Answer **all** the questions.

Section A

1 Here is a list of units.

$J\,s^{-1}$ $\quad$ $kg\,m\,s^{-2}$ $\quad$ $J\,s$ $\quad$ $N\,m$ $\quad$ $W\,s$

(a) Choose the correct unit for force.

$F = ma$

$kgms^{-2}$ [1]

(b) Which two are units of energy?

$W = Fs$ $\quad$ $E = Pt$

Nm and Ws [1]

2 Here is a list of magnitudes.

10^{-9} $\quad$ 10^{-6} $\quad$ 10^{-3} $\quad$ 1 $\quad$ 10^{3} $\quad$ 10^{6}

(a) Choose the value closest to the wavelength of visible light in m.

100s nm

10^{-6} [1]

(b) Choose the value closest to the weight of a person in N.

$70\text{ kg} \times 10 = 700\text{ N}$

10^{3} [1]

3 Fig. 3.1 shows three different paths for a photon travelling from a source S to a point P on a distant screen.

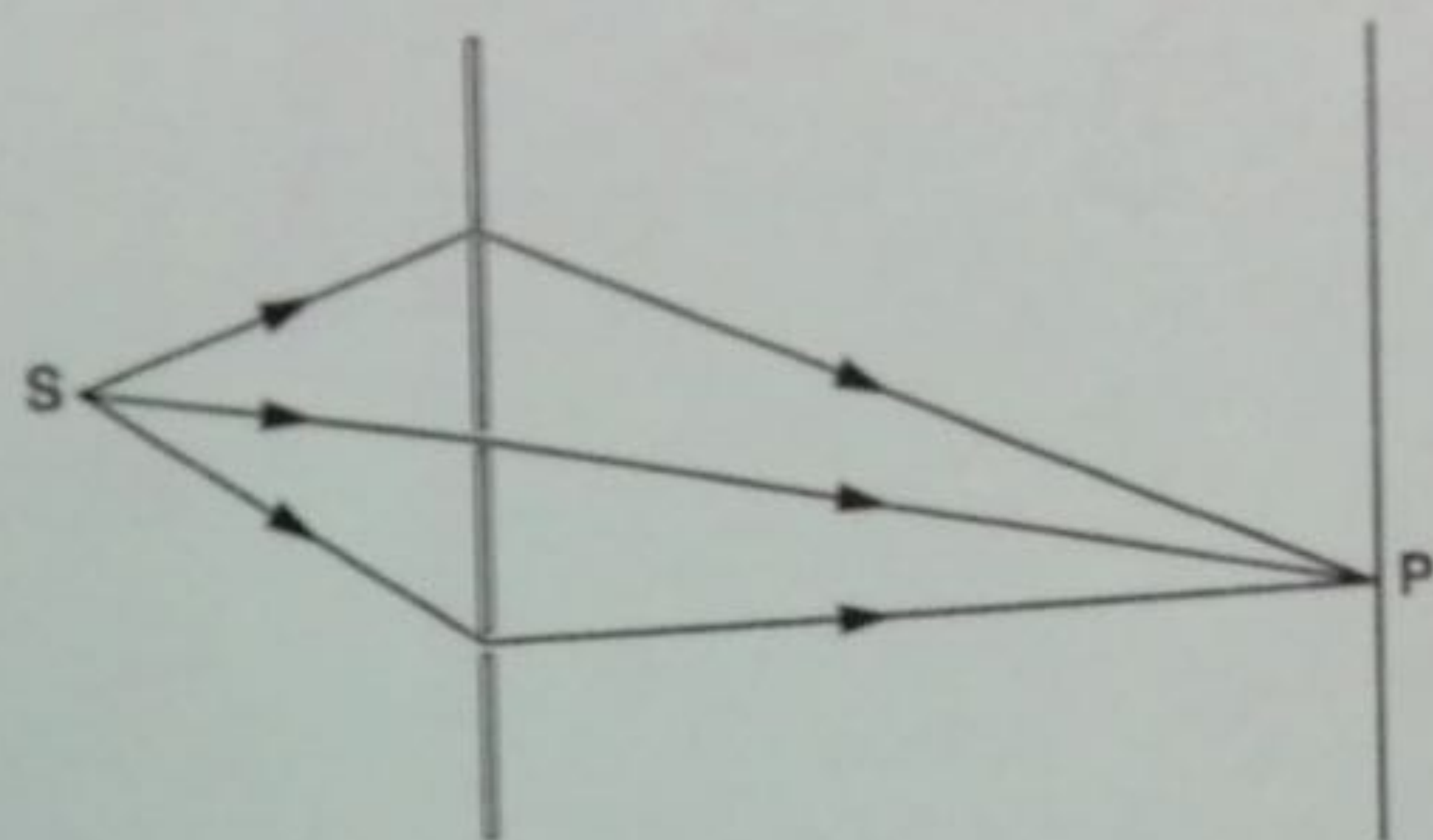


Fig. 3.1

At P, the phasor for each path has the same amplitude as shown by this arrow:

Draw a diagram to show a combination of the three phasors which would give zero light intensity at P.

[2]

4 Diffraction causes light passing though a narrow aperture to spread out.
Which of the following changes, on its own, would **decrease** the amount of diffraction?
Put a tick (✓) in the box next to **each** correct change.

increasing the amplitude of the light ✗	☐
increasing the frequency of the light ✓	✓
increasing the intensity of the light ✗	☐
increasing the wavelength of the light ✗	☐
increasing the width of the aperture ✓	✓

$n\lambda = d \sin\theta$

$\therefore \sin\theta = \frac{n\lambda}{d}$

[2]

Turn over

5 A diffraction grating has 400 lines per millimetre.

(a) Calculate the grating spacing d.

$$d = \frac{\text{length}}{\text{Lines}} = \frac{1 \times 10^{-3} m}{400}$$

d = 2.5×10^{-6} m [1]

(b) Another diffraction grating, of grating spacing $d = 1.6 \times 10^{-6}$ m, is illuminated by light of wavelength 5.0×10^{-7} m.
Calculate the angle θ_2 of the **second-order** maximum in the spectrum.

$$n\lambda = d \sin\theta \quad \therefore \quad \theta = \sin^{-1} \frac{n\lambda}{d}$$

$$= \sin^{-1} \frac{2 \times 5 \times 10^{-7} m}{1.6 \times 10^{-6} m} = \sin^{-1} 0.625$$

θ_2 = $39°$ ° [2]

6 A car of mass 850 kg can accelerate from 0 to 27 m s^{-1} in 15 s.

(a) Show that the mean accelerating force is about 1500 N.

$$a = \frac{\Delta v}{\Delta t} = \frac{27 ms^{-1}}{15 s} = 1.8 ms^{-2}$$

$$F = ma = 850 kg \times 1.8 ms^{-2} = 1530 N$$

[2]

(b) The car moves along a straight, horizontal road at a constant speed of 27 m s^{-1}. The engine provides a constant driving force of 1100 N.
Calculate the power dissipated against friction.

$$P = Fv = 1100 N \times 27 ms^{-1} = 29{,}700 W$$

power = 30,000 W [1]

