Answer **all** the questions.

SECTION A

1 Here is a list of units.

kg m s^{-1} **J s^{-1}** **kg m^2 s^{-2}** **J m** **kg m s^{-2}**

(a) Which unit is equivalent to a watt? $P = E/t$ ......J s^{-1}...... **[1]**

(b) Which unit is equivalent to a newton? $F = ma$ ......kg m s^{-2}...... **[1]**

2 Fig. 2.1 shows four graphs, **A**, **B**, **C** and **D**.

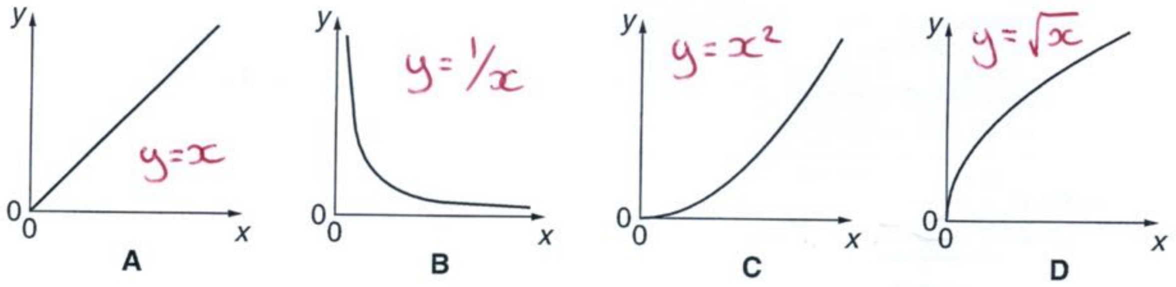


Fig. 2.1

Which graph best fits the situation when the *y*- and *x*-axes represent the two quantities given in each case below?

Each graph may be used once, more than once, or not at all.

(a) *y*-axis: the period of a wave
x-axis: its frequency

$T = 1/f$

......B...... **[1]**

(b) *y*-axis: the kinetic energy of a moving object
x-axis: its speed

$E_k = mv^2/2$

......C...... **[1]**

(c) *y*-axis: the separation of interference fringes on a distant screen after light passes through two slits
x-axis: the distance between the two slits and the screen

$n\lambda = dx/L \therefore x = n\lambda L/d$

......A...... **[1]**

(d) *y*-axis: the distance travelled by an object moving from rest with constant acceleration
x-axis: the time taken

$s = \frac{1}{2}at^2$

......C...... **[1]**

3 Here is a list of orders of magnitude.

10^{-6} 10^{-4} 10^{-2} 1 10^{2} 10^{4}

(a) Choose the value closest to the height, in m, of an adult human being. ≈ 1·8 m

1 .... [1]

(b) Choose the value closest to the area of cross-section, in m^2, of your finger. $1\,cm^2 \approx 10^{-4}\,m^2$

10^{-4} .... [1]

4 Which one of the following comparisons between red light of wavelength 650 nm and violet light of wavelength 400 nm is correct?

Put a tick (✓) in the box after the correct statement.

1	The red light has the ~~higher~~ lower frequency. $f = c/\lambda$	☐
2	The red light will diffract though a wider angle when passing through a narrow slit $x = n\lambda L/d$	✓
3	The red light travels slower in a vacuum. ✗ c is constant	☐
4	The interference maxima formed on a distant screen by light passing through two narrow slits will be closer together for red light. ✗ opposite of 2	☐

[1]

5 Fig. 5.1 shows a wave at an instant in time with eight positions along the wave labelled **A**–**H**.

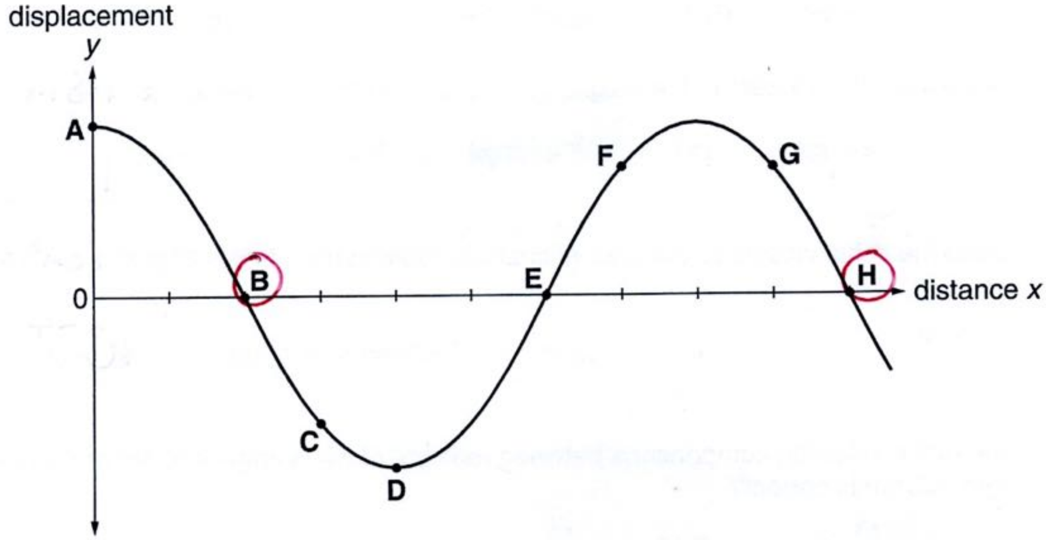


Fig. 5.1

(a) Write down the letters for **two** positions where the wave has the same phase.

B .... and .... H **[1]**

(b) The phasor for the wave at position **A** at this instant is shown in Fig. 5.2.

