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9792/03

October/November 2013

3 hours

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

DO **NOT** WRITE IN ANY BARCODES.

You are advised to spend about 1 hour 30 minutes on this section.

You are advised to spend about 1 hour 30 minutes on this section.

You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use	
1	
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7	
8	
9	
10	
11	
12	
Total	

This document consists of **43** printed pages and **1** blank page.

Data

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

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \left(\frac{u+v}{2} \right)t$	change of state	$\Delta E = mL$
		refraction	$n = \frac{\sin \theta_1}{\sin \theta_2}$ $n = \frac{v_1}{v_2}$
heating	$\Delta E = mc\Delta\theta$		

diffraction
single slit, minima $n\lambda = b \sin \theta$

grating, maxima $n\lambda = d \sin \theta$

double slit interference $\lambda = \frac{ax}{D}$

Rayleigh criterion $\theta \approx \frac{\lambda}{b}$

photon energy $E = hf$

de Broglie wavelength $\lambda = \frac{h}{p}$

simple harmonic motion

$$x = A \cos \omega t$$

$$v = -A\omega \sin \omega t$$

$$a = -A\omega^2 \cos \omega t$$

$$F = -m\omega^2 x$$

$$E = \frac{1}{2}mA^2\omega^2$$

energy stored in a capacitor $W = \frac{1}{2}QV$

electric force $F = \frac{Q_1 Q_2}{4\pi\epsilon_0 r^2}$

electrostatic potential energy $W = \frac{Q_1 Q_2}{4\pi\epsilon_0 r}$

gravitational force $F = -\frac{Gm_1 m_2}{r^2}$

gravitational potential energy $E = -\frac{Gm_1 m_2}{r}$

magnetic force

$$F = BIl \sin \theta$$

$$F = BQv \sin \theta$$

electromagnetic induction $E = -\frac{d(N\Phi)}{dt}$

Hall effect $V = Bvd$

time dilation $t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$

kinetic theory $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$

work done on/by a gas $W = p\Delta V$

radioactive decay $\frac{dN}{dt} = -\lambda N$

$$N = N_0 e^{-\lambda t}$$

$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

attenuation losses $I = I_0 e^{-\mu x}$

mass-energy equivalence $\Delta E = c^2 \Delta m$

hydrogen energy levels $E_n = \frac{-13.6 \text{ eV}}{n^2}$

Heisenberg uncertainty principle $\Delta p \Delta x \geq \frac{h}{2\pi}$

$$\Delta E \Delta t \geq \frac{h}{2\pi}$$

Wien's displacement law $\lambda_{\max} \propto \frac{1}{T}$

Stefan's law $L = 4\pi\sigma r^2 T^4$

electromagnetic radiation from a moving source $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

Section A

Answer **all** questions in this section.

You are advised to spend about 1 hour 30 minutes on this section.

For
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Use

- 1 (a) Draw a diagram to illustrate what is meant by diffraction of a wave at a narrow slit.

[2]

- (b) Fig. 1.1 shows two slits illuminated by monochromatic light.

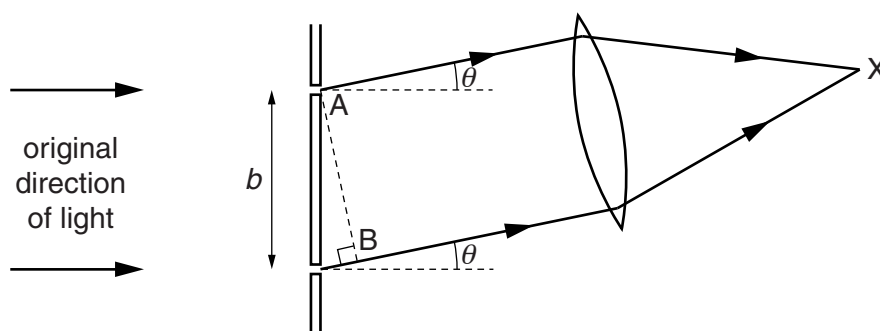


Fig. 1.1 (not to scale)

The slits are separated by a distance b of 5.2×10^{-6} m. A converging lens is used to focus the light emerging from the slits at X. The monochromatic light has a wavelength of 5.9×10^{-7} m. Fig. 1.1 shows only the part of the waves emerging from the two slits at an angle θ to the original direction.

(i) Calculate

1. the path difference between the two beams when they meet at X, for a value of $\theta = 10^\circ$,

path difference = m [1]

2. the value of θ that will give a phase difference of 2π at X,

$\theta =$ degrees [2]

3. the number of values of θ , that will result in the two beams arriving in phase at X.

number of values = [3]

- (ii) Consider a point in the interference pattern at X where the waves from the two slits have a phase difference of $\pi/2$ (90°).

For
Examiner's
Use

1. Draw a diagram to show the resulting wave when two waves, each of amplitude A and with a phase difference of $\pi/2$ (90°) superpose to form an image. Your diagram can be a phasor diagram or a wave diagram.

[2]

2. Calculate how the intensity at this point compares with the maximum intensity of the interference pattern.

intensity = maximum intensity \times [3]

[Total: 13]

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2 (a) State Kepler's laws of planetary motion.

For
Examiner's
Use

first law

.....

second law

.....

third law

.....

.....

[4]

(b) Newton's law of gravitation can be summarised by the equation

$$F = -\frac{GMm}{r^2}$$

where F is the gravitational force between two point masses M and m , separated by a distance r , and G is the gravitational constant.

A planet of mass m moves around a sun of much larger mass M in a circular orbit of radius r . It takes a time T to complete an orbit.

Show that Newton's law of gravitation, applied to this planet, is in agreement with Kepler's third law.

[3]

- (c) The Earth completes one orbit of the Sun in one year. Saturn takes 29.5 years to complete an orbit of the Sun. The distance of the Earth from the Sun is 1.50×10^{11} m.

For
Examiner's
Use

- (i) Calculate the distance of Saturn from the Sun. Assume that both orbits are circular.

distance = m [3]

- (ii) State the other main assumption you have had to make in order to answer question (c)(i).

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

- (d) The Sun rotates on its axis with a period of 23.4 days. A satellite is placed so that it orbits the Sun with the same angular speed as the Sun's rotation.

Use the expression derived in (b) to determine the distance of the satellite from the Sun.

Mass of the Sun = 1.99×10^{30} kg.

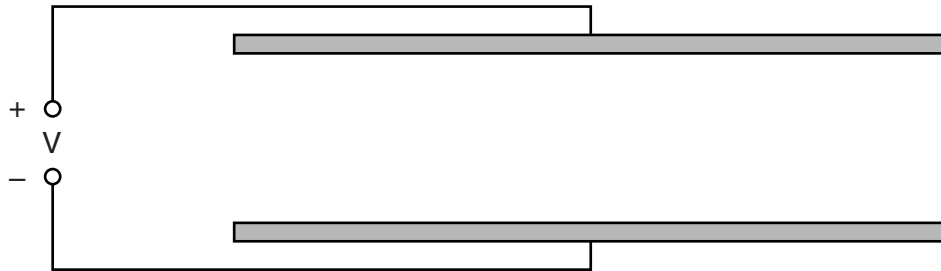
distance = m [2]

[Total: 13]

- 3 (a) (i) Define the term *electric field strength*.

