Making Measurements and Analysing Data

1. A student determines the power P dissipated in a resistor. The measured values of the current **I** in the resistor and the resistance R of the resistor are:

$$I = (4.0 \pm 0.2)\ \text{A and } R = (3.0 \pm 0.3)\Omega$$

The equation $P = I^2R$ is used to calculate P.
What is the percentage uncertainty in the value of P?

A 15%
B 20%
C 25%
D 30%

Your answer **[1]**

2. The initial temperature T_1 of water in a beaker was 20.1 °C ± 0.2 °C. After the water had been heated for some time, the final temperature T_2 was 27.3 °C ± 0.3 °C. The temperature increase ΔAT is given by $\Delta T = T_2 - T_1$

What is the best estimate of the uncertainty in ΔT?

A. ± 0.05 °C
B. ± 0.1 °C
C. ± 0.25 °C
D. ± 0.5 °C

Your answer

[1]

3. The acoustic impedance Z of a material in the shape of a cube can be determined using the equation

$$Z = \frac{Mc}{L^3}$$

where M is the mass of the material, L is the length of each side of the cube and c is the speed of ultrasound in the material.

The percentage uncertainty in L is 1.2 % and the percentage uncertainty in c is 1.8 %. The percentage uncertainty in M is negligible.

What is the percentage uncertainty in Z?

A 2.2 %
B 3.0 %
C 4.2 %
D 5.4 %

Your answer ☐ **[1]**

4. A student determines the resistance R of a filament lamp by measuring the potential difference V across it and the current I in it. The values recorded by the student are:

V = (5.00 ± 0.20) V and I = (40.0 ± 1.0) mA.

What is the percentage uncertainty in the value of R ?

A 1.5%
B 1.6%
C 6.5%
D 20%

Your answer ☐

[1]

5. To find the density ρ of a metal wire, a student makes the following measurements:

length l = 100 ± 1 mm
diameter d = 2.50 ± 0.05 mm
mass m = 4.00 ± 0.02 g

The equation $\rho = \frac{4m}{\pi d^2 l}$ is used to calculate the density of the metal.

What is the percentage uncertainty in the answer?

A. ± 2.5%
B. ± 3.5%
C. ± 4.5%
D. ± 5.5%

Your answer

[1]

6. Which is the **best** value for the elementary charge *e* in terms of both accuracy and uncertainty?

A $(1.5 \pm 0.5) \times 10^{-19}$ C
B $(1.5 \pm 0.4) \times 10^{-19}$ C
C $(1.7 \pm 0.2) \times 10^{-19}$ C
D $(1.8 \pm 0.2) \times 10^{-19}$ C

Your answer **[1]**

7. Which is **not** an International System (S.I.) base unit?

A second (s)
B kelvin (K)
C kilogram (kg)
D coulomb (C)

Your answer **[1]**

8. The Young modulus E of a metal can be determined using the expression $E = \frac{4F}{\varepsilon \pi d^2}$, where F is the tension in the wire, d is the diameter of the wire and ε is the strain of the wire.

Here is some data.

Quantity	**Percentage uncertainty**
F	5.3
ε	1.2
D	1.0

What is the percentage uncertainty in the calculated value of *E*?

A 2.1 %
B 6.4 %
C 7.5 %
D 8.5 %

Your answer [1]

9. A car travels a distance 166 ± 2 m in a time 5.2 ± 0.1 s.

What is the best estimate of the speed of the car?

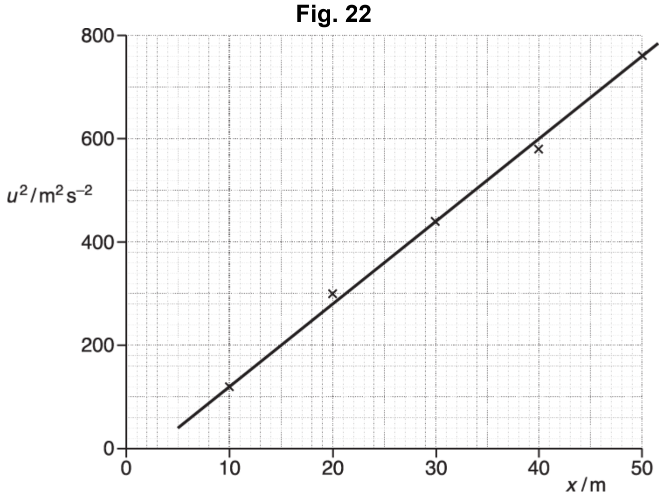
A. 32 ± 1 m s^{-1}
B. 32.0 ± 2.1 m s^{-1}
C. 32.0 ± 0.2 m s^{-1}
D. 32 ± 0.999 m s^{-1}