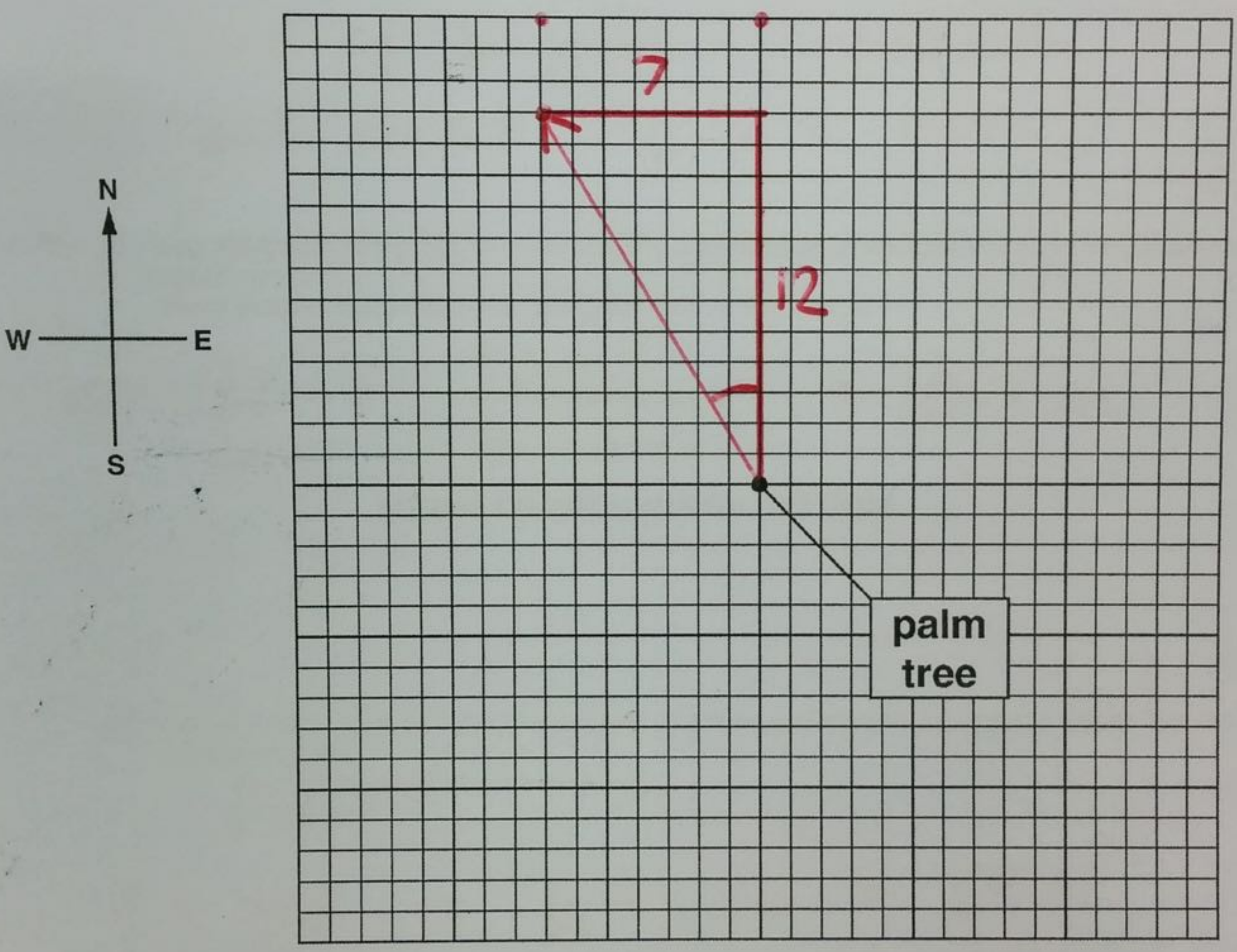
7 A treasure map states:

- from the palm tree, go 15 paces north,
- then go 7 paces west
- the treasure is buried 3 paces south.

By calculation or drawing, find the magnitude and direction of the displacement of the treasure from the palm tree.

The central dot represents the palm tree.

Each small square on the grid below represents one pace.



$d = \sqrt{7^2 + 12^2} = 13.9$ paces

bearing $= \tan^{-1}(7/12) = 30.2°$ W of N

or $330°$

displacement = ... paces

in a direction .... [3]

8 A standing wave is set up on a string as shown in Fig. 8.1.

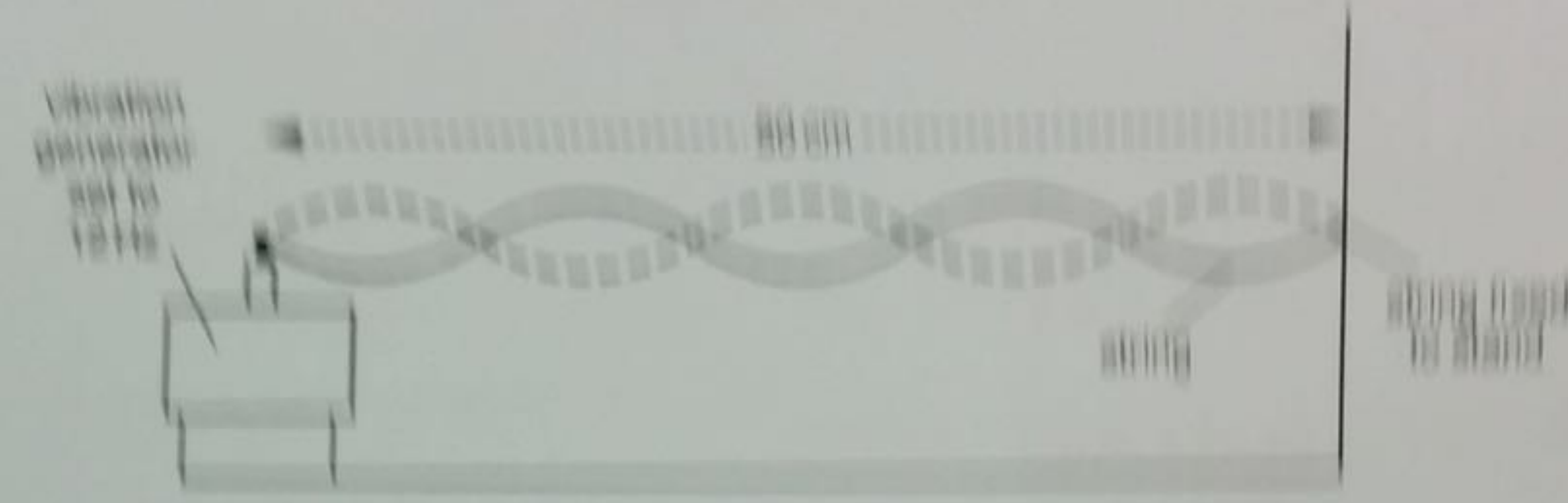


Fig. 8.1

(a) Explain how the diagram shows that the wavelength of waves along the string is 20 cm.

Each loop is $\frac{\lambda}{2}$, 1 loop is $\frac{50\,cm}{5} = 10\,cm$

so $\lambda = 20\,cm$

[1]

(b) When the tension in the string is increased, the frequency must also be increased to keep five loops in the string. The length is unchanged. The table below shows three values of frequency f and tension T which give the standing wave pattern shown in Fig. 8.1.

f/Hz	T/N
12	10
17	20
21	30

Theory suggests that the frequency should be directly proportional to the square root of the tension, $f \propto \sqrt{T}$.

Propose and carry out a test using these data to see whether they fit this relationship.

$f \propto \sqrt{T}$

$\therefore f = k\sqrt{T}$

$\therefore f^2 = k^2 T$

$\therefore \frac{f^2}{T} = k^2 = \text{constant}$

$12^2/10 = 14.4$

$17^2/20 = 14.5$

$21^2/30 = 14.7$

so a good fit.

Better than 2 sig fig given.

[3]

[Section A Total: 21]

Section B

9 This question is about a small rocket taking off.
The rocket has a **constant** upward thrust T provided by the rocket engines, which work by ejecting gases at high velocity.
As gas is ejected, the weight W of the rocket decreases.