.....
 [1]

- (ii) Complete the diagram in Fig. 3.1 to show the electric field pattern between the parallel plates.



[2]

Fig. 3.1

- (iii) The plates in Fig. 3.1 are separated by a distance d and there is a potential difference V between them. A small charge of $+Q$, is moved from the centre of the negative plate up to the positive plate.

State an expression for the work W done on the charge

1. in terms of V and Q ,

$$W = \dots\dots\dots [1]$$

2. in terms of the force F on the charge and d .

$$W = \dots\dots\dots [1]$$

- (iv) Use your answers to (iii) to show that the electric field strength between the plates in (ii) is equal to the potential gradient.

[2]

- (b) The electric field pattern around two charges of $+1\ \mu\text{C}$ and $+4\ \mu\text{C}$ is shown in Fig. 3.2.

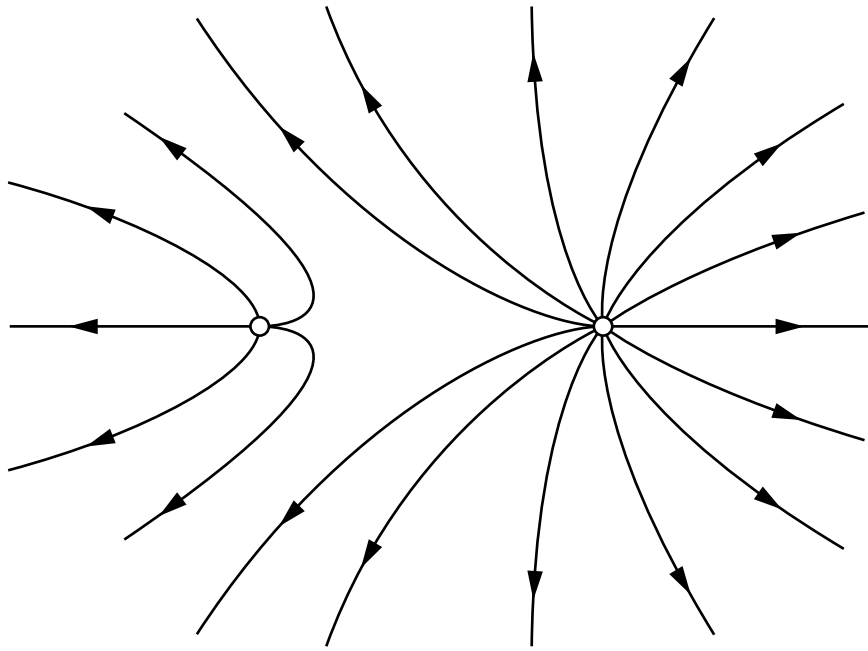


Fig. 3.2 (not to scale)

The distance between the two charges is 6.0 cm.

- (i) Calculate the force of repulsion between the two charges.

force = N [2]

- (ii) There is a neutral point between the charges. A point charge placed at the neutral point does not experience a force.

Calculate the distance of the neutral point from the $1.0\ \mu\text{C}$ charge.

distance = cm [3]

- (iii) On Fig. 3.2, draw a series of equipotential lines around the charges. [3]

[Total: 15]

- 4 (a) The equation $\frac{1}{2}m\langle c^2 \rangle = \frac{3}{2}kT$ can be used in calculations to determine the internal energy of a gas.

(i) Calculate the value of $\frac{3}{2}kT$ at a temperature of 27 °C. Give the unit with your answer.

$$\frac{3}{2}kT = \dots\dots\dots \text{unit} \dots\dots\dots [2]$$

(ii) State the meaning of the following.

1. m

2. $\langle c^2 \rangle$

.....

3. $\frac{1}{2}m\langle c^2 \rangle$

.....

[3]

(b) The atmosphere is mostly a mixture of nitrogen and oxygen molecules.

For molecules in the atmosphere, deduce the ratio:

$$\frac{\text{r.m.s speed of a nitrogen molecule}}{\text{r.m.s speed of an oxygen molecule}}$$

Mass of a nitrogen molecule = $28 \times 1.66 \times 10^{-27}$ kg.

Mass of an oxygen molecule = $32 \times 1.66 \times 10^{-27}$ kg.

$$\text{ratio} = \dots\dots\dots [2]$$

(c) Complete, in words, the equation summarising the first law of thermodynamics.

The increase in the internal energy of a system equals

.....

..... [2]

- (d) During the first part of the power stroke in a diesel engine, the pressure of the burning gas remains constant at $8.00 \times 10^6 \text{ Pa}$, while the volume of the gas increases from $3.00 \times 10^{-5} \text{ m}^3$ to $7.10 \times 10^{-5} \text{ m}^3$.

- (i) Calculate the work done by the gas during the first part of the power stroke.

work done = J [2]

- (ii) While this expansion is taking place, the temperature of the gas rises by 900 K . The mass of the gas is $1.27 \times 10^{-3} \text{ kg}$ and its specific heat capacity at constant pressure is $1.01 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$.

Calculate the heat gained by the burning gas.

heat gained = J [2]

- (iii) Deduce, using your answers to (d)(i) and (d)(ii), the change in the internal energy of the burning gas.

change in internal energy = J [1]

[Total: 14]

- 5 (a) (i) Show that the nature of radioactive decay leads to the differential equation

$$\frac{dN}{dt} = -\lambda N.$$

For
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Use

[3]

- (ii) Show that a solution to the equation in (a)(i) is

$$N = N_0 e^{-\lambda t}$$

where N_0 is the number of radioactive nuclei when the time $t = 0$.

[4]

- (b) When decommissioning a nuclear reactor, two radioactive isotopes of nickel are found to be present in the steel of the reactor shielding. The details of these two isotopes are as follows.

For
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Use

isotope	half-life / years	present activity / 10^{12} Bq
$^{59}_{28}\text{Ni}$	80 000	2.1
$^{63}_{28}\text{Ni}$	92	230

- (i) Calculate the activity of both isotopes in 1000 years time.

activity of nickel-59 = Bq

activity of nickel-63 = Bq
[4]

- (ii) Comment on your answers to (b)(i) in relation to storage problems for the two isotopes.

.....

 [2]

[Total: 13]

- 6 The energy levels E_n of the hydrogen atom are described by the empirical equation

$$E_n = \frac{-13.6 \text{ eV}}{n^2}$$

- (a) (i) Calculate the energy, in joules, of a photon of ultra-violet light emitted when an electron in a hydrogen atom falls from energy level $n = 3$ to energy level $n = 1$.

energy = J [3]

- (ii) Calculate the wavelength of these photons.

wavelength = m [2]

- (b) The hydrogen spectrum is observed in light from a distant galaxy. It is found that the wavelength corresponding to an electron in a hydrogen atom falling from energy level $n = 3$ to energy level $n = 1$ has increased to $1.28 \times 10^{-7} \text{ m}$.

- (i) Explain why this increase takes place.

.....

 [2]

- (ii) Calculate the speed of the galaxy relative to the Earth.

speed = ms^{-1} [2]

- (c) Explain why changes in wavelength, such as this, have led to the idea that the Universe is expanding and to the Big Bang theory.