Your answer

[1]

10. A group of engineers are testing a new car. They are investigating how the braking distance x of the car varies with its initial speed u when a constant braking force is applied.
Fig. 22 shows the data points plotted on a u^2 against x graph. The straight line of best fit has been drawn through the data points.

Fig. 22



The theoretical relationship between u and x for the car is

$$u^2 = 2ax$$

where a is the magnitude of the deceleration of the car.

Fig. 22 shows that the straight line does not pass through the origin because of a systematic error in the measurement of the braking distance x. The u^2 values are accurate.
Suggest why a systematic error in x does not introduce any difference between the actual value and the experimental value for the deceleration of the car.

[1]

11. The cross-sectional area of a wire is recorded as 0.14 ± 0.01 mm^2.
The length of the wire is recorded as 100 ± 1 mm.

What is the percentage uncertainty in the volume of the wire?

A 1.0 %
B 4.6 %
C 7.1 %
D 8.1 %

Your answer ☐

[1]

12. Which is the **best** estimate of the area of a rectangular field of length 98 ± 3 m and width 47 ± 2 m?

A 4600 ± 5 m^2
B 4600 ± 6 m^2
C 4600 ± 300 m^2
D 4606 ± 337 m^2

Your answer [1]

13. Four students each carry out an experiment to determine the acceleration of free fall *g*.

Which is the **least** accurate value?

A (9.0 ± 1.0) ms^{-2}
B (9.5 ± 0.1) ms^{-2}
C (9.6 ± 0.4) ms^{-2}
D (9.7 ± 0.2) ms^{-2}

Your answer [1]

14. A length *x* is 50 mm ± 2 mm. Length *y* is 100 mm ± 6 mm. The length *z* is given by *z* = *y* − *x*.

What is the best estimate of the uncertainty in z?

A. ± 1 mm
B. ± 4 mm
C. ± 5 mm
D. ± 8 mm

Your answer

[1]

15. A solid cylindrical glass rod has length 20.0 ± 0.1 cm and diameter 5.00 ± 0.01 mm.

What is the percentage uncertainty in the calculated volume of this rod?

A 0.1%
B 0.2%
C 0.7%
D 0.9%

Your answer **[1]**

16. A student records the following data during an experiment to determine the internal resistance of a battery.

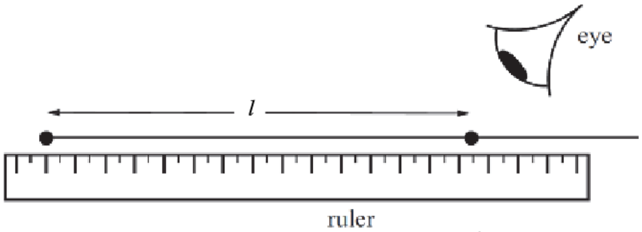
e.m.f. = (4.5 ± 0.2) V
terminal p.d. = (3.0 ± 0.1) V
current = (2.0 ± 0.1) A

What is the percentage uncertainty in the value for the internal resistance of the battery?

A 5.0 %
B 6.1 %
C 13 %
D 25 %

Your answer **[1]**

17. A metre rule is being used to measure the length ℓ of a section of wire. The end of the ruler is displaced from the start of the wire.



What is the nature of the errors associated with the length measurement?

A. There are random errors but no systematic errors.
B. There are systematic errors but no random errors.
C. There are both systematic and random errors.
D. There is no overall error because the random and systematic errors cancel out.

Your answer ☐

[1]

18. The table below shows the measurements recorded by a student for a solid metal sphere. The absolute uncertainties in the mass of the sphere and in its radius are also shown.

mass	100 ± 6 g
radius	1.60 ± 0.08 cm

What is the percentage uncertainty in the density of the sphere?