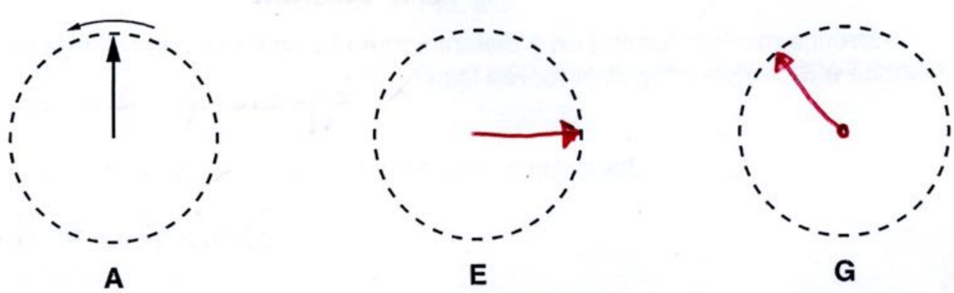


Fig. 5.2

Sketch phasors for points **E** and **G** in the appropriate places in Fig. 5.2. **[2]**

(c) Three waves, each with the same amplitude and wavelength, can superpose to give a resultant amplitude of zero.
Complete the phasor diagram below to show this.

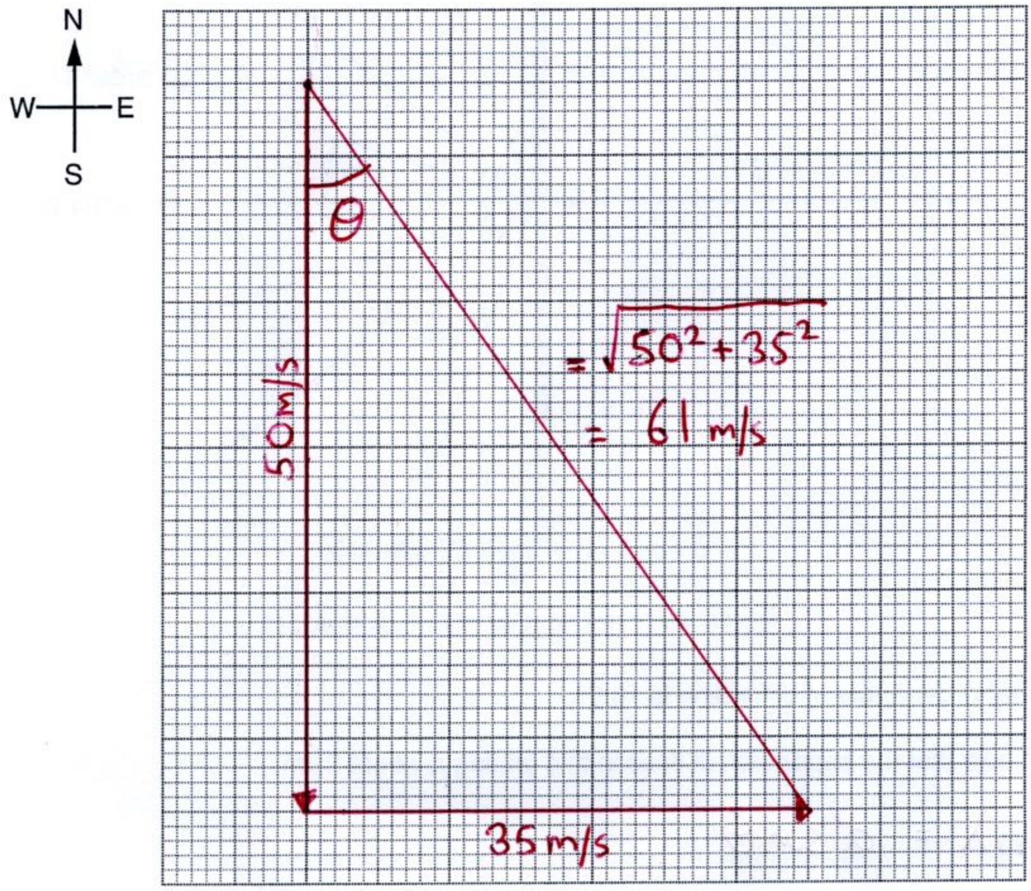
[1]

6 An aircraft is in level flight through still air.

It has the following components of velocity:

north-south: $50\,\text{m}\,\text{s}^{-1}$ towards the south
east-west: $35\,\text{m}\,\text{s}^{-1}$ towards the east

(a) Using a suitable scale, draw these components on the grid below.
Hence or otherwise find the speed and direction of flight of the aircraft.



speed = 61 $\text{m}\,\text{s}^{-1}$

$\theta = \tan^{-1}(35/50) = 35°$ East of South

direction = 145°

[4]

(b) A wind later acts upon the aircraft, changing the aircraft's direction so that it travels due south. Deduce the speed and direction of this wind.

speed = 35 $\text{m}\,\text{s}^{-1}$

direction = West

[2]

or any other where E-W component is 35m/s west.

7 Light of wavelength 590 nm is incident on a diffraction grating as shown in Fig. 7.1. Three orders of diffraction are produced.