*For
Examiner's
Use*

.....

.....

.....

.....

.....

.....[3]

[Total: 12]

Section B

Answer any **three** questions in this section.
You are advised to spend about 1 hour 30 minutes on this section.

For
Examiner's
Use

- 7 (a) Explain what is meant by the term *longitudinal wave*.

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

- (b) State two differences between a standing wave and a progressive wave. Refer to both waves in each answer.

difference 1.
.....
.....
difference 2.
.....
.....[2]

- (c) Fig. 7.1 is a graph of the displacement of particles in a **standing wave** against distance, at the instant when the displacement is a maximum.

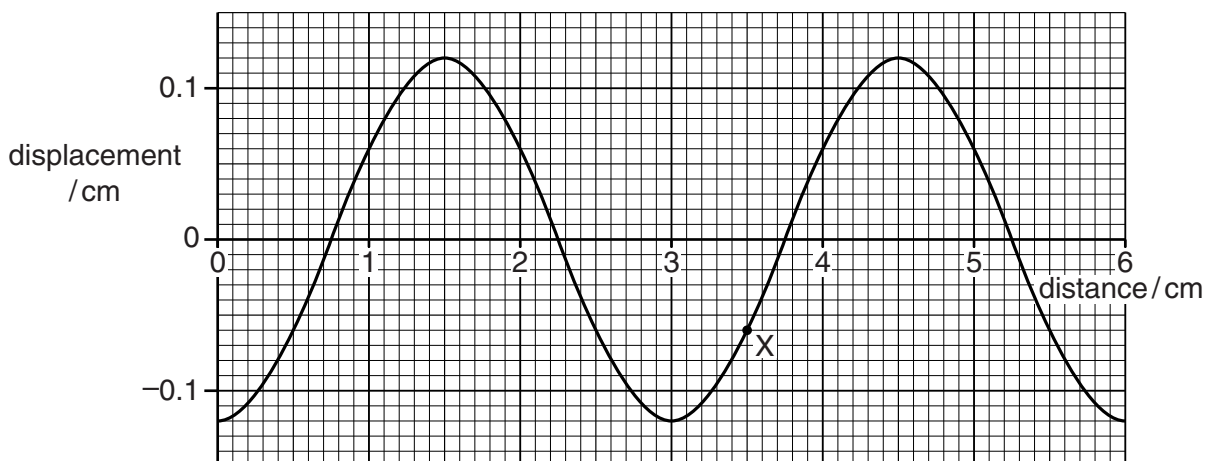


Fig. 7.1

The position of particle X is shown on the wave.

- (i) 1. On Fig. 7.1, mark the position of any particle which is π radians out of phase with particle X. Label it O. [1]
2. On Fig. 7.1, draw an arrow from particle X showing the direction of its instantaneous velocity. [1]

- (ii) Use the information in Fig. 7.1 to determine the distance moved by particle X during half a cycle.

distance = cm [1]

- (d) Fig. 7.2 shows a **progressive wave** at an instant as it travels along.

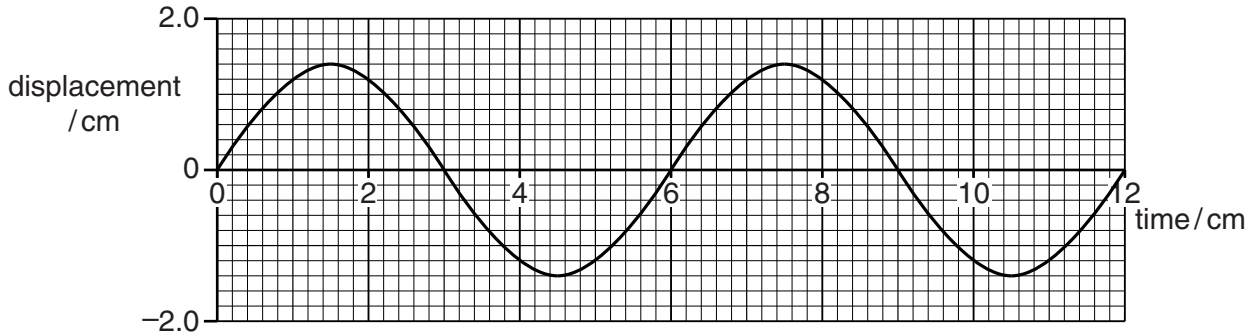


Fig. 7.2

On Fig. 7.2, draw another progressive wave of the same amplitude and wavelength which has a phase difference of $\frac{\pi}{3}$ (60°) relative to this progressive wave. [3]

- (e) To locate their prey, some spiders use vibrations transmitted through their web. The threads of the web are under tension. When the threads are disturbed by trapped prey, progressive transverse waves travel along sections of thread. These reflect and form standing waves.

On damp days, small droplets of water collect at equally spaced points along these threads.

Fig. 7.3 shows such a thread.

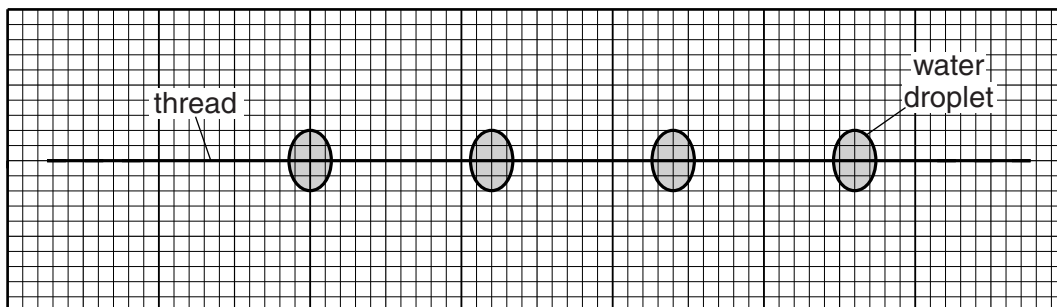


Fig. 7.3

- (i) Explain why water droplets of moisture only form at these points.

..... [1]

- (ii) The speed of a progressive transverse wave sent along the thread is 9.7 cm s^{-1} .

Use information from the diagram in Fig. 7.3 to determine the frequency of the standing wave. The diagram is drawn to a scale 1 cm representing 0.25 cm of thread.

frequency = Hz. [3]

- (f) The decibel (dB) is a logarithmic unit used to describe the loudness of a sound relative to a standard sound.

The loudness x of a sound of power P is given by

$$x = 10 \log_{10} \left(\frac{P}{P_s} \right) \text{ dB}$$

where P_s , the standard sound, is the power of a sound just perceptible to the human ear.

Fig. 7.4 shows the axes for a graph of loudness x , in decibels, against the ratio of powers $\left(\frac{P}{P_s} \right)$.