A. 1%
B. 11%
C. 16%
D. 21%

Your answer ☐

[1]

19. In their laboratory notes, one student writes about the **accuracy** of the measurements whereas the other writes about their **precision**.
Define these terms.

accuracy:

precision:

[2]

20. A toy parachute is falling through air.
The air resistance *F* acting on the parachute is given by the expression

$F = kv^2$

where *v* is the speed of the parachute and *k* is a constant.

The S.I. base units for *F* are kg m s^{-2}.

Show that the S.I. base units for *k* are kg m^{-1}.

[2]

21 (a). A student is investigating the resistance of a conducting putty.

The student rolls the putty into a cylinder shape and connects the ends of the cylinder to metal plates as shown in Fig. 5.1. The ohm-meter is used to measure the resistance *R* of the conducting putty.

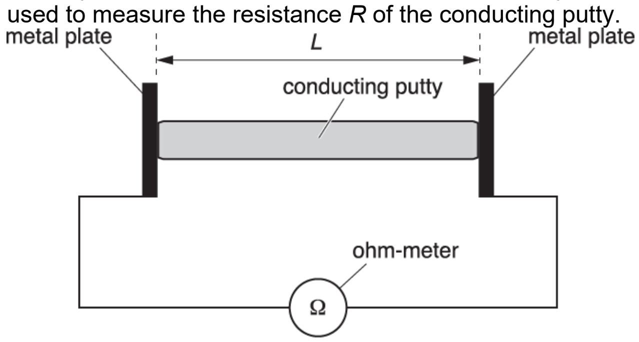


Fig. 5.1

i. Suggest why the student uses large metal plates at the ends of the conducting putty.

[1]

ii. Describe how the student can check that the diameter of the conducting putty is constant.

[2]

(b). The student measures the resistance *R* of the conducting putty for different length *L*.
The volume of the conducting putty is kept constant.

The student's results are shown in Table 5.2.

L / m	R / Ω	L^2 / 10^{-3} m^2
0.049	14	2.4
0.060	21	3.6
0.069	28	4.8
0.081	37	
0.090	46	8.1
0.099	57	9.8

Table 5.2

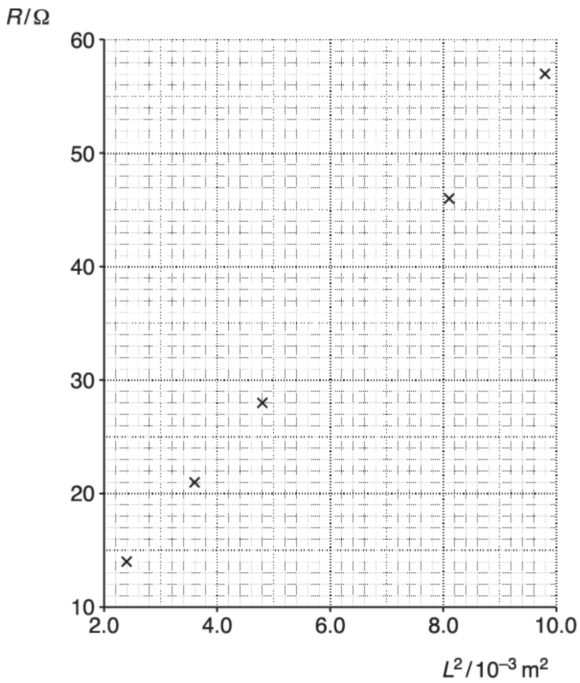
i. Complete the table for the missing value of L^2.

[1]

ii. Each length is measured to the nearest millimetre using a ruler.
Determine the percentage uncertainty in L^2 for L = 0.049 m.

percentage uncertainty = ...% **[1]**

(c). Fig. 5.3 shows the graph of *R* (*y*-axis) against L^2 (*x*-axis).



i. Plot the missing data point and draw the straight line of best fit.

[2]

ii. Determine the gradient of the line of best fit.

gradient = ... **[2]**

Fig. 5.3

(d). The relationship between R and L is

$$R = \frac{\rho}{V} L^2$$

where ρ is the resistivity of the conducting putty and V is the volume.

Use your answer to **(ii)** from the previous question and $V = 1.9 \times 10^{-5}$ m^3 to determine a value for ρ. Include an appropriate unit.

ρ = ... unit: .... **[3]**

22. A toy parachute is falling through air.
The air resistance F acting on the parachute is given by the expression

$F = kv^2$

where v is the speed of the parachute and k is a constant.