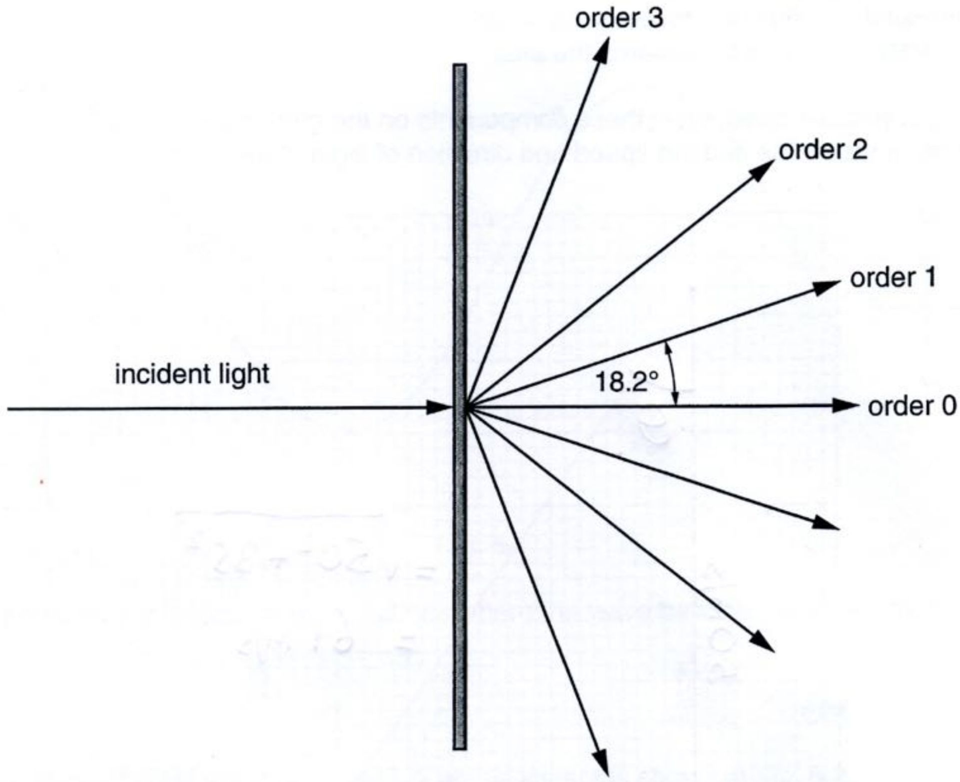


Fig. 7.1

The first-order angle of diffraction is 18.2°.

(a) Show that the separation of lines in this grating is about 2 μm.

$n\lambda = d \sin\theta$

$\therefore d = n\lambda / \sin\theta = \frac{590\times10^{-9}}{\sin 18.2} = 1.89\times10^{-6}\,m$

$\approx 2\,\mu m$

[2]

(b) Calculate the longest wavelength of light which will produce three orders of diffraction with this grating.

Max $\theta = 90°$ & $\sin 90 = 1$

so $3\lambda = d \quad \therefore \lambda = d/3 = \frac{1.89\times10^{-6}}{3}$

$= 6.3\times10^{-7}\,m$

$= 630\,nm$

[1]

SECTION B

8 One alternative energy project involves extracting energy from tidal flows of water.
The test unit, shown in Fig. 8.1, has three turbines on a triangular frame of side 35 m. The unit is fixed to the sea bed and is completely submerged at all times. The turbines turn to face the direction of water flow.

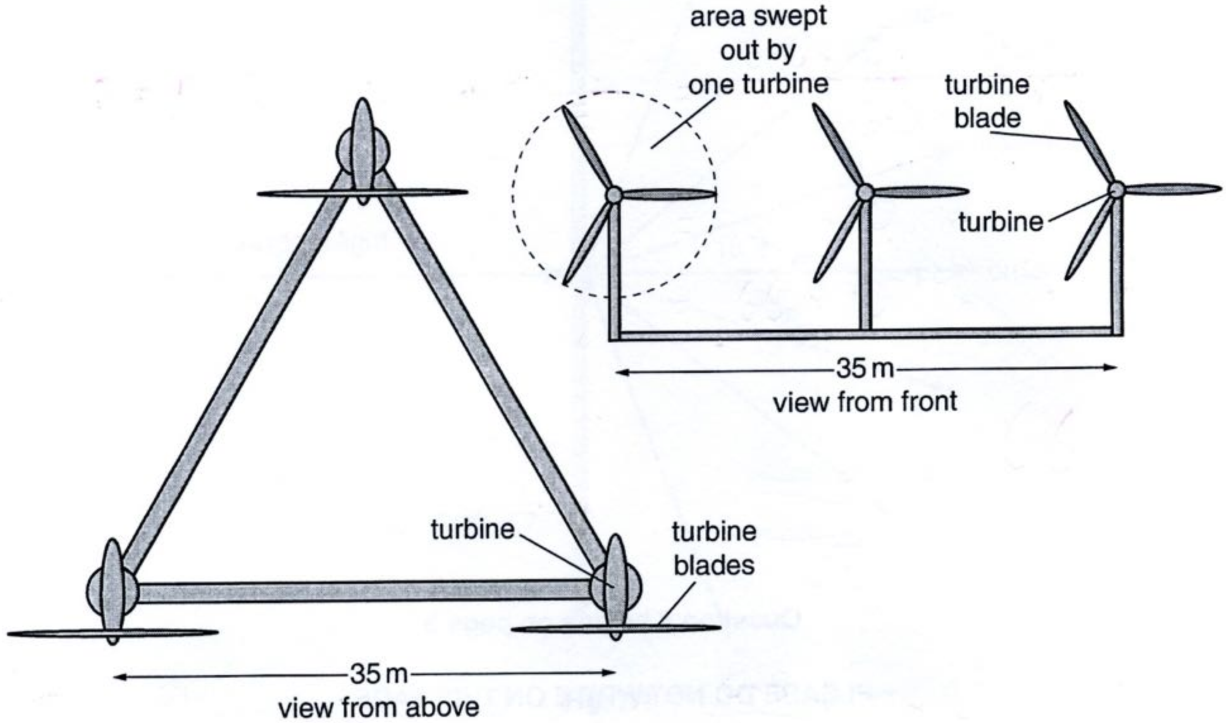


Fig. 8.1

(a) (i) The diagrams are drawn to scale.
Use measurements from the diagram to show that the area swept out by all three turbines is about 500 m^2.