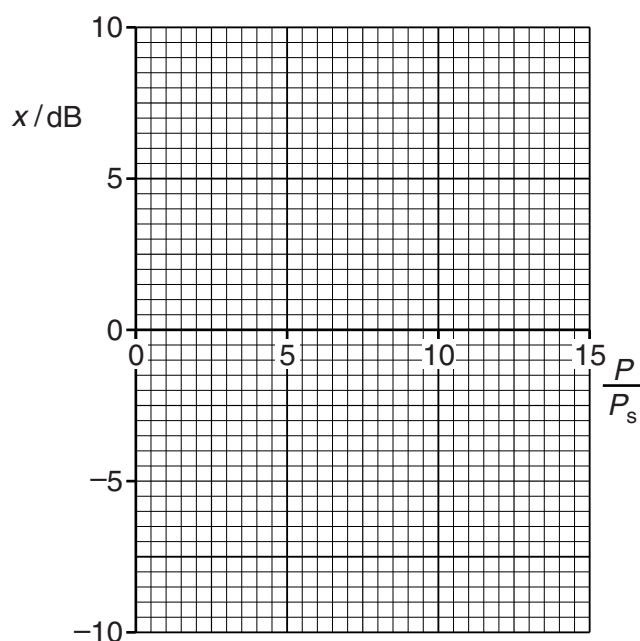


Fig. 7.4

- (i) 1. Use the expression for x to complete the following table.

P	$x = 10 \log_{10} \left(\frac{P}{P_s} \right) / \text{dB}$
$10P_s$	10
$5P_s$	
P_s	
	-10

[2]

2. Use the axes in Fig. 7.4 and the data from the table in (f)(i) to draw the graph of the loudness x , in decibels, against $\left(\frac{P}{P_s} \right)$. [1]

- (ii) Blue whales can emit sound waves from beneath huge shoals of fish. The waves are powerful enough to stun large numbers of fish and drive them to the surface of the sea. The whale then sweeps them into its open jaws as it follows them from below.

The pistol-shrimp is only about 2 cm in length. It stuns its prey by clicking its claw, emitting a very brief pulse of sound.

The table gives typical values for the loudness of the blue whale and the pistol-shrimp.

	power P	loudness x / dB
pistol-shrimp	P_{ps}	200
blue whale	P_w	180

1. Determine the magnitude of the ratio $\left(\frac{P_{\text{ps}}}{P_w} \right)$.

$$\left(\frac{P_{\text{ps}}}{P_w} \right) = \dots\dots\dots [2]$$

2. By considering what is meant by power, suggest why it is possible for the very small pistol-shrimp to emit a wave which has a loudness so much larger than that emitted by an enormous blue whale.

.....

 [1]

[Total: 20]

- 8 Fig. 8.1 shows a small mass attached to the end of a fixed spring.

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Use

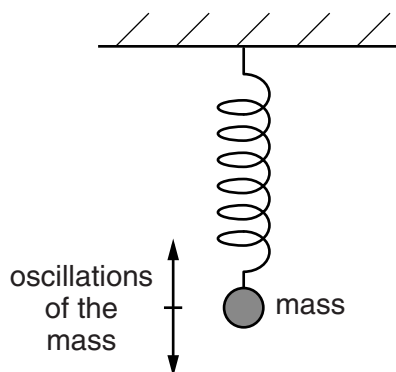


Fig. 8.1 (not to scale)

The mass is given a small vertical displacement and then released. It oscillates with simple harmonic motion about its equilibrium position.

- (a) Define the term *simple harmonic motion*.

.....

.....

.....

.....[2]

- (b) The graph in Fig. 8.2 shows how the displacement x varies with time t for the motion of the mass on the spring.

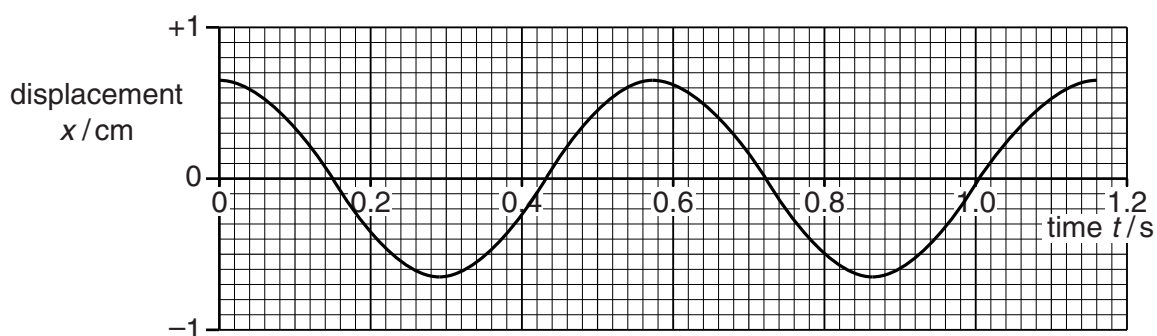


Fig. 8.2

The equation of the graph is

$$x = A \cos \omega t$$

where A and ω are constants.

- (i) Differentiate this equation with respect to time in order to derive an expression for the instantaneous velocity v .

For
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Use

[1]

- (ii) Using your expression in (b)(i) and data from the graph in Fig. 8.2, determine the velocity of the mass at time $t = 0.94$ s.

velocity = cm s^{-1} [4]

- (iii) Fig. 8.3 shows the spring and the position of the mass at instant $t = 0.94$ s.

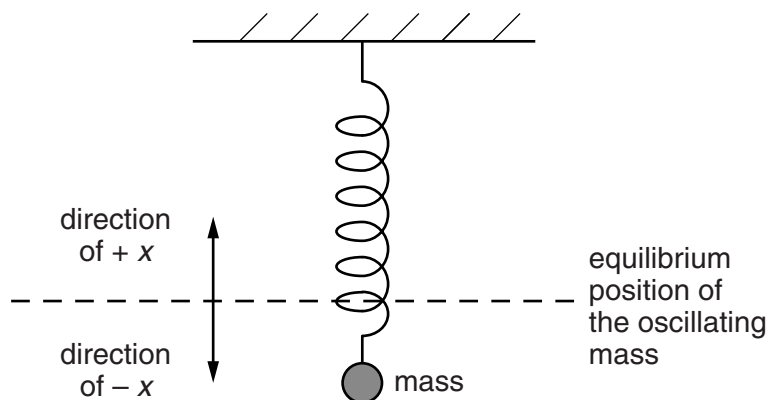


Fig. 8.3

On Fig. 8.3, add arrows labelled a and v to show the directions of the acceleration and the velocity, respectively, at this instant in time. [2]

- (iv) The period of oscillation T_s for an oscillating mass of mass m is given by

$$T_s = 2\pi \sqrt{\frac{m}{k}} \quad \text{where } k \text{ is the spring constant.}$$

Using this expression and your definition of simple harmonic motion in (a), show that $\frac{d^2x}{dt^2} = -\frac{k}{m}x$ for this oscillating mass and spring.

[2]

- (c) Fig. 8.4 shows a trolley attached to two identical horizontal springs each connected to a rigid stand. The trolley is at rest at its equilibrium position.

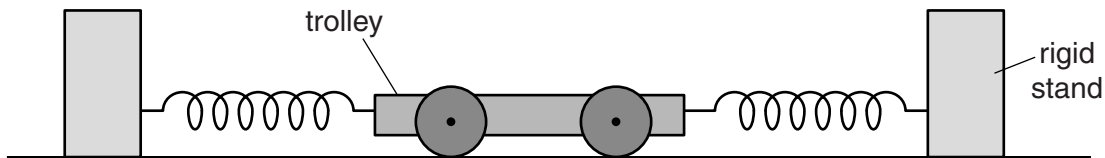


Fig. 8.4 (not to scale)

The trolley is pulled to one side and released. Its subsequent oscillations are lightly damped.