The following items of data are collected for the parachute.

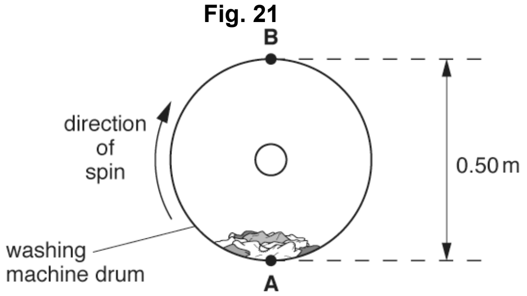
- $v = 1.20 \pm 0.12$ m s^{-1}
- $F = 4.00 \pm 0.24$ N

Calculate the absolute uncertainty in k. Write your answer to 2 significant figures.

absolute uncertainty in k = ... kg m^{-1} **[3]**

23. Fig. 21 shows the drum of a washing machine.

Fig. 21



The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

The drum has diameter 0.50 m. The manufacturer of the washing machine claims that the drum spins at 1600 ± 100 revolutions per minute.

Calculate the speed of rotation of the drum and the absolute uncertainty in this value.

speed = ± ms^{-1} **[3]**

24 (a). A group of students are conducting an experiment in the laboratory to determine the value of absolute zero by heating a fixed mass of gas. The volume of the gas is kept constant.
Fig. 17.1 shows the arrangement used by the students.

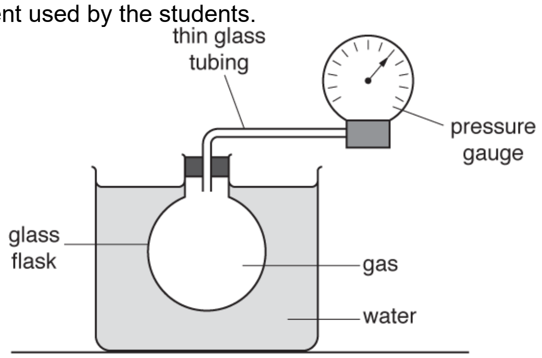


Fig. 17.1

The gas is heated using a water bath. The temperature θ of the water is increased from 5 °C to 70 °C.
The temperature of the water bath is assumed to be the same as the temperature of the gas. The pressure p of the gas is measured using a pressure gauge.

The results from the students are shown in a table.

θ / °C	***p* / kPa**
5 ± 1	224 ± 3
13 ± 1	231 ± 3
22 ± 1	238 ± 3
35 ± 1	248 ± 3
44 ± 1	

53 ± 1	262 ± 3
62 ± 1	269 ± 3
70 ± 1	276 ± 3

Describe and explain how the students may have made accurate measurements of the temperature θ.

[2]

(b). Fig. 17.2 shows the pressure gauge. Measurements of p can be made using the kPa scale or the psi (pounds per square inch) scale. The students used the psi scale to measure pressure and then converted the reading to pressure in kPa.

Fig. 17.2

i. Suggest why it was sensible to use the psi scale to measure p.

[1]

ii. The students made a reading of p of 37.0 ± 0.5 psi when θ was 44 ± 1°C.
Convert this value of p from psi to kPa. Complete the table for the missing value of p. Include the absolute uncertainty in p.

1 pound of force = 4.448 N

1 inch = 0.0254 m

[2]

(c). Fig. 17.3 shows the graph of p against θ.