On diagram 35m = 66mm & diameter = 27mm

∴ Actual diameter = $\frac{27}{66} \times 35$ = 14.32m

so radius = 7.16 m & Area = $3 \times \pi \times 7.16^2$ = **483 m^2**

[2]

(ii) The speed of the water moving into the turbines is $2.5\,m\,s^{-1}$.

Show that the mass of water passing through an area of $500\,m^2$ in one second is about 1×10^6 kg.

density of sea water = $1030\,kg\,m^{-3}$

Volume in 1s = $500m^2 \times 2.5m = 1250\,m^3$

mass = density × volume = $1030 \times 1250 = \underline{1.29 \times 10^6\ kg}$

[2]

(b) (i) Use the answer to **(a)(ii)** to show that the total kinetic energy of the water passing into the three turbines in one second is about 4 MJ.

$E_K = mv^2/2 = 1.29 \times 10^6 \times 2.5^2/2 = 4.03 \times 10^6\,J \approx 4MJ$

[1]

(ii) The electrical energy output of the test unit is 1.2 MJ per second under the conditions above.

Suggest and explain **two** reasons for the difference between this value and the answer to **(b)(i)**.

In your answer, distinguish clearly between the two reasons you suggest and link each reason to its explanation.

- Not all E_K is extracted from the water as it still has to flow away ∴ v can't be zero & $\Delta v < 2.5\,ms^{-1}$
- The generator can't be 100% efficient - energy will be lost as heat due to electrical resistance in the coils of wire.

[4]

[Total: 9]

9 This question is about the quantum behaviour of photons and electrons.

(a) An X-ray photon has an energy of 3.0×10^{-15} J.

(i) Calculate the wavelength of these X-rays. Express your answer in pm.

$c = 3.0 \times 10^8\,\text{m}\,\text{s}^{-1}$
$h = 6.6 \times 10^{-34}\,\text{J}\,\text{s}$

$E = hc/\lambda \quad \therefore \quad \lambda = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{3.0 \times 10^{-15}}$

$= 6.6 \times 10^{-11}\,\text{m}$

$= 66 \times 10^{-12}\,\text{m} = 66\,\text{pm}$

wavelength = 66 pm **[2]**

(ii) An X-ray generator of input power 12 kW transfers 0.50 % of the input energy into photons of energy 3.0×10^{-15} J.

Calculate the number of photons emitted each second.

Total Photon energy per second $\frac{0.5}{100} \times 12 \times 10^3 = 60\,\text{J}$

No of photons $= 60/3 \times 10^{-15} =$

number per second = 2×10^{16} s^{-1} **[2]**

(iii) Suggest why the X-ray generator in **(ii)** has to be fitted with a powerful cooling device.

With 12 kW of energy going in and only 60 W of photons coming out it will soon overheat and probably melt if it is not cooled.

[1]

(b) The wavelength associated with electrons of mass m and speed v is

$$\lambda = \frac{h}{mv}.$$

(i) The electrons used in an electron diffraction experiment each have a kinetic energy of 7.0×10^{-17} J.

Show that the electron speed v is about $1 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

$m = 9.1 \times 10^{-31}$ kg

$E_K = mv^2/2 \quad \therefore \quad v = \sqrt{2E_K/m}$

$v = \sqrt{\dfrac{2 \times 7 \times 10^{-17}}{9.1 \times 10^{-31}}} = 1.24 \times 10^{7}\ \mathrm{ms^{-1}}$

[2]

(ii) Show that these electrons show wave behaviour corresponding to a wavelength of about 60 pm.

$h = 6.6 \times 10^{-34}$ J s

$\lambda = \dfrac{h}{mv} = \dfrac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.24 \times 10^{7}} = 5.85 \times 10^{-11}\ \mathrm{m}$

$= 58.5\ \mathrm{pm}$

[1]

(iii) Explain what would happen to this wavelength if the kinetic energy of the electrons was reduced by a factor of 4.

If E_K is reduced by 4x then v will be reduced by 2x as $v = \sqrt{2E_K/m}$

If v is halved then λ is doubled as $\lambda = h/mv$

[2]

[Total: 10]

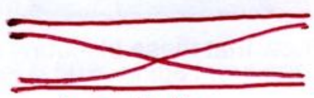
10 A flautist (Fig. 10.1) produces notes on the flute by blowing near one end. This produces stationary waves in the flute. In this question, the flautist uses her fingers to close the holes so that the flute is treated as a tube open at both ends.

Fig. 10.1

(a) Any standing wave produced in the flute has a displacement antinode at each end.

(i) Calculate the **lowest** (fundamental) frequency that can be produced.

speed of sound in air = $340\,\mathrm{m\,s^{-1}}$
length of flute = 66 cm



$L = \lambda/2$

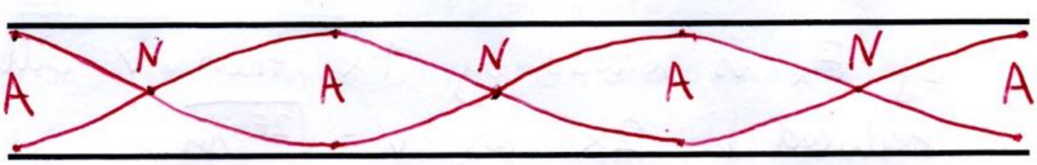
$\lambda = 2L = 2 \times 0.66 = 1.32\,\mathrm{m}$

$f = c/\lambda = 340/1.32 =$

frequency = 258 Hz **[2]**

(ii) By blowing differently, a note of three times the fundamental frequency can be produced.