- (i) Explain what is meant by *lightly damped* oscillations.

.....

.....

..... [1]

Question 8 continues on page 26

- (ii) The graph in Fig. 8.5 shows how the trolley's displacement varies with time as it oscillates about its equilibrium position.

For
Examiner's
Use

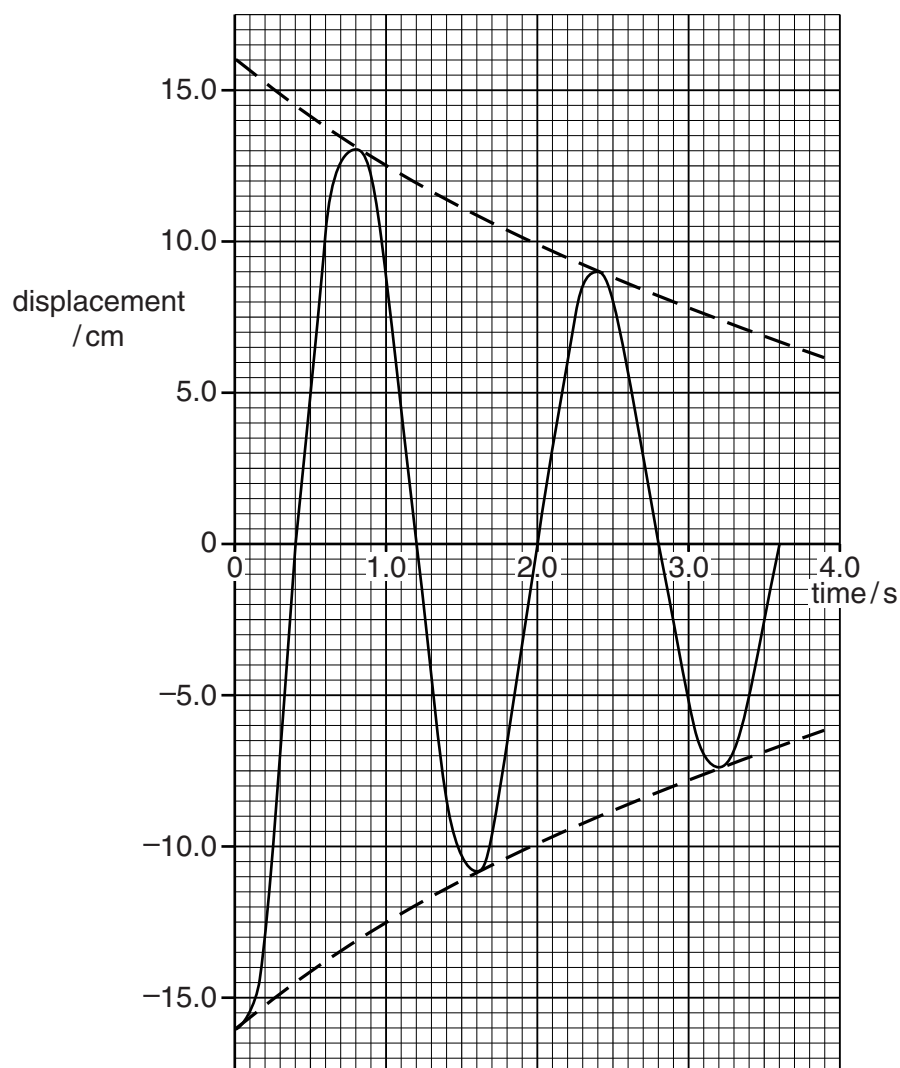


Fig. 8.5

1. As time t elapses, the amplitude A of the oscillation changes.

Use data from the dashed curves in Fig. 8.5 to complete the table below for missing values of amplitude A and the natural logarithm of A .

A / cm	t / s	$\ln (A / \text{cm})$
16.0	0.0	2.8
	0.8	
10.9	1.6	2.4
	2.4	
7.4	3.2	2.0

[2]

2. On Fig. 8.6, draw a graph to show how $\ln A$ varies with time t .

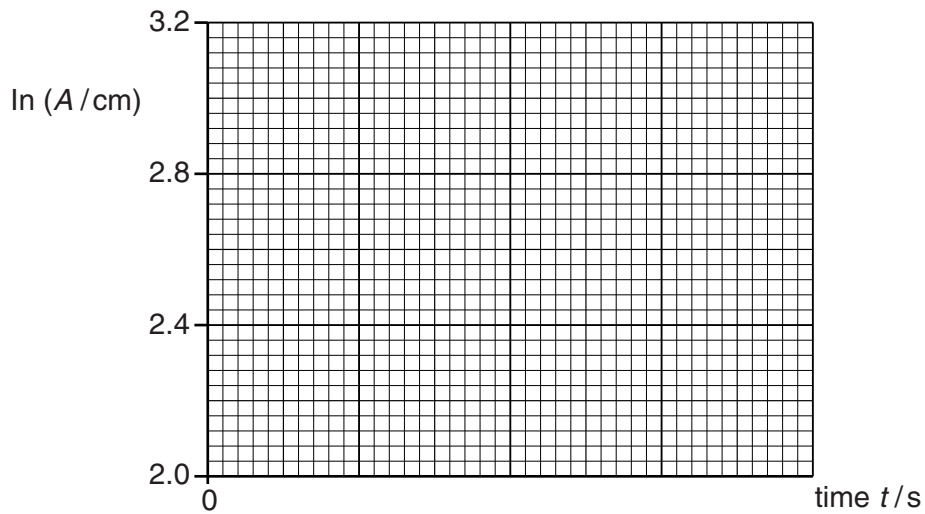


Fig. 8.6

[2]

3. Determine the magnitude of the gradient of your graph.

gradient = [1]

4. Hence, state the equation for your graph in Fig. 8.6.

..... [1]

5. Hence, determine the expression for A as a function of t that represents the dashed curve in Fig. 8.5.

$A =$ [2]

[Total: 20]

- 9 (a) Hall probes are used to measure the strength of a magnetic field.

For
Examiner's
Use

Fig. 9.1 shows a slice of semiconducting material in a uniform magnetic field of magnetic flux density B . The direction of the field is perpendicular to the slice, into the page.