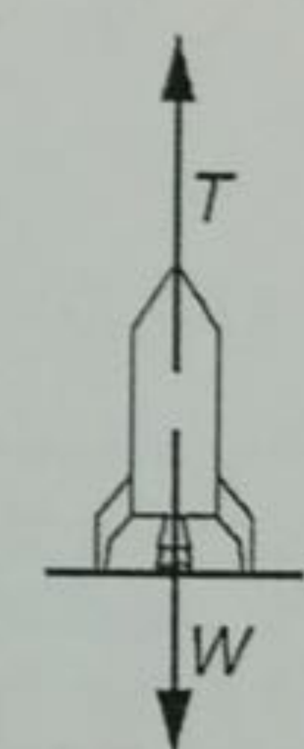


Fig. 9.1

The velocity-time graph for this rocket is shown in Fig. 9.2.
The rocket engines start at time $t = 0\,s$.

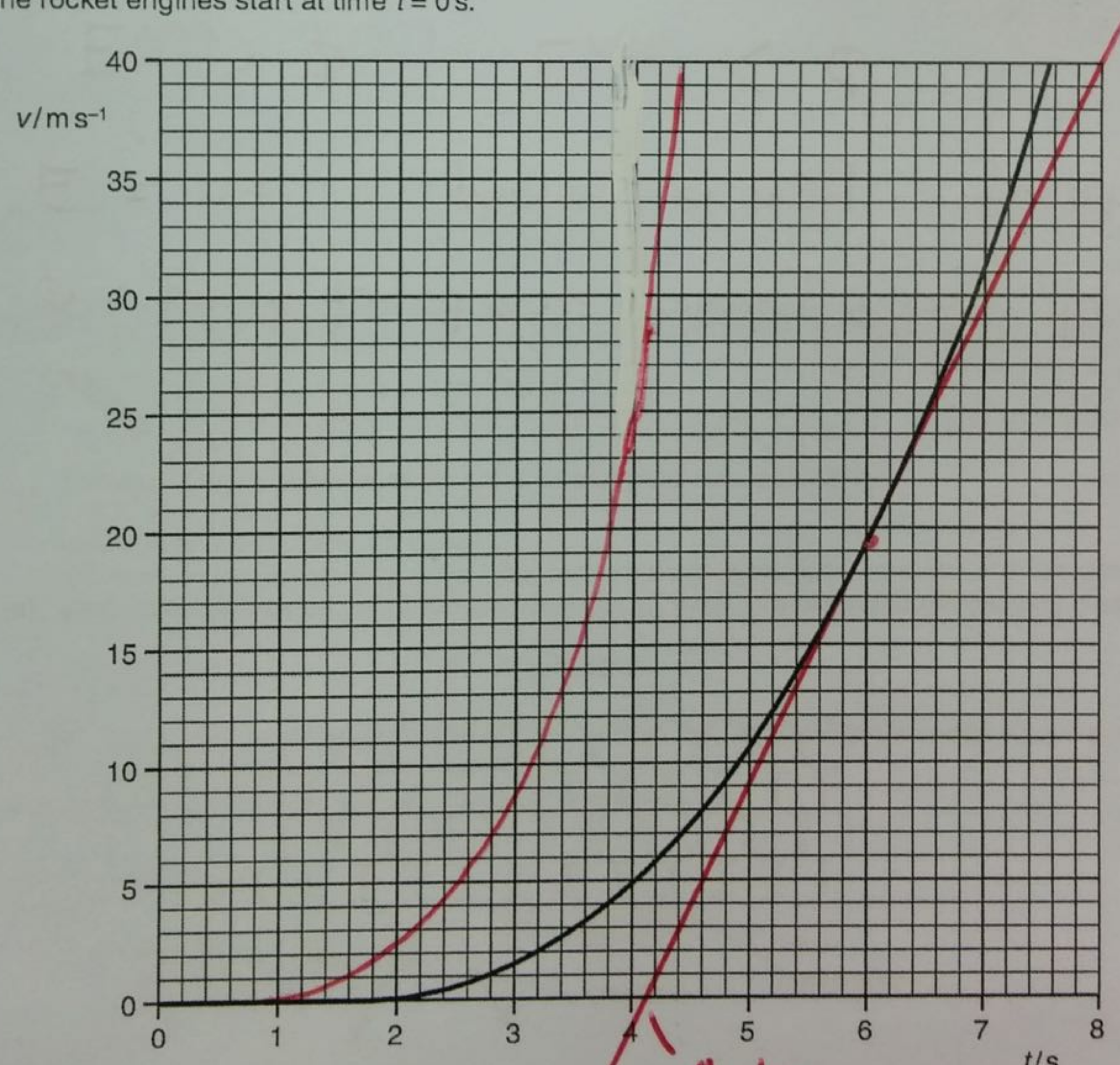


Fig. 9.2

(a) (i) State how the graph of Fig. 9.2 shows that the rocket remains stationary for a short while after the rocket engines start.

V = 0 for first 2s

[1]

(ii) Explain in terms of the forces T and W why the rocket remains stationary for a short while, then begins to rise.

For first 2s W > T. As fuel is used up W falls. Eventually T > W and rocket begins to rise.

[2]

(b) (i) Use the graph of Fig. 9.2 to show that the acceleration of the rocket at the time $t = 6.0\,s$ is about $10\,m\,s^{-2}$.
Show your working clearly on the graph and in this space.

$$a = \frac{\Delta v}{\Delta t} = \frac{40\,ms^{-1}}{8s - 4.1s} = 10.3\,ms^{-1}$$

[3]

(ii) Show that at time $t = 6.0\,s$, the weight W of the rocket is about half the thrust T of the rocket engines.

mass of rocket at this time = 6.9 kg
$g = 9.8\,m\,s^{-2}$

$F = ma = 6.9 \times 10 = 69\,N$

$W = mg = 6.9 \times 9.8 = 68\,N$ ½

$F = T - W \quad \therefore \; T = F + W = 137\,N$

[2]

(c) On Fig. 9.2 opposite, sketch the graph you would expect if the rocket had taken off with a slightly greater mass of gas ejected each second, giving a slightly larger thrust, T.

[2]

[Total: 10]

10 When light illuminates a clean surface of potassium, electrons can be emitted. This is the photoelectric effect. Fig. 10.1 shows a section of the surface at a microscopic scale.