On the sectional diagram of a flute in Fig. 10.2, indicate the positions of displacement nodes and antinodes for this higher note. Mark each node **N** and each antinode **A**.



not to scale

Fig. 10.2

[3]

(b) During a long concert, the flute and the air inside it become warmer, making the speed of sound higher. To compensate for this, the flautist must adjust the length of the flute.

(i) Explain whether the flute needs to be made shorter or longer to keep it in tune.

If speed of sound is higher then the frequency for a given length will be higher as $f = c/\lambda$. To get the frequency back then the length must be increased by the same proportion as c increased.

[2]

(ii) The speed of sound v in air depends on the air temperature according to the relationship

$$v = k\sqrt{T}$$

where k is a constant and T is the absolute temperature of the air in kelvin, obtained from

T in kelvin = temperature in °C + 273.

283K → 298K

In a concert, the air temperature inside the flute can rise from 10 °C to 25 °C.

Calculate the percentage change in the frequency of the note that this temperature rise would produce if the player did not adjust the length of the flute.

Temperature increases by a factor of $\frac{298}{283}$

$\therefore$ v increases by a factor of $\sqrt{\frac{298}{283}} = 1.0261$

which is an increase of 2.61%. The frequency will increase by the same amount as $f = v/\lambda$

change in frequency = ...2.6.......... % **[3]**

[Total: 10]

11 This question is about a person diving into a swimming pool from a springboard.
Fig. 11.1 shows the sequence of events.

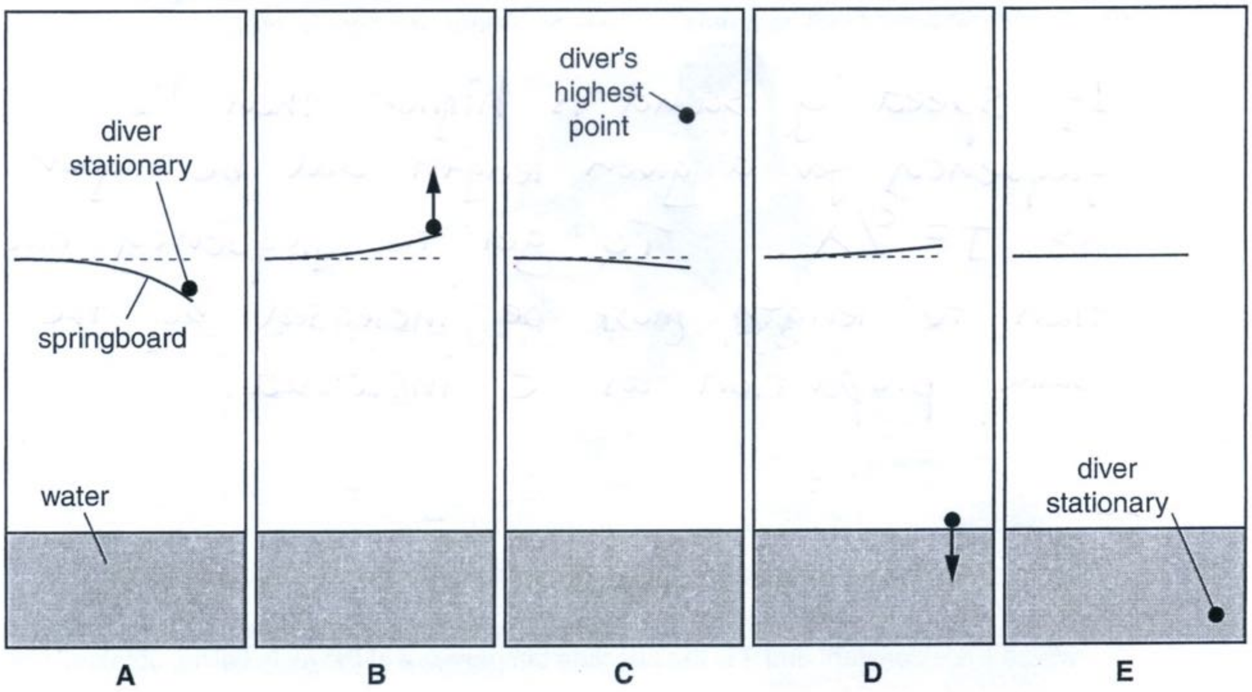


Fig. 11.1

In this simplified model, the diver is shown as a point and the horizontal outwards component of the diver's velocity is ignored, so only vertical motion is shown.

The diver jumps vertically at the end of the springboard and then lands on it, bending it downwards to the position shown in **A**. This is the time $t = 0$. The board then accelerates the diver upwards as it springs back, launching the diver upwards (time **B**). On leaving the board, the diver is in free-fall, rising to his highest point (time **C**), until he hits the water (time **D**). He then decelerates to a stop (time **E**).

Fig. 11.2 shows the velocity-time graph for the diver's vertical motion with the times **A** to **E** shown.