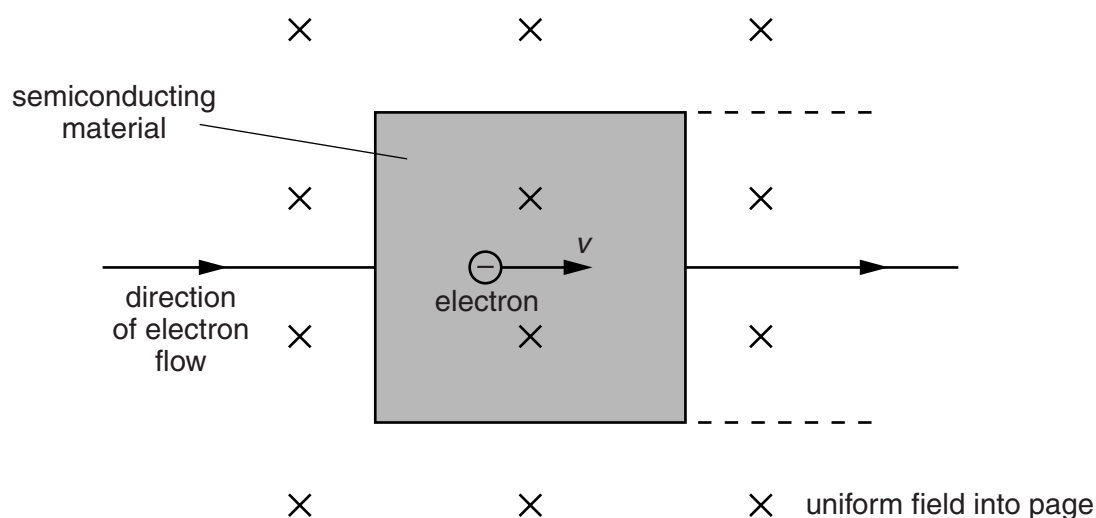


Fig. 9.1

Electrons in the semiconducting material flow from left to right with average speed v . Eventually a small potential difference V_H , the Hall voltage, is established across the semiconductor.

- (i) Describe how the Hall voltage is created.

.....

.....

.....

.....

.....[3]

- (ii) On Fig. 9.1, draw and label the forces that are exerted on the electron once the Hall voltage is established. [1]

Question 9 continues on page 30

- (iii) Fig. 9.2 shows a slice of semiconducting material of thickness t , height d and length l in a uniform magnetic field of magnetic flux density B . The direction of the field is perpendicular to the large face of the slice. Charge carriers flow through the shaded face creating a current I .

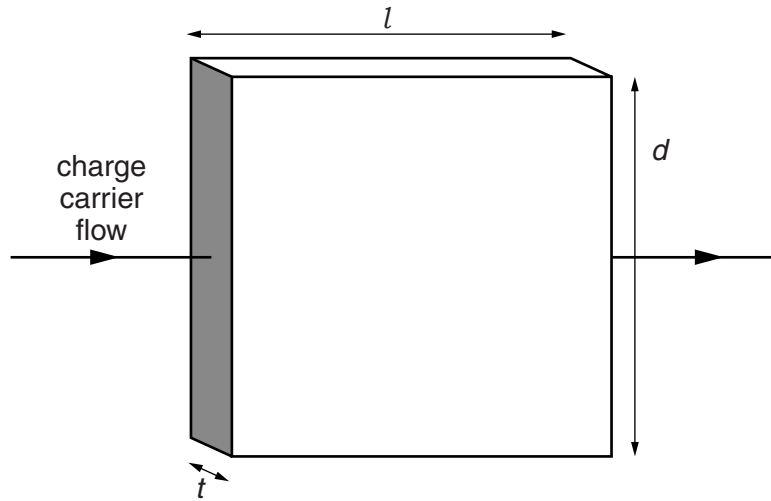


Fig. 9.2

The current I in a slice of semiconducting material is given by the relationship

$$I = nAve$$

where n is the number of charge carriers per unit volume,
 A is the area of the face through which charge flows,
 v is the average speed of the electrons, and
 e is the magnitude of the charge on an electron.

1. Show that the Hall voltage V_H can be expressed as

$$V_H = \frac{BI}{nte}$$

Show all stages of your working.

[4]

2. A thin square slice of semiconductor of dimensions $10\text{ mm} \times 10\text{ mm} \times 0.56\text{ mm}$, as shown in Fig. 9.2, has a current of 140 mA . The number of charge carriers per unit volume is $4.3 \times 10^{21}\text{ m}^{-3}$ and $e = 1.6 \times 10^{-19}\text{ C}$. The Hall voltage is 62 mV .

Calculate the magnetic flux density of the magnetic field.

magnetic flux density = T [3]

- (b) Fig. 9.3 shows a side view of a U-shaped permanent magnet of mass 82.0 g resting on an electronic top-pan balance.

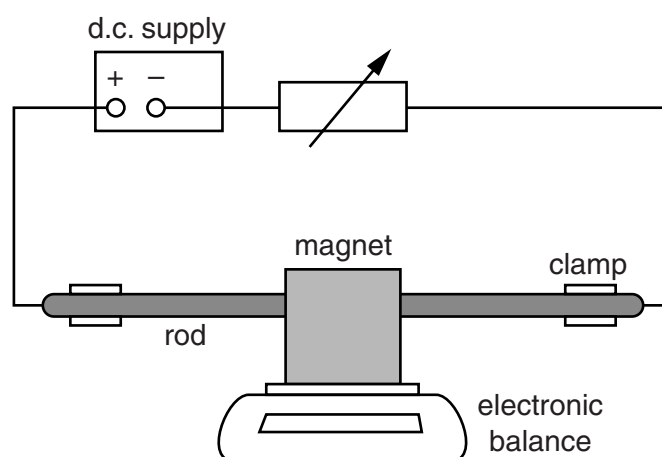


Fig. 9.3

An aluminium rod is clamped between the poles of the magnet so that the rod cannot move. The rod is connected in the circuit shown.

The d.c. supply is switched on. The reading on the balance increases to 82.4 g .

- (i) Calculate the additional force exerted on the magnet when there is a current in the circuit.

additional force = N [1]

- (ii) Explain how this additional force originates.

.....

.....

.....

.....[3]

- (iii) Fig. 9.4 shows a plan view, from above, of part of the apparatus shown in Fig. 9.3. The plan shows the aluminium rod fixed between the poles of the U-shaped magnet. The direction of current in the aluminium rod is from left to right.

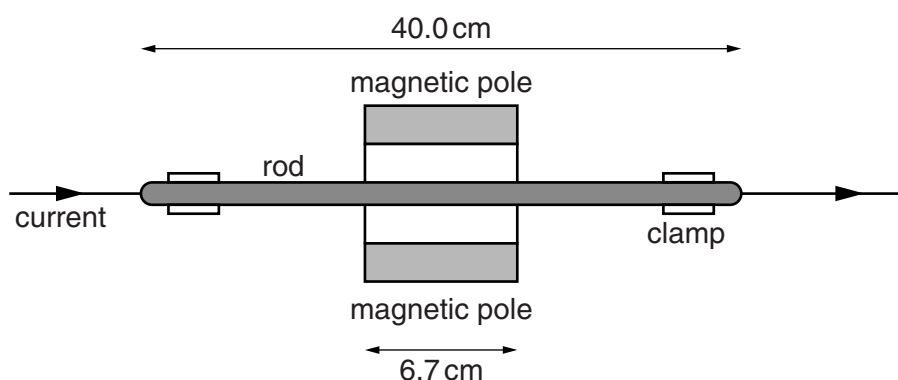


Fig. 9.4

- On Fig. 9.4, draw an arrow to show the direction of the magnetic field between the poles that would produce a downward force on the magnet. [1]
- The aluminium rod is 40.0 cm long and the length of each magnetic pole is 6.7 cm. The magnetic flux density between the poles of the magnet is 28.6 mT.

Calculate the current in the aluminium rod.

current = A [3]

- The connections to the d.c. supply are switched over so that the current is reversed. The reading on the electronic balance changes.