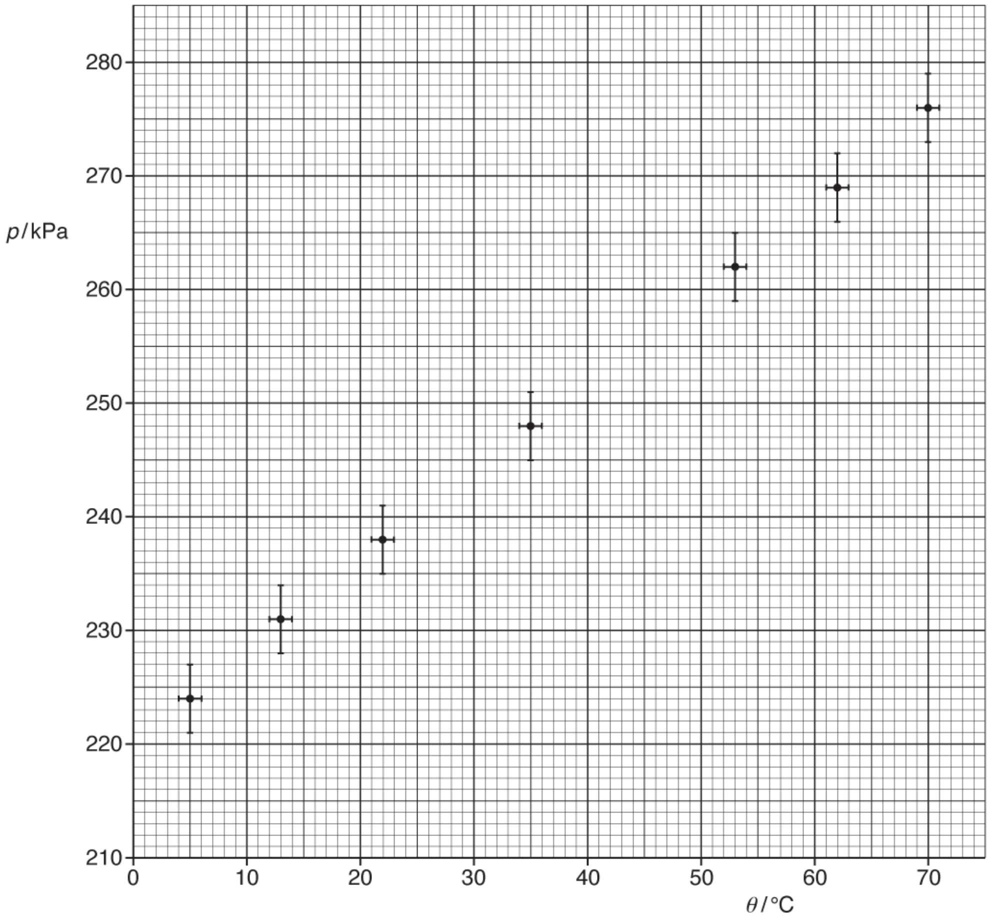


Fig. 17.3

i. Plot the missing data point and the error bars on Fig. 17.3.

[1]

ii. Explain what is meant by *absolute zero*. Describe how Fig. 17.3 can be used to determine the value of absolute zero.
Determine the value of absolute zero. You may assume that the gas behaves as an ideal gas.

[6]

(d). Describe, without doing any calculations, how you could use Fig. 17.3 to determine the actual uncertainty in the value of absolute zero in **(c)(ii)**.

[2]

(e). The experiment is repeated as the water bath quickly cools from 70 °C to 5 °C. Absolute zero was found to be −390°C.

Compare this value with your value from **(c)(ii)** and explain why the values may differ. Describe an experimental approach that could be taken to avoid systematic error in the determination of absolute zero.

[4]

25. A student is determining the acceleration of free fall g using a metal sphere on a ramp. The sphere is released from the ramp at different heights. The speed v of the sphere at the bottom of the ramp is determined.

The acceleration of free fall g is given by the expression $g = \frac{v^2}{2d}$, where d is the initial height of the sphere and v is speed of the sphere at the bottom of the ramp.

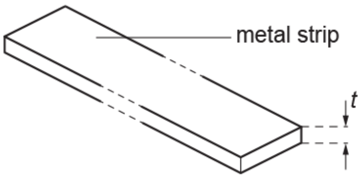
The student records the following data.

- $d = 0.100 \pm 0.002$m
- $v = 1.4 \pm 0.1$ms^{-1}

Calculate the absolute uncertainty in g. Write your answer to **2** significant figures.

absolute uncertainty = ... ms^{-2} **[3]**

26. A metal strip has thickness t, as shown below.



Five measurements of the thickness t at different positions along the length of the strip are shown below.

1.86 mm 1.88 mm 1.85 mm 1.89 mm 1.88 mm

Determine the percentage uncertainty in the thickness t.

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

27 (a). A student is investigating stationary waves in the air column inside a tube, using the apparatus shown in **Fig. 5.1**.

The loudspeaker emits sound of frequency *f* and wavelength λ. The tube is initially fully immersed in the water. The student then slowly raises the tube until the oscilloscope trace shows its first maximum. A stationary wave of fundamental frequency *f* is produced in the air column. When this occurs, the student measures the length *l* of the tube above the water level.