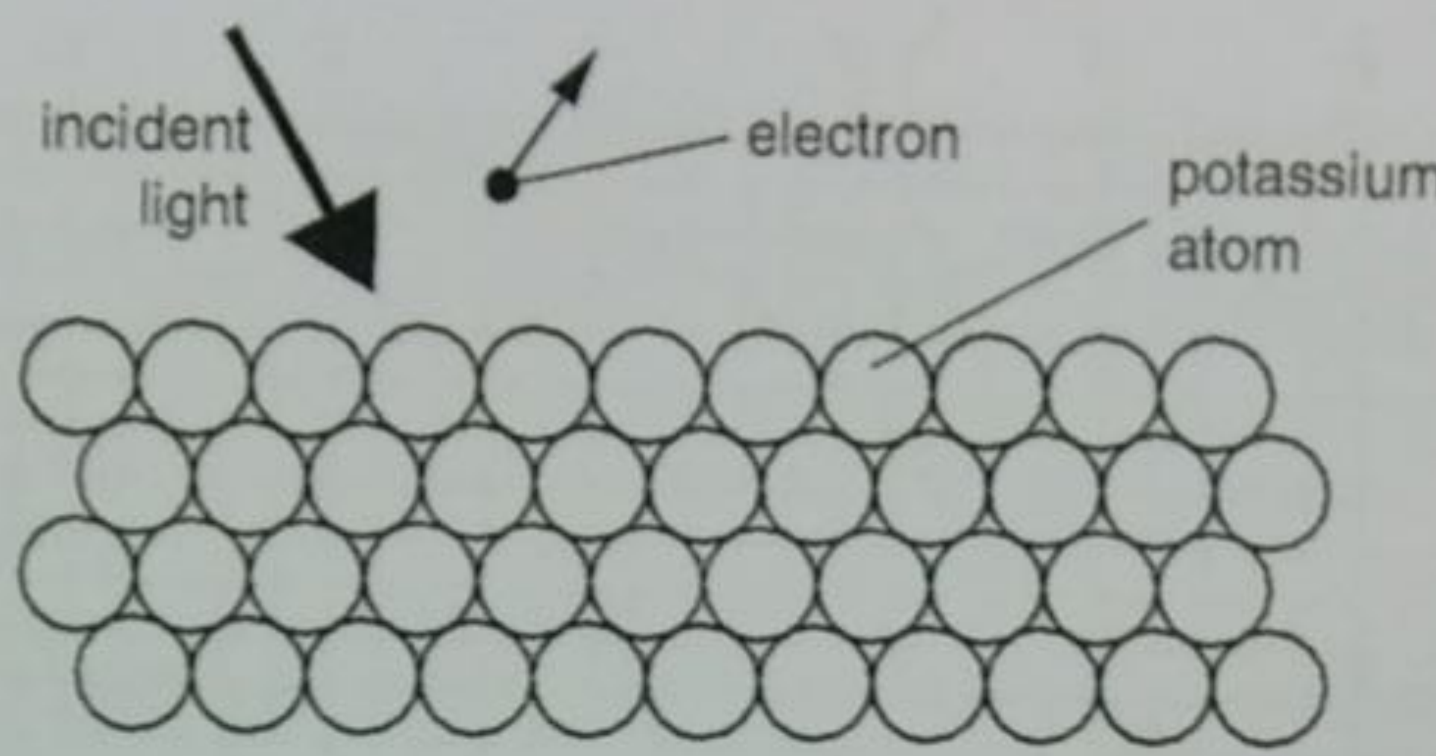


Fig. 10.1

(a) Electrons are emitted when the incident light is violet, but not when the incident light is red. Increasing the intensity of violet light causes more electrons to be emitted. Increasing the intensity of red light has no effect.

Explain how this is evidence for the quantum behaviour of light.

In your answer, you should link the quantum behaviour of light with the different effects seen with red and violet light.

ϕ = work function = energy needed to emit eletron

$E = hf$ = photon energy $f_{violet} > f_{red}$

$E_{violet} > \phi$, $E_{red} < \phi$

One photon emits one electron. If I greater there are more photons per second so more electrons per second.

In wave modle red light would emit photons if intense enough ...

[4]

(b) Einstein explained the photoelectric effect by suggesting that there is a minimum energy ϕ, the work function, which must be supplied to remove an electron from the surface of a metal. The work function for potassium is 3.7×10^{-19} J.
Show that photons of frequency less than 5.6×10^{14} Hz cannot remove electrons from a potassium surface.

the Planck constant, $h = 6.6 \times 10^{-34}$ J s

$E = hf = 6.6 \times 10^{-34} \times 5.6 \times 10^{14}$
$= 3.7 \times 10^{-19}$ J

If f lower E not high enough to emit an electron.

[2]

(c) Fig. 10.2 shows how the maximum energy of electrons emitted by potassium depends on the energy of the incident photons.

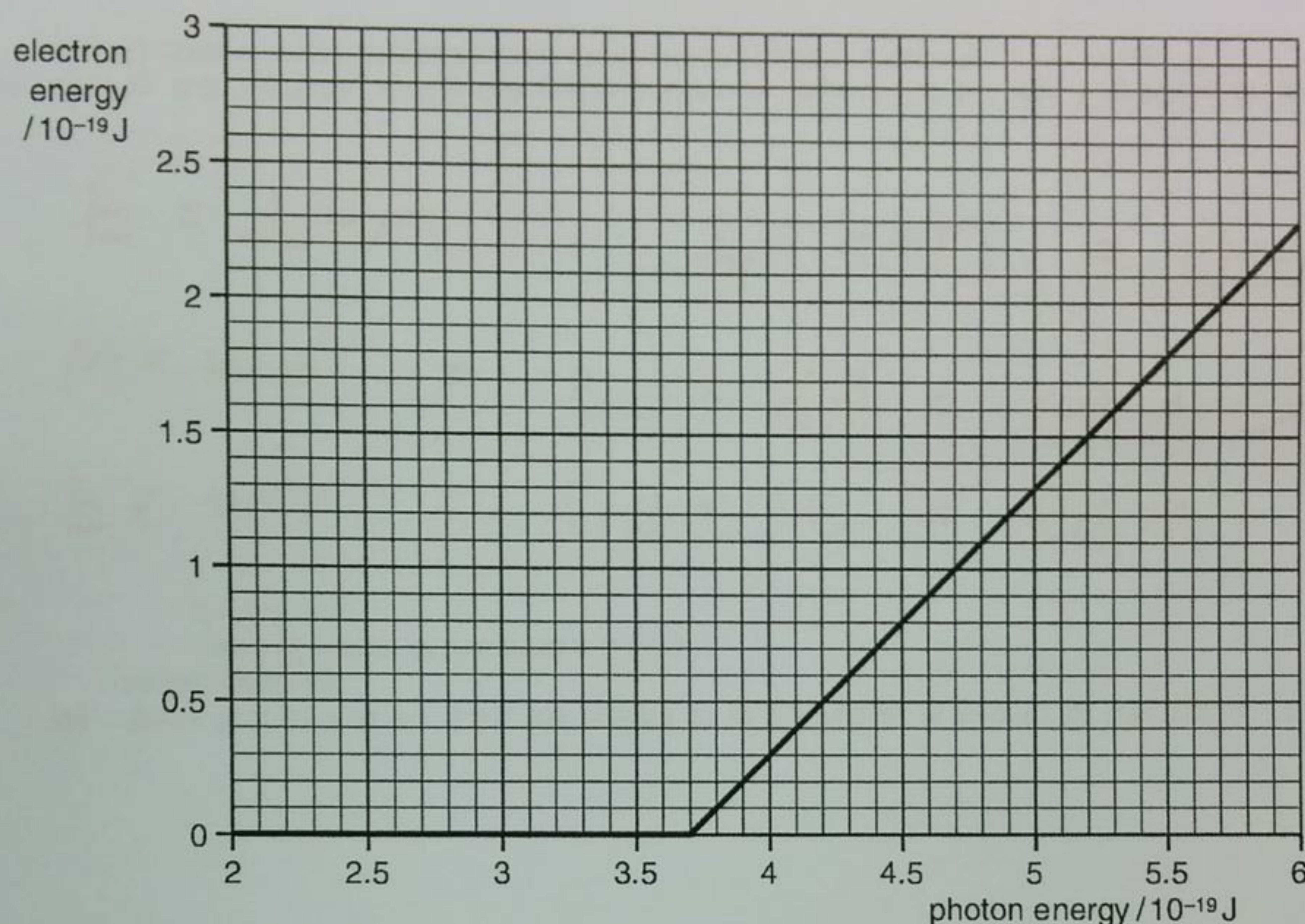


Fig. 10.2

Explain the shape of the graph in Fig. 10.2.

Below 3.7×10^{-19} J . $hf < \phi$ so no electrons

After that electron energy $= hf - \phi$

[2]

(d) One early device using the photoelectric effect was the photoelectric cell. This cell sets up a current in an external circuit when light falls on it.

Suggest one use for a photoelectric cell containing a potassium surface and any limitations it may have in practice.