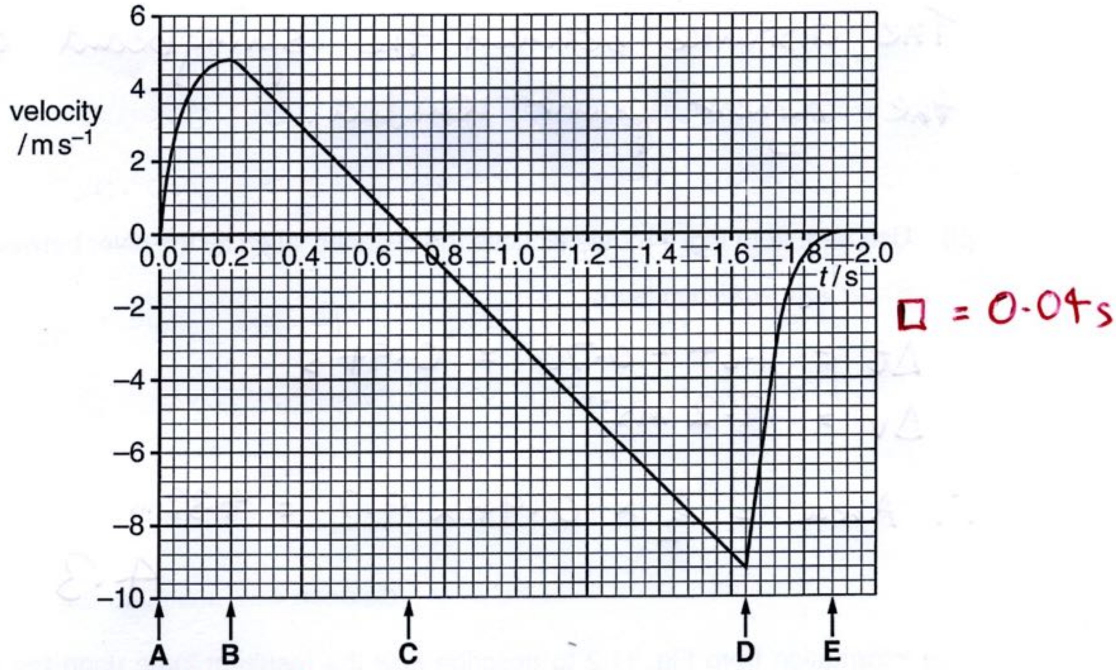


Fig. 11.2

(a) Explain how the graph of Fig. 11.2 shows that the force exerted on the diver by the springboard between times **A** and **B** is greatest at the start.

$F \propto a$ and $a = \Delta v / \Delta t$ = gradient

The gradient is greatest at the start ($t = 0$ s)

[2]

(b) Explain how the graph shows that:

(i) The diver leaves the board at time **B**,

At B the upwards velocity stops increasing so the board is no longer pushing the diver up **[1]**

(ii) The diver is at his highest point at time **C**.

At C the diver's velocity is changing from +ve to −ve and is instantaneously at zero. **[1]**

The diver must be at peak height.

(c) **(i)** State what the area between the graph and the time axis between **B** and **C** represents.

The distance between the springboard and the highest point reached.

[1]

(ii) Use data from Fig. 11.2 to calculate the distance fallen by the diver between **C** and **D**.

Show your working clearly.

$\Delta t = 1.64 - 0.70 = 0.94\ s$

$\Delta v = 9.2\ ms^{-1}$

$\therefore$ Area $= \frac{1}{2} \times 0.94 \times 9.2 = 4.32\ m$

distance = ...4.3.... m **[2]**

(d) Use information from Fig. 11.2 to describe how the resultant force upon the diver changes between **D** and **E**.

Suggest why the force changes in this way.

The force is upwards and starts with a large magnitude which decreases rapidly at first and then less so as v approaches zero. The force is due to drag from the water which will depend on the divers velocity.

[2]

[Total: 9]

Question 12 begins on page 18

SECTION C

The questions in this section are based on the material in the insert.

12 This question is about the article *Oscilloscopes*.

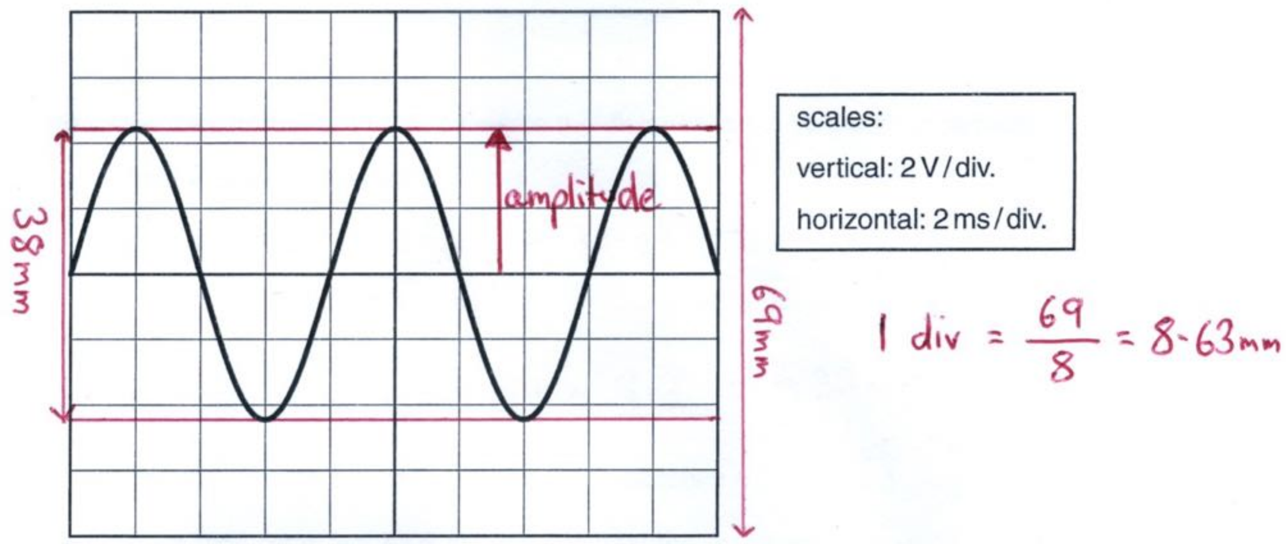


Fig. 12.1

(a) (i) Use data from Fig. 12.1 to calculate a value for the amplitude of the signal.

$\frac{38/2}{8\text{-}63} = 2\cdot2$ div $\times 2$ =

amplitude = 4·4 V **[1]**

(ii) Use data from Fig. 12.1 to calculate the frequency of the signal shown.