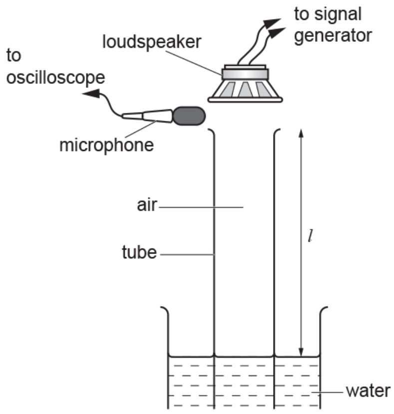
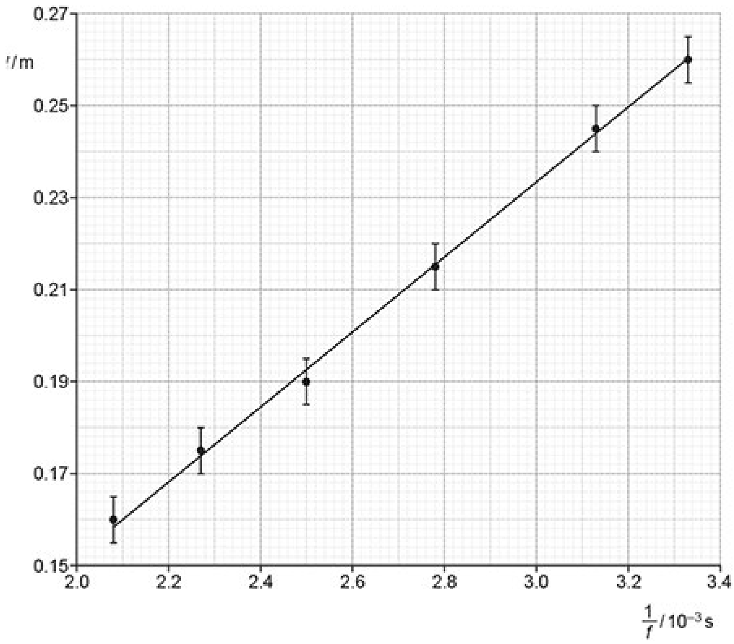


Fig. 5.1

Theory suggests that f and l are related by the e quation $4(l + k) = \frac{v}{f}$ 'where v is the speed of sound in air and k is a constant.

The student measures corresponding values of *l* and *f* and plots a graph of *l* against $\frac{1}{f}$.

The data points, error bars and the line of best fit drawn by the student are shown in the graph below



i. Show that the line of best fit has gradient $= \frac{v}{4}$ and y-intercept = – k.

[2]

ii. Calculate v from the gradient of the line of best fit.

v = ... m s^{-1} **[3]**

(b). The experiment is repeated using the same tube and an unlabelled tuning fork, as shown in **Fig. 5.2**. The distance l is measured as 22 cm.

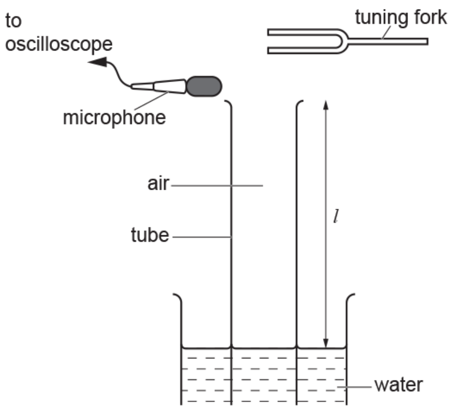


Fig. 5.2

The frequency of the vibrating tuning fork is *F*.

i. Use the line of best fit on the graph to estimate *F*.

F = ...Hz**[2]**

ii. The percentage uncertainty in the value of *F* can be written as $100\,\frac{\Delta F}{F}$ where $\Delta F$is the absolute uncertainty in *F*.

Use the rules for combining uncertainties to write an expression for the percentage uncertainty in the value of *F* in terms of *v* and its absolute uncertainty Δv, *l* and its absolute uncertainty Δl and k and its absolute uncertainty Δk.

[2]

28. Fig. 26.1 shows the variation of displacement *y* with position *x* of a progressive transverse wave on a stretched string at a particular instant.