Light sensor. It does not detect light with a wavelength longer than $\lambda = \frac{c}{f}$ $\frac{3 \times 10^8}{5.6 \times 10^{14}} = 536\text{nm}$

[2]

[Total: 10]

Turn over

11 This question is about the first measurement of the speed of light by the Danish astronomer Ole Rømer in 1676.
He found that there were two times in the year when Jupiter and Io were at the same point in the sky, relative to the stars. The two positions of the Earth at these two times are shown as **A** and **B**, a distance d apart, in Fig. 11.1.

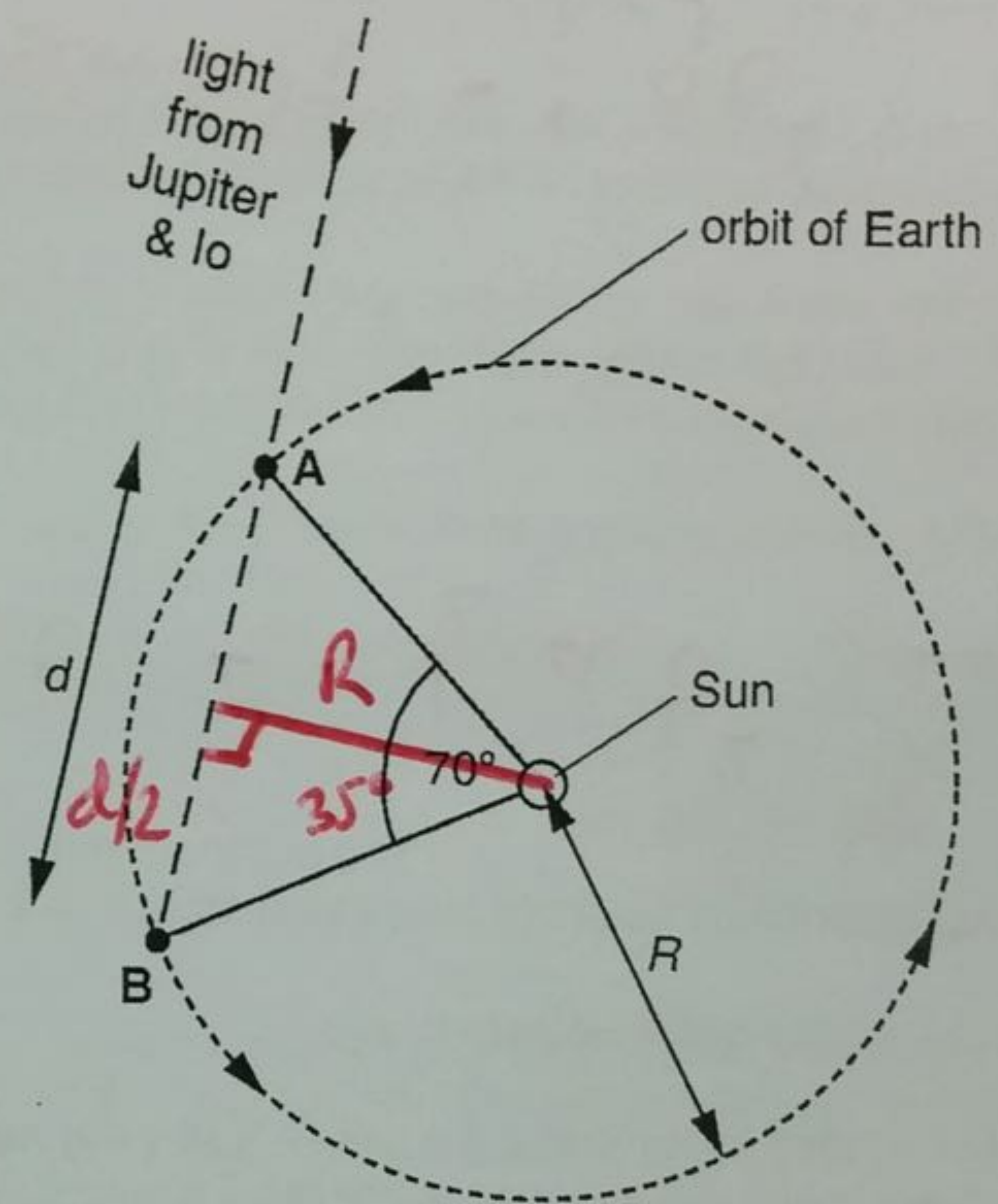


Fig. 11.1

(a) **(i)** Use data from Fig. 11.1 to show that the Earth took 71 days to move from **A** to **B**.
1 year = 365 days

$$\frac{70°}{360°} \times 365 = 71 \text{ days}$$

[2]

(ii) During the time it took the Earth to move from **A** to **B**, the moon Io made 40 orbits around Jupiter.
Calculate the time for one orbit of Io in minutes.

$$\frac{71}{40} \times 24 \times 60$$

time = 2556 minutes **[2]**

(b) Knowing the time for one orbit of Io, Rømer was able to calculate that the time taken for light to travel from **A** to **B** was 11 minutes.

(i) Use the geometry of Fig. 11.1 to show that

$$d = 2R \sin(35°)$$

where R is the radius of the Earth's orbit. Show your working clearly.

$\frac{d}{2} / R = \sin 35°$ (see diagram)

$\frac{d}{2} = R \sin 35°$

$d = 2R \sin 35°$

[2]

(ii) The radius R of the Earth's orbit was estimated in Rømer's time to be 1.4×10^{11} m. Use this value, together with the 11 minutes it took light to travel from **A** to **B**, to calculate the speed of light, c.

$s = \frac{d}{t} = \frac{2 \times 1.4 \times 10^{11} \sin 35}{11 \times 60}$

$= 2.4 \times 10^{8}\ \text{m s}^{-1}$

c = ... m s^{-1} [2]

(iii) Suggest and explain one reason why the value for c obtained in **(ii)** is too low.

Estimate of R is too low.
This makes d too low and hence speed too low.

[2]

[Total: 10]

Turn over

12 This question is about a game in which each player must throw a hard wooden ball into a bucket so that the ball stays in the bucket.
The thrower throws the ball, with initial velocity u at an angle θ to the horizontal, towards a bucket as shown in Fig. 12.1. The ball enters the bucket after time t.