Determine the new reading on the electronic balance.

new reading = g [1]

[Total: 20]

- 10** Werner Heisenberg argued that we can only be clear about what is meant by 'the position of an object' if we can specify experiments by which its position can be measured.

- (a)** Imagine using a microscope with visible light to measure the position of a small visible particle such as a tiny particle of smoke.

Explain why there is a limit to the resolution of the image and therefore an uncertainty about the exact location of the object.

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- (b)** Heisenberg realised that visible light would be useless for making a precise measurement of the position of something as small as an electron. To get around this problem Heisenberg suggested using a 'gamma-ray microscope'. In his thought experiment for this device gamma-rays bounce off the electron and into a measuring device which can be used to determine the location of the electron.

Explain why using gamma-rays could improve the resolution of the image formed when using such a microscope and so allow a more precise measurement of position to be made.

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- (c) (i)** Explain why scattering light or gamma-rays from an electron causes the electron to change its momentum.

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- (ii) Describe how the momentum change of the electron depends on the wavelength of the electromagnetic radiation that is used to observe it.

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- (iii) Explain how Heisenberg's gamma-ray microscope thought experiment seems to explain (qualitatively) the Uncertainty Principle

$$\Delta p \Delta x \geq \frac{h}{2\pi}.$$

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- (d) The Uncertainty Principle does not seem to affect us noticeably in everyday life. For example, when an 80 kg man walks in a straight line at 2.0 m s^{-1} and passes through a doorway of width 1.2 m he is not obviously deflected from his path.

Carry out a calculation to show that the deflection due to the Uncertainty Principle is utterly negligible.

[3]

- (e) Whilst Heisenberg's gamma-ray microscope thought experiment seems to 'explain' the Uncertainty Principle, it should not be taken as a realistic description of how such a microscope would actually work. Physicists do not think that photons and electrons are really like tiny billiard balls; uncertainty is fundamental.

For
Examiner's
Use

Explain how quantum theory has led to the view that the world is indeterministic rather than deterministic.

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11 (a) For centuries inventors have dreamed of building a perpetual motion machine. There are two kinds of perpetual motion machine.

- A perpetual motion machine of the first kind does more work than the energy supplied to it.
- A perpetual motion machine of the second kind converts thermal energy into mechanical work with 100% efficiency.

(i) Use a law of physics to explain why a perpetual motion machine of the **first** kind is impossible.

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(ii) Use a law of physics to explain why a perpetual motion machine of the **second** kind is impossible.

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(b) Fig. 11.1 shows a proposal for a perpetual motion machine.

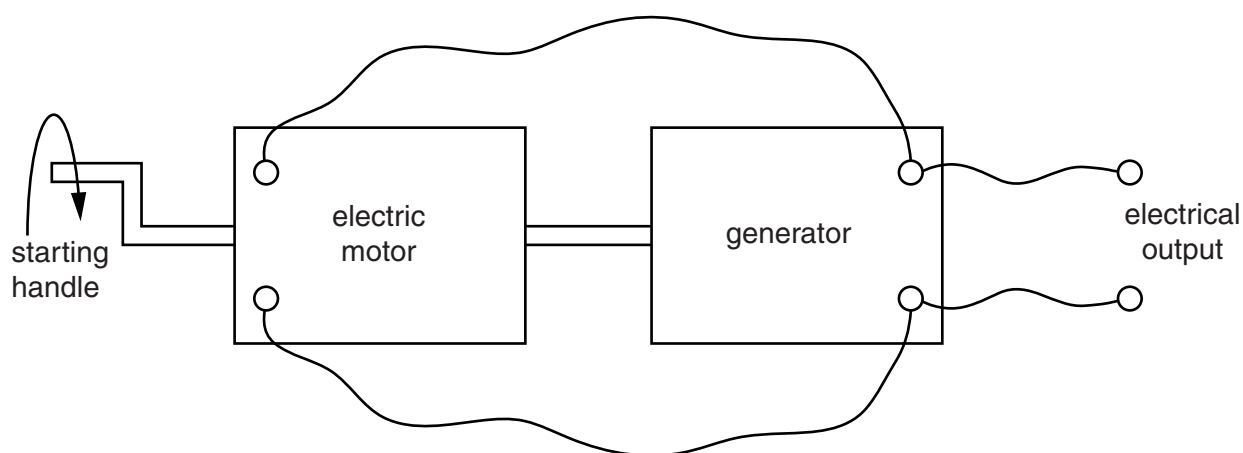


Fig. 11.1

An electric motor is connected to an electrical generator by a fixed axle so that when the motor turns it also turns the generator. The output of the generator is connected to the input of the motor and excess electricity is used to provide useful work (e.g. to power a house).

The inventor claims that when the starting handle is turned and released the system will continue to spin at an ever increasing rate, or else can be used as a constant supply of electrical energy for useful work.

- (i) In order for the machine to work, the inventor has to make an assumption about the output of the generator. Explain what this is.

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- (ii) State and explain whether this is an example of a perpetual motion machine of the first or second kind.

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- (iii) If a simple version of this machine is constructed in the laboratory, and the starting handle is used to make it start spinning, it just slows down and stops once the handle is released.

Explain why it cannot be used as a continual source of energy **and** why it eventually stops.

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- (c) (i) The equation:

$$E = - \frac{d(N\Phi)}{dt}$$

is an expression of Faraday's law of electromagnetic induction and Lenz's law.

Explain what is meant by Lenz's law and how this relates to the minus sign in the equation.

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- (ii) When a strong magnet is dropped through a long vertical copper pipe, it falls at a very slow, constant velocity, even though it is not rubbing against the inside surface of the pipe and copper is not magnetic.

Use Faraday's and Lenz's laws to give a qualitative explanation of this unusual effect.

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- (iii) If it were possible to change the sign of Lenz's law, then a strong magnet and a copper pipe could be used to generate energy and to build a perpetual motion machine of the first kind.

Explain in principle how this could work. You are not expected to design a machine.

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- (d) The atmosphere contains an enormous amount of thermal energy. If we could transfer just a small amount of this thermal energy to useful work (e.g. electricity) with 100% efficiency, then we would have a huge, new global energy resource.

Explain why this is not possible.

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[Total: 20]

- 12 One assumption of Einstein's special theory of relativity is that the velocity of light c is the same for all uniformly moving observers. This leads to situations which seem to contradict common sense. Fig. 12.1 shows such an example.