$f = 1/T = 1/4 \times 2 \times 10^{-3}$ =

frequency = 125 Hz **[2]**

(b) A CRO has time-base settings ranging from 20 ns / div to 5 s / div. It is possible to take a reading from the screen of this CRO to the nearest 0.1 division.

State the best possible time-resolution of this CRO.

$20 \times 10^{-9} \times 0\cdot1$

resolution = 2×10^{-9} s **[1]**

or 2 ns

(c) Describe and explain one advantage and one disadvantage of a CRO as a method of displaying changing voltages.

Advantage = • wide range of voltage scales
• can follow rapidly changing V.
• 'wave form' display allows easy reading

Disadvantage = • can only deal with periodic (repeating signal) as it needs to repeatedly re-draw to display.

[2]

(d) Over the past 20 years, CROs have been largely replaced by digital storage oscilloscopes.

Describe and explain developments that were necessary for this change to happen.

Cheap and fast computer memory - large amounts of data needs to be stored over very short time intervals.

The voltage sensor and electronic circuits need to have rapid response times to keep track with rapidly changing voltages

[4]

[Total: 10]

13 This question is about the article *Powering electric cars.*

(a) Table 1 in the article (reproduced below) compares three different types of battery.

Battery type	Max energy density/Wh kg^{-1}	Percentage energy efficiency in discharging	Battery cost per kWh capacity
lead-acid	35	85	£65
NiMH	80	80	£320
lithium-ion	200	90	£500

Table 1

(i) Modern electric vehicles have batteries of 24 kWh capacity.

Show that a lead-acid battery of this capacity has a mass of over half a tonne (1 tonne = 1000 kg).

$$\frac{24000\ \text{Wh}}{35\ \text{Wh kg}^{-1}} = 686\ \text{kg}$$

[2]

(ii) Explain why this would be a disadvantage for a car, but an advantage for a forklift truck.

In your answer, you should describe in detail the physics of the disadvantage and advantage.

Increasing the mass of a car will reduce its acceleration and increase the energy needed to climb hills.

A fork lift can be made more stable by using a high mass battery to lower its centre of mass.

[3]

(iii) NiMH batteries have the lowest efficiency in charging and discharging.

Use data from Table 1 to calculate the energy dissipated per second in the battery when it delivers an output power of 50 kW.

80% efficient ∴ 20% lost

50 kW × 0.2 = 10,000 J/s

energy dissipated in one second = 10,000 J **[2]**

(iv) Explain why this energy dissipation is a significant disadvantage for NiMH batteries.

The range of the vehicle will be reduced as it will require more frequent charging. The battery could also suffer from overheating which may dammage it.

[2]

(b) Table 2 in the article has performance data for different electric cars. The performance data for the Peugeot Ion car are reproduced below.

Mass /kg	**Maximum power/kW**	**Charging time/h**	**Time/s to accelerate from 0–27 m s^{-1}**	**Battery capacity /kWh**
1170	49	7	15.4	16

(i) Show that the mean resultant force on the Peugeot Ion while accelerating from 0–27 m s^{-1} is about 2 kN.

$$F = ma = \frac{m\Delta v}{\Delta t} = \frac{1170 \times 27}{15.4} = \underline{\underline{2050\ N}}$$

[2]

(ii) Calculate the mean power required to accelerate this car from 0–27 m s^{-1}.

Make your method clear.

$$P = \Delta E/\Delta t = \frac{\frac{1}{2} m \Delta v^2}{\Delta t} = \frac{\frac{1}{2} \times 1170 \times 27^2}{15.4} = 2.77 \times 10^4$$

mean power = 2.77×10^4 W **[2]**

(iii) Peugeot state the range of the Ion is 120 km at a cruising speed of 80 km/h for a battery charged to 16 kWh.

Show that these data imply an output power much less than the 49 kW given in the table.

$$t = s/v = 120\ km / 80\ kmh^{-1} = 1.5\ h$$

$$P = E/t = 16\ kWh / 1.5\ h = \underline{\underline{10.7\ kW}}$$

[2]

[Total: 15]

14 This question is about the article *Simple pendulum experiment.*

(a) A student obtains the following data for a pendulum of length 30 cm.

Time for 10 oscillations/s									
10.9	10.9	11.0	11.0	10.9	11.0	11.0	11.1	10.9	11.0

(i) The student uses a stopwatch which records time to the nearest 0.01 s.

She decides to quote the data to one decimal place.

Give a reason for this choice.

The stopwatch relys on human reaction time which is variable and is the limiting factor here.

[1]

(ii) State why measuring the time for 10 oscillations instead of one improves the quality of the results.

The absolute uncertainty is the same but gets divided by 10 so the percentage uncertainty is divided by 10.

[1]

(iii) For the data above, the student correctly writes:

mean time for 10 oscillations = 11.0 ± 0.1 s.

Explain why the uncertainty in the period T is ± 0.01 s.

$\frac{\pm 0.1\text{s}}{10} = \pm 0.01\text{s}$

The uncertainty is divided by 10 when calculating the time for 1 oscillation.

[1]

*Or double % error.

(iv) Show that a period $T = 1.10 \pm 0.01$ s leads to a value of

$$T^2 = 1.21 \pm 0.02\,s^2.$$

$T^2 = 1.1^2 = 1.21 s^2$

$T_{min} = 1.10 - 0.01 = 1.09 s \quad T_{min}^2 = 1.09^2 = 1.188 s^2$

$T_{max} = 1.10 + 0.01 = 1.11 s \quad T_{max}^2 = 1.11^2 = 1.232 s^2$

$- \quad 1.21 - 1.188 = 0.022 \quad \therefore \pm 0.02$ to 1 sig fig.

$+ \quad 1.232 - 1.21 = 0.022$

[2]

(b) A second student times 10 oscillations for the range of lengths given in the table. He does not repeat the timing at each length.