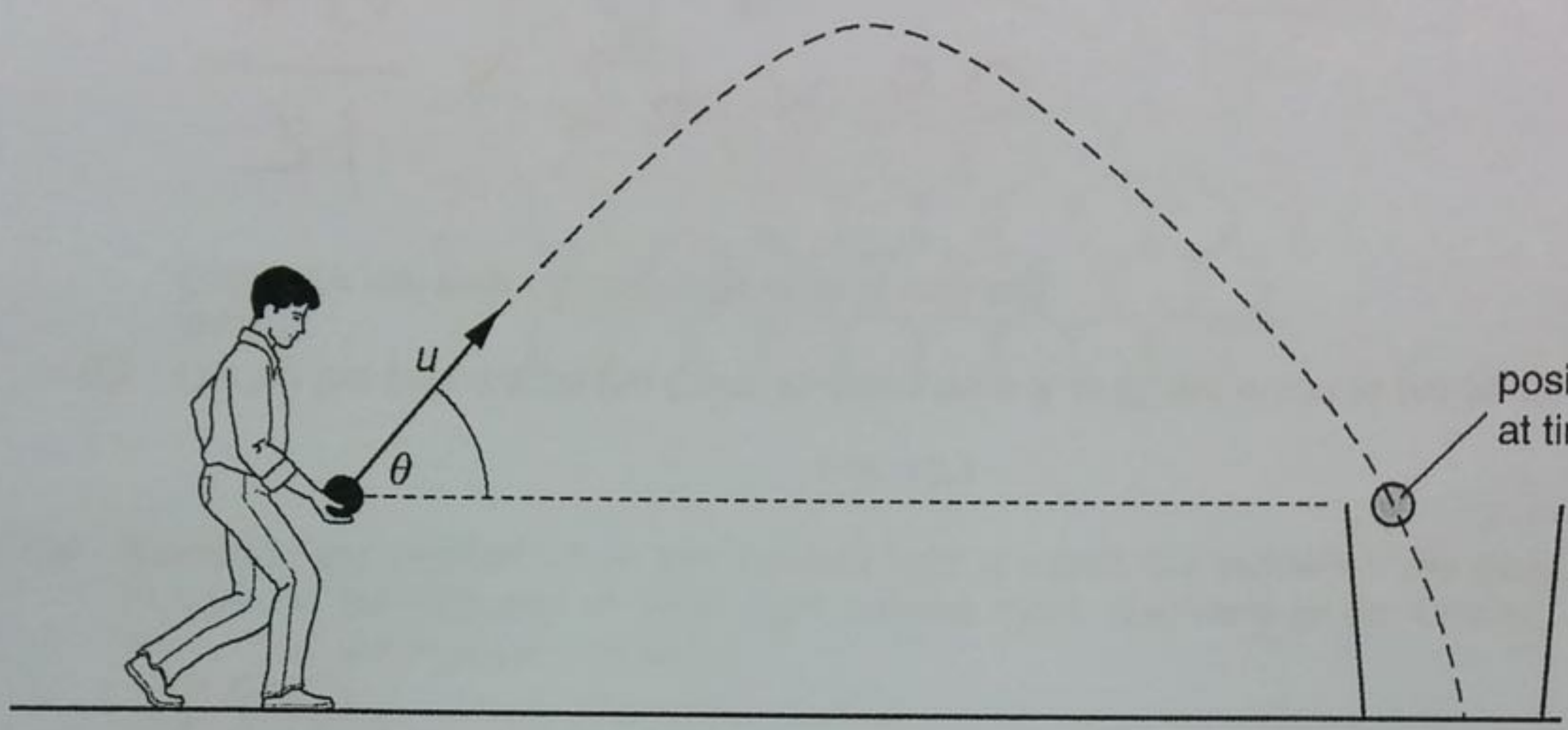


Fig. 12.1

(a) Write down expressions for the horizontal and vertical components of u.

horizontal component of u = u cos θ

vertical component of u = u sin θ [1]

(b) The ball leaves the player's hand at the same height above the ground as the top of the bucket. The time t taken for the ball to reach the top of the bucket is given by the equation

$$0 = (u \sin\theta)t - \tfrac{1}{2}gt^2.$$

(i) Show that this equation arises from applying an equation for uniformly accelerated motion to the vertical motion of the ball.

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

$a = -g \downarrow$

$s = 0$

$u = u\sin\theta \uparrow$

$0 = (u\sin\theta)t - \frac{1}{2}gt^2$

[3]

(ii) Calculate the time taken for a ball thrown at $8.0\,\mathrm{m\,s^{-1}}$ at an angle of $50°$ to the horizontal to reach the top of the bucket.
$g = 9.8\,\mathrm{m\,s^{-2}}$

$$0 = (u \sin\theta)t - \tfrac{1}{2}gt^2$$

$$\therefore \; u \sin\theta = \tfrac{1}{2}gt$$

$$\therefore \; t = \frac{2u\sin\theta}{g} = \frac{2 \times 8 \sin 50}{9.8}$$

$t =$ 1.25 s **[3]**

(c) When the hard wooden ball, thrown as shown at an angle of 50° to the horizontal, hits the **bottom** of the bucket, some kinetic energy is dissipated during the collision, but the remaining kinetic energy is usually enough to allow the ball to bounce back out.
Suggest and explain a strategy for **throwing** the given ball which might increase the chance of the ball staying in the bucket.

Throw at smaller angle so verticle component of bounce is smaller. It will hit the side of the bucket.

[2]

[Total: 9]

[Section B Total: 39]

Section C

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

13 This question is based on the article *Using the speed of water waves to determine g.*

(a) Student A does the experiment by making a wave with a ruler and starting the stop watch at the same time. He stops the watch when it reaches the end of the tank.

Student B makes the wave in the same way, but does not start the watch until the wave reaches the far end of the tank. She then allows the wave to travel up and down the tank several times, stopping the stopwatch when it reaches one end of the tank.

Give **one** reason why student B's method is better than student A's method.

Increasing t reduces % uncertainty
A has to do two things at once.

[1]

(b) Systematic errors can affect the results obtained from this experiment.
Suggest one systematic error which might occur in making these measurements, and how it might be prevented.

End of ruler worn so distances all too short. New ruler.

[2]

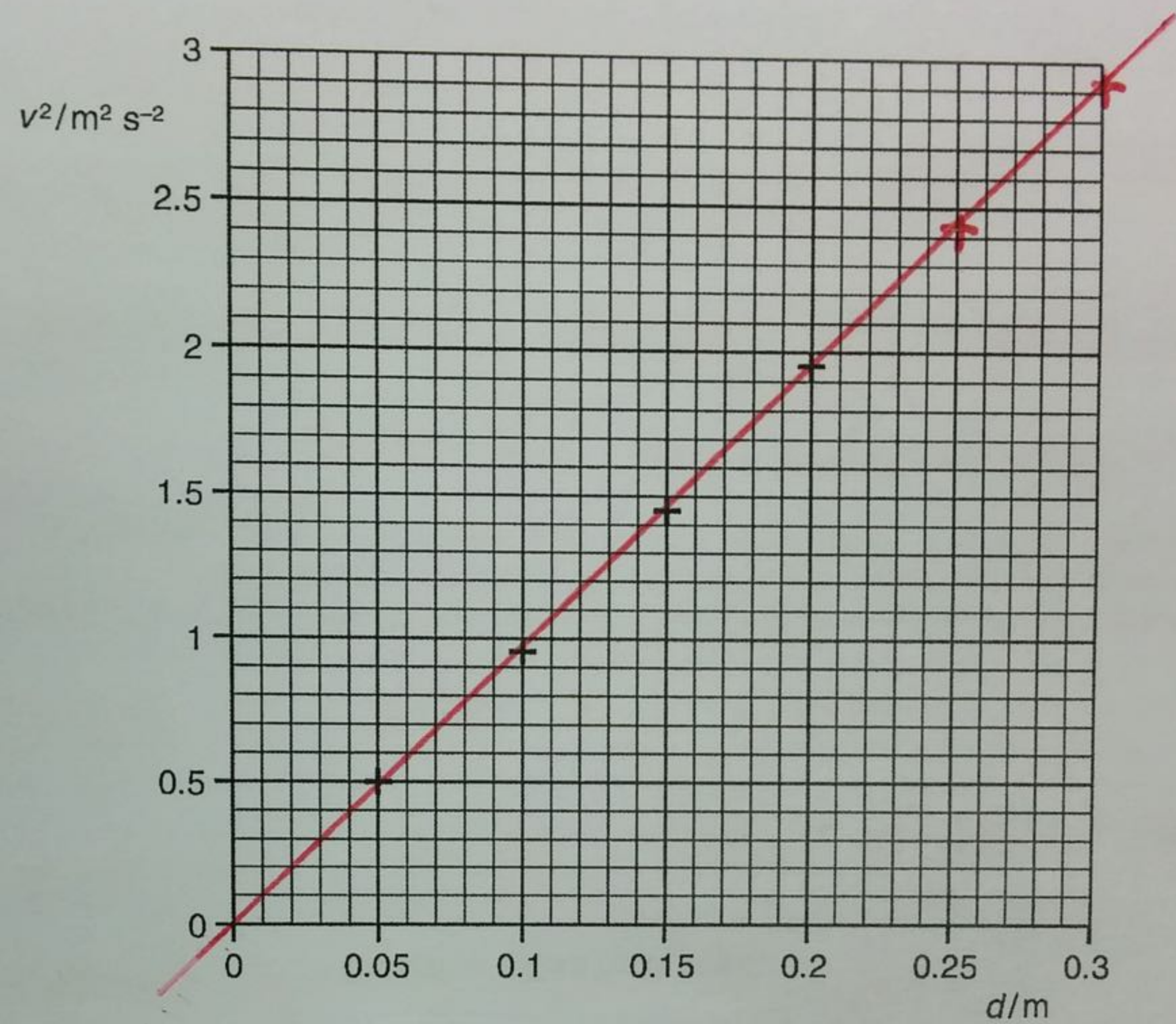
(c) The following data was obtained in an experiment in which the depth *d* and speed *v* were measured rather precisely.