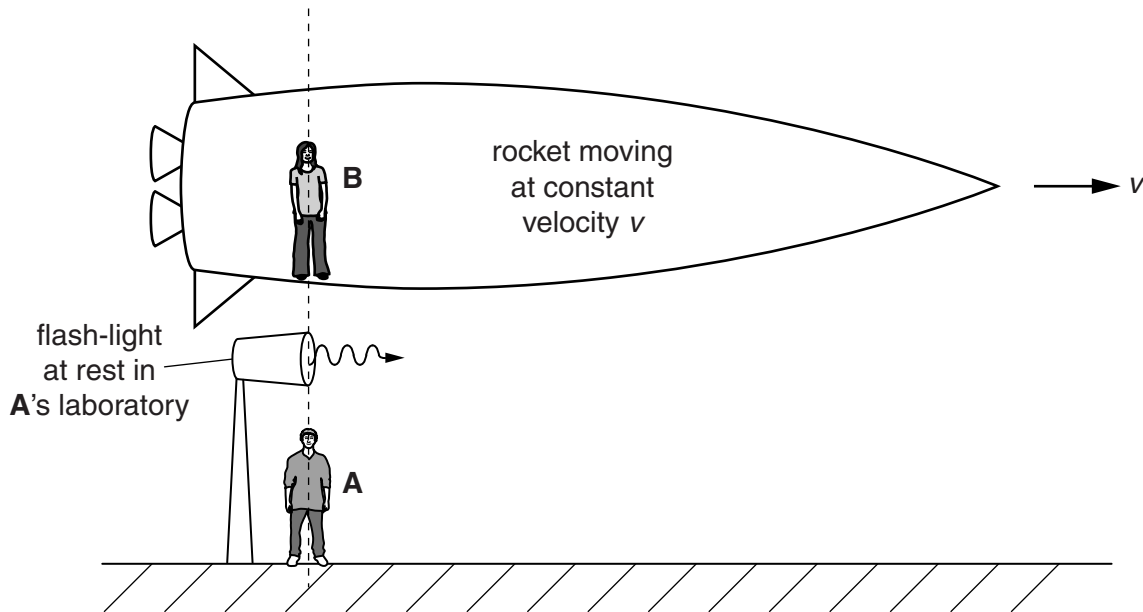


Fig. 12.1

Observer **A** is in a laboratory at rest while observer **B** passes in a rocket travelling at a constant velocity v relative to **A**'s laboratory.

- (a) At the moment that **B** passes **A**, a flash-light in **A**'s laboratory emits a very short pulse of light in the same direction as the rocket's motion.

- (i) What is the velocity of the light pulse relative to **A**, as measured by equipment at rest in **A**'s laboratory?

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- (ii) What is the velocity of the light pulse relative to **B** as measured by **A**?
Explain your answer.

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- (iii) What is the velocity of the light pulse relative to **B** as measured by equipment at rest in **B**'s rocket?

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- (iv) Explain, by referring to the measuring equipment used by **A** and by **B**, how they can disagree over the velocity of the light pulse relative to **B**.

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- (b) If we want to know the time interval between events at different locations we need to compare times at different places.

For example, if a friend leaves you when your clock is at 1 pm and later tells you that she arrived home when her home clock reads 4pm you can work out that the time of her journey was 3 hours, assuming the two clocks were synchronised.

In the Newtonian world this is just common sense, but in the relativistic world things are more complicated.

Consider different ways in which the two clocks might be synchronised.

Method 1: Start two clocks at your house and then get someone to transport one of the clocks to your friend's house.

- (i) Explain why this would introduce a small difference into the times shown on the two clocks.

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- (ii) State and explain whether the time difference in (b)(i) leads to an over-estimate or under-estimate of the actual time for the journey as measured in your reference frame.

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- (iii) Discuss qualitatively whether the velocity at which the clocks are separated is likely to make any difference to the time difference between the clock times.

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Method 2: A better way to synchronise two different clocks is to attach a light detector to each clock so that it can start the clock when it receives a pulse of light. The clocks are set to zero and a flashlight is placed exactly half way between them, as shown in Fig. 12.2. A single flash is then used to start both clocks at the same moment.

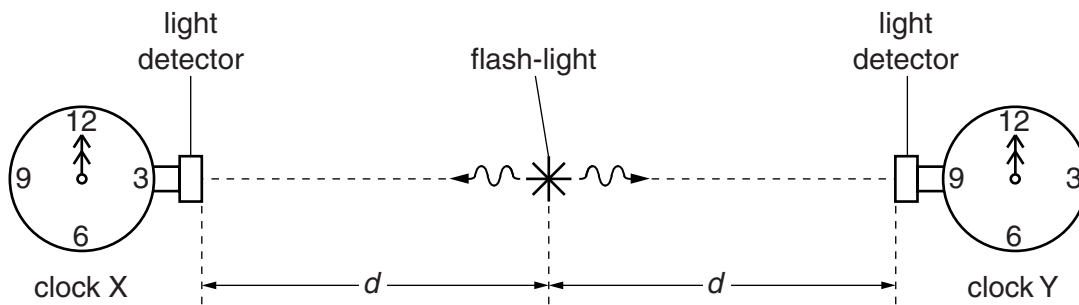


Fig. 12.2

- (iv) Explain why both clocks start at the same moment and then continue to keep time with each other (tick at the same rate) for an observer at rest with respect to both clocks.

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- (v) Method 2 is used to synchronise the two clocks in one reference frame.

Fig. 12.3 shows an observer moving past this reference frame at uniform velocity v .

For
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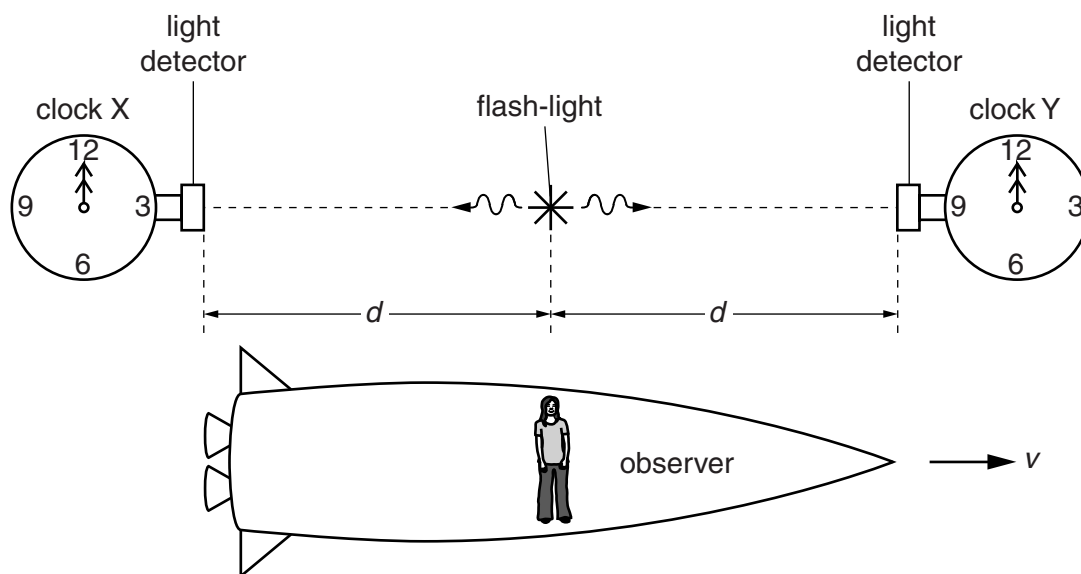


Fig. 12.3

Explain carefully, by referring to the synchronisation process and the velocity of light, why the observer will conclude that the clocks are **not** synchronised, and explain which clock the observer thinks has started first.

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- (vi) Two civilisations, in different parts of the galaxy, are at rest with respect to one another. They have been in contact for a very long time and have managed to synchronise their clocks and calendars using Method 2. They decide to hold simultaneous festivals on both planets to celebrate their friendship.

Discuss whether an observer travelling between the civilisations would agree that the festivals were simultaneous events.

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[Total: 20]

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