L/m	Time for 10 oscillations/s	T/s	T^2/s^2
0.10	6.0	0.60	0.36
0.15	7.9	0.79	0.62
0.20	9.2	0.92	0.85
0.25	10.0	1.00	1.00
0.30	11.2	1.12	1.25
0.35	11.7	1.17	1.37
0.40	12.5	1.25	1.56

(i) Complete the first two rows of the table, and use those data to complete the graph opposite. **[2]**

(ii) Explain why the gradient of this graph should be

$$\frac{4\pi^2}{g}$$

given that

$$T = 2\pi\sqrt{\frac{L}{g}}$$

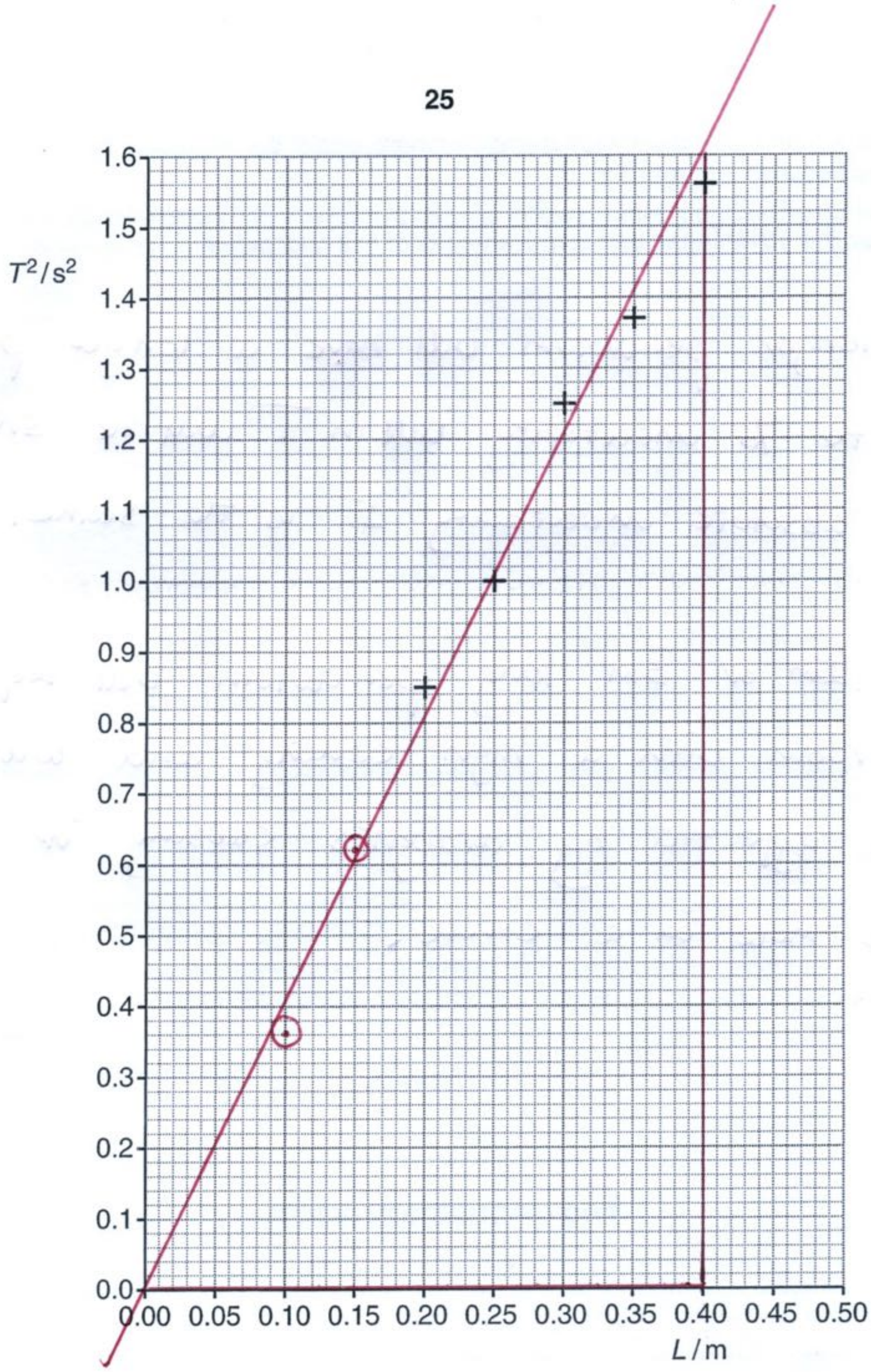
$$\therefore \quad T^2 = \frac{4\pi^2 L}{g}$$

$$\& \quad T^2 = \frac{4\pi^2}{g} L$$

$$\uparrow \qquad \uparrow \qquad \uparrow$$

$y = m \; x$ = Equation of straight line of gradient m.

[2]



(iii) Use the graph to determine a value for g. Show your working clearly.

gradient $= \frac{1.6\,s^2}{0.4\,m} = 4.0\,s^2m^{-1} = \frac{4\pi^2}{g}$

$\therefore g = \frac{4\pi^2}{4.0} = \pi^2 =$

(9.9 prob. more appropriat. answer.)

g = 9.87 m s^{-2} **[3]**

Question 14 continues on page 26

(c) A third student suggests that the experiment could be improved by using pendulums of lengths between 2 m and 3 m.

Discuss the advantages and disadvantages of this suggestion.

A longer pendulum will have a longer period so the % uncertainty in T will be smaller as the absolute uncertainty ΔT is the same.

A 2m or 3m long pendulum will require a room with a high ceiling and will be more affected by draughts causing it to move more in a circle.

[3]

[Total: 15]

END OF QUESTION PAPER