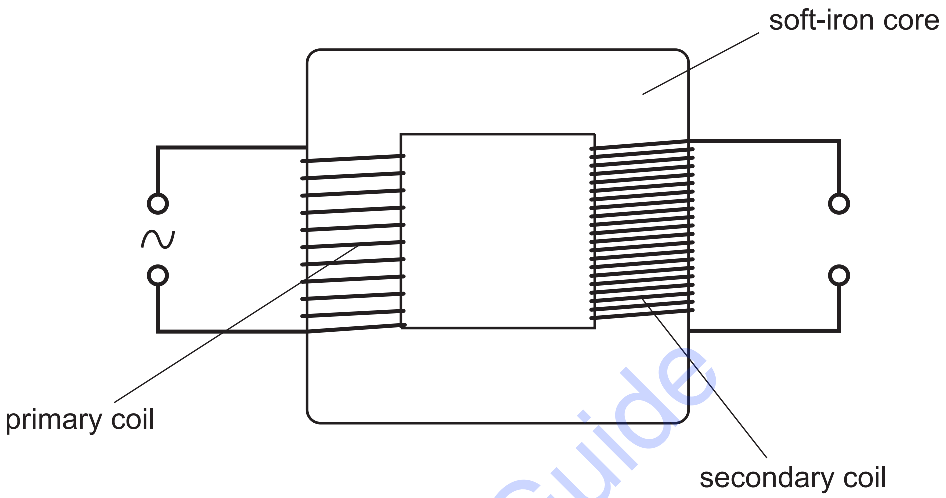


**Fig. 9.1**



There is a sinusoidal current in the primary coil.

Explain:

**(i)** how this current gives rise to an induced electromotive force (e.m.f.) in the secondary coil

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**(ii)** why the e.m.f. induced in the secondary coil is not constant.

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**(c)** Explain why the soft-iron core in **(b)** is laminated.

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[Total: 9]



 

**10 (a)** Outline briefly the principles of computed tomography (CT scanning).

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**(b)** One section of a model designed to illustrate CT scanning is divided into four voxels. The pixel numbers K, L, M and N of the voxels are shown in Fig. 10.1.

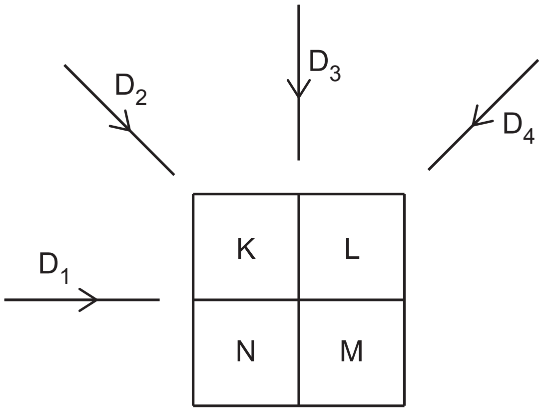


**Fig. 10.1**

The section is viewed, in turn, from four different directions $D_1$, $D_2$, $D_3$ and $D_4$, as shown in Fig. 10.1.

The detector readings for each direction are noted and these are summed to give the values shown in Fig. 10.2.

| | |
|---|---|
| 42 | 45 |
| 51 | 30 |

**Fig. 10.2**



The background reading is 24.

Determine the pixel numbers K, L, M and N shown in Fig. 10.1.

K = ..............................................................

L = ..............................................................

M = ..............................................................

N = ..............................................................
[3]

[Total: 8]

 

**11** A photon of wavelength 540 nm collides with an isolated stationary electron, as illustrated in Fig. 11.1.

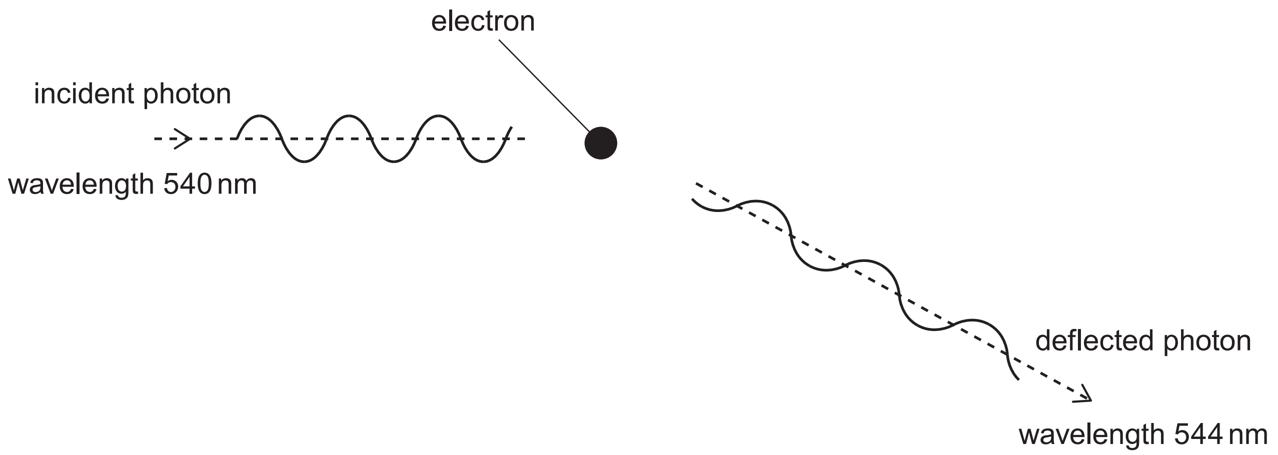


**Fig. 11.1**

The photon is deflected elastically by the electron.
The wavelength of the deflected photon is 544 nm.

**(a)** **(i)** State what is meant by a *photon*.

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

**(ii)** On Fig. 11.1, draw an arrow to indicate the approximate direction of motion of the deflected electron. [1]

 

**(b)** Calculate:

**(i)** the momentum of the deflected photon

momentum = .................................................. N s [2]

**(ii)** the energy transferred to the deflected electron.

energy = ..................................................... J [2]

**(c)** Another photon of wavelength 540 nm collides with an isolated stationary electron.

Explain why it is not possible for the deflected photon to have a wavelength less than 540 nm.

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[Total: 9]



 