(i) Complete the table.

d/m	v/m s^{-1}	v^2/m^2 s^{-2}
0.05	0.70	0.49
0.10	0.98	0.96
0.15	1.20	1.44
0.20	1.40	1.96
0.25	1.56	2.43
0.30	1.71	2.92

[1]

(ii) Plot your values from the table to complete the graph.
Draw a best-fit straight line.



[3]

(iii) Rearrange the equation $v = \sqrt{gd}$ to show that the gradient of the graph is g.

$v^2 = gd$

c.f. $y = mx$

[1]

(iv) Use the graph to calculate a value for g.
Show all your working on the graph or in this space.

$g = \frac{\Delta v^2}{\Delta d} = \frac{2.92}{0.3}$

$g =$ 9.7 m s^{-2} **[2]**

(d) Another, less carefully done experiment, gave the following measurements.

The student measured the time for a wave to travel from the near end of the tank to the far end and then back to the near end.

	measured value	uncertainty	percentage uncertainty
length of tank/m	0.62	±0.01	2%
time for return journey/s	0.7	±0.2	30%
depth of water/m	0.30	±0.01	3%

(i) Complete the table by calculating the percentage uncertainty for the depth of water. [1]

(ii) Suggest why the uncertainties in the length of the tank and the depth of the water can be ignored when estimating the percentage uncertainty in *g*.

% uncertantity in t >> rest

[1]

(iii) Using the measured values in the table gives a value for *g* of 10.5 m s^{-2}.

Use the maximum possible value of the time for a return journey, together with the measured values of the length of the tank and the depth of water, to calculate the percentage uncertainty in *g*.

$$v = \frac{d}{t} = \frac{0.62 \times 2}{0.7 + 0.2} = 1.38 \text{ ms}^{-1}$$

$$g = \frac{v^2}{d} = \frac{1.38^2}{0.3} = 6.3 \text{ ms}^{-2}$$

percentage uncertainty in *g* = ... % [3]

[Total: 15]

$$10.5 - 6.3 = 4.2$$

$$\frac{4.2}{10.5} \times 100 = 40\%$$

14 This question is about the article *Rolling Friction in Bicycle Tyres – interpreting trends in data.*

(a) Explain why comparing the performance of different tyres is difficult.

Many variables, size, construction, compound etc. [1]

(b) The table of results shows a comparison of type A and type B tyres.

inflation pressure /N cm^{-2}	rolling friction/N					
	type A tyres			type B tyres		
	tyre 1	tyre 2	tyre 3	tyre 1	tyre 2	tyre 3
35	5.76	5.96	5.75	4.80	4.83	4.82
40	5.22	5.40	5.20	4.37	4.37	4.36
45	4.83	5.03	4.80	3.99	4.01	3.98
50	4.52	4.74	4.55	3.73	3.72	3.73
55	4.27	4.49	4.29	3.51	3.50	3.50
60	4.02	4.20	4.02	3.34	3.33	**3.65**
65	3.79	3.99	3.77	3.20	3.22	3.18
70	3.62	3.79	3.62	3.09	3.06	3.09
75	3.48	3.65	3.46	2.97	2.97	2.95
80	3.35	3.55	3.36	2.86	2.85	2.86

The tests on one tyre had a systematic error in the collection of the data.

(i) State the test which was faulty.

test for tyre ....2.... of type ....A.... [1]

(ii) Justify your answer to (i).

All values > other two

[1]

(iii) Suggest and explain what might have been done in the test, illustrated in Fig. 2 in the article, to give rise to this systematic error.

systematic error in pressure. reading being ~ 5 Ncm^{-2} too high

[2]

(c) (i) Using evidence from the variations between tests, explain why it would be justifiable to give the values of rolling friction to 3 significant figures.

Variation is 0·01 - 0·02 N
so loss of 3rd sig fig would loose
information. 4 sig fig gives more
precision than the uncertantity.

[2]

(ii) The value of 3.65 N for the third type B tyres at 60 N cm^{-2} has been highlighted in the table. Give **two** reasons, supported by data from the table, why it is reasonable to be suspicious of this value, and to consider checking it or eliminating it from the data.

3·65 > other two tests.
and is not in line with downward
trend going down column.

[2]

(d) Use the table to suggest and explain which type of tyre would be the more suitable to achieve a high speed, and the best inflation pressure for that tyre.

Type B at 80 N cm^{-2} because
friction is lowest.

[2]

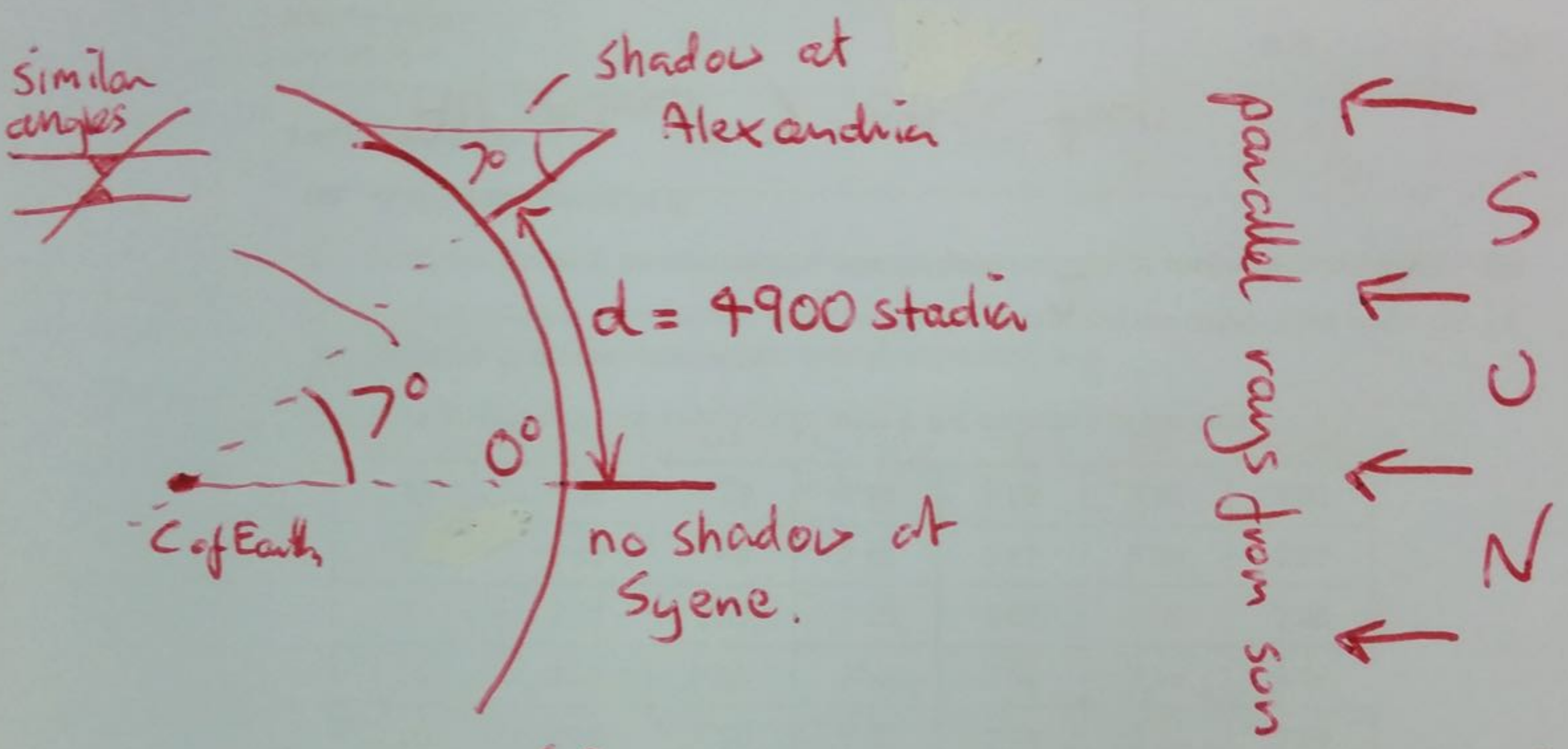
[Total: 11]