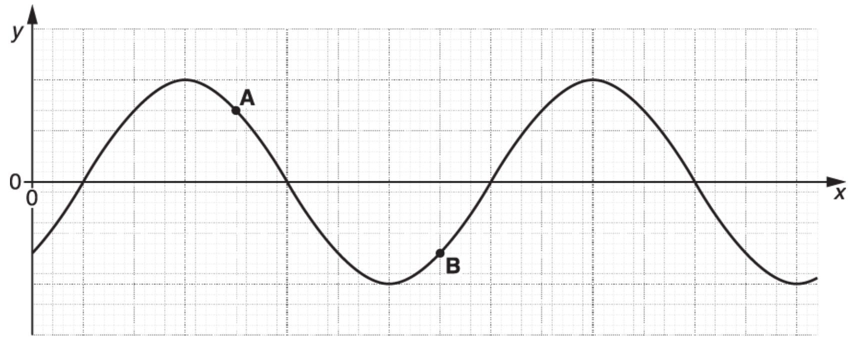


Fig. 26.1

The motions of particles **A** and **B** of the string is analysed over a short period of time. The distance between the positions of **A** and **B** is half a wavelength of the wave. The particles **A** and **B** have the same speed.

i. State **one** difference between the motions of these particles.

[1]

ii. The particle **A** oscillates with frequency 75 Hz.
The distance between the positions of **A** and **B** is (40.0 ± 2.0) cm.
Calculate the speed *v* of the transverse wave on the string and the absolute uncertainty in this value.

v = ... ± .... m s^{-1} **[3]**

29 (a). Fig. 3.1 shows an experiment to investigate the extension of two identical springs connected side by side. A student uses a 30 cm ruler to measure the length L_0 of the two-spring combination without a load attached.

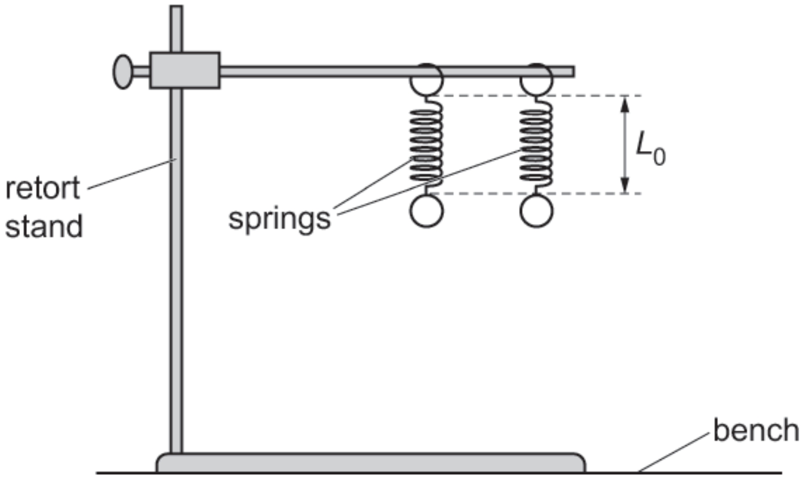


Fig. 3.1

The student then adds a rod and a mass *M* to the spring combination as shown in **Fig. 3.2**.