15 This question is about the article *Eratosthenes' measurement of the Earth's circumference.*

(a) The unit of distance used by Eratosthenes was the stadion. In his original calculation he estimated the circumference of the Earth to be 252 000 stadia.

Describe how he reached this value from his initial measurement of the angle of the shadow of a vertical post (Fig. 3 in the article).

In your answer, you should make the steps in his calculation clear.



$$C = \frac{4900}{7} \times 360 = 252000 \text{ stadia.}$$

[4]

(b) Suggest one disadvantage to people in Ancient Egypt of measuring distances in terms of the number of days taken for camel caravans to travel them.

Will be affected by health of camels so not consistent.

[1]

(c) (i) The stadion was commonly used at the time but its actual value was not consistent or exact.
An estimate of the value used by Eratosthenes is 1 stadion = 170 m, with an uncertainty of 5%.
Calculate the minimum and maximum values of 1 stadion. Express your answers to two significant figures.

5% of 170m = 8.5 $\approx$ 10m

minimum value = 160 m

maximum value = 180m m **[2]**

(ii) Eratosthenes measured the angle of the shadow at Alexandria as $7 \pm 1°$. He knew that this angle on the Earth's surface corresponded to 4900 stadia.
Use these data, together with the value of 170 m for a stadion, to calculate the maximum and minimum values for the circumference of the Earth.
Compare your results with the current accepted mean circumference of the Earth of 40 010 km (4.001×10^7 m).

max $4900 \times 170 \times \frac{360}{6} = 50,000,000$

min $4900 \times 170 \times \frac{360}{8} = 37,500,000$

maximum value = ... m

minimum value = ... m

His values lie either side of modern value.

[3]

(iii) Explain why the uncertainty in the length of a stadion was not used in **(c)(ii)** to calculate the maximum and minimum values of the circumference of the Earth.

1° in 7° $\approx$ 14% which is $\gg$ 5%

[2]

Question 15 continues on the next page

(d) The article refers to an assumption made by Eratosthenes about the relative locations of Alexandria and Syene.

Eratosthenes thought that Syene was due south of Alexandria. In fact, it was some distance to the east, as shown in Fig. 15.1.

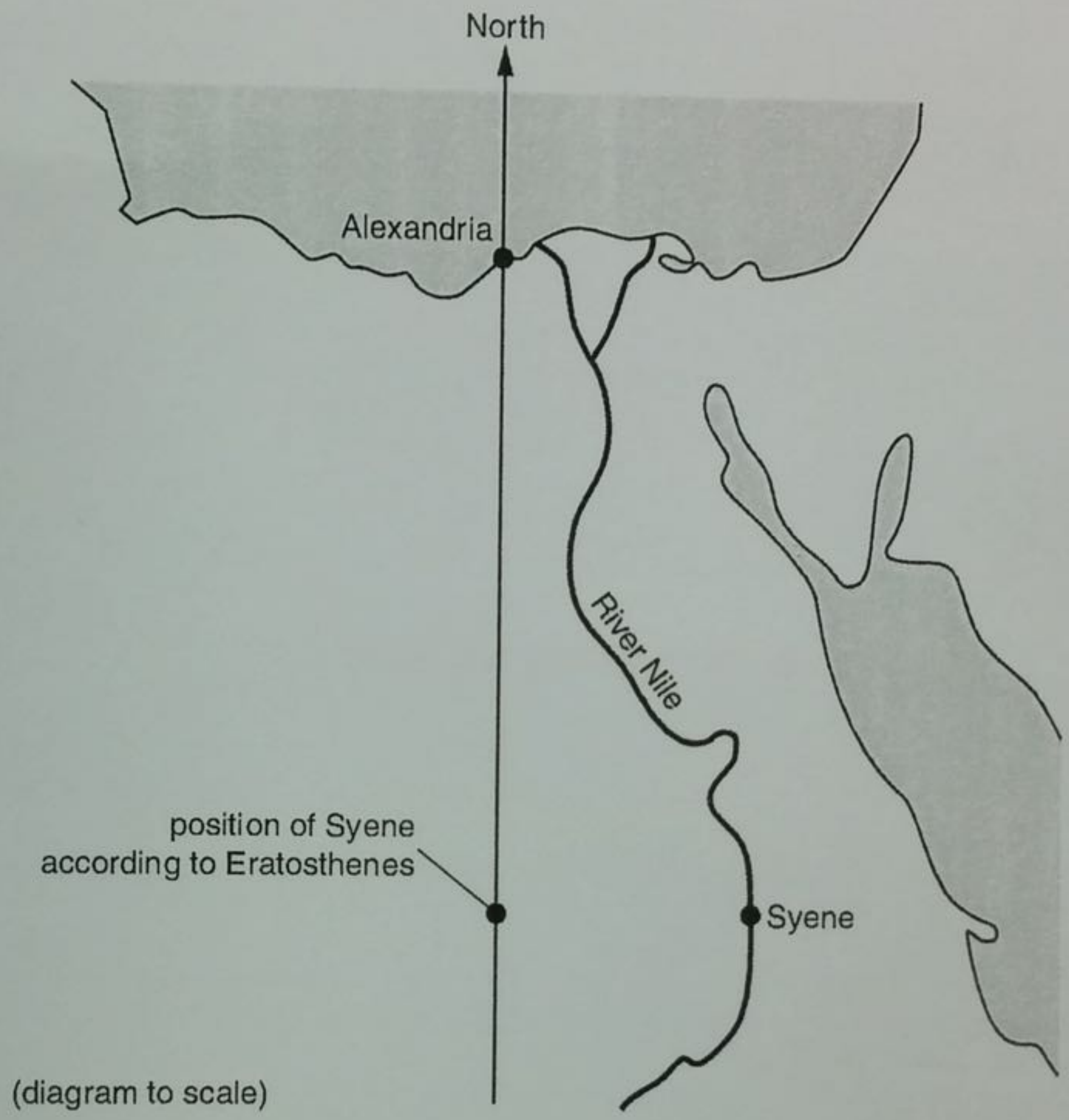


Fig. 15.1

Suggest and explain how this systematic error might affect his calculated value for the circumference of the Earth.

True distance < one he used so final circumference is too big.

[2]
[Total: 14]
[Section C Total: 40]

END OF QUESTION PAPER