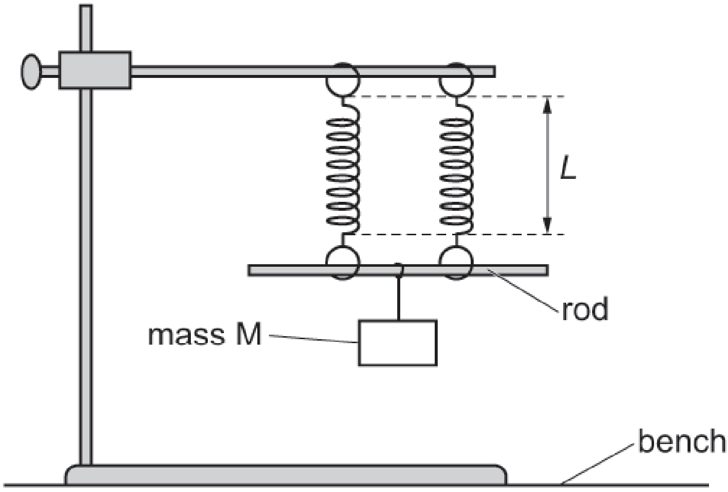
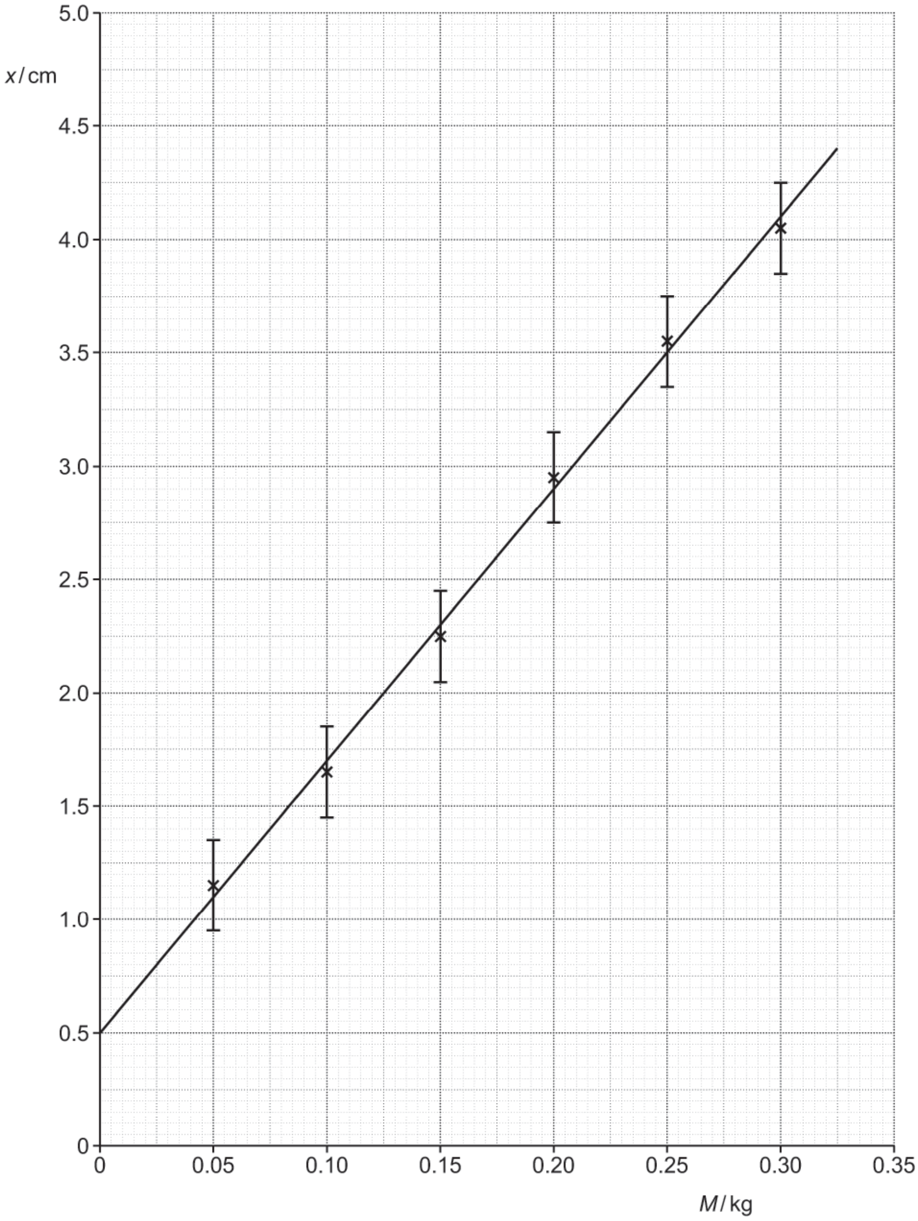


Fig. 3.2

The
student then repeats the experiment for different values of *M*. For each value of *M*, the student determines the extension *x* of the spring combination and the absolute uncertainty in *x*.

The student plots a graph of extension *x* (*y*-axis) against mass *M* (*x*-axis) including error bars in *x*. The straight line of best fit is drawn.



It is suggested that the relationship between *x* and *M* is

$$x = \frac{Mg}{k} + R$$

where *k* is the force constant of the spring combination, *g* is the acceleration of free fall and *R* is a constant.

i. Show that the gradient of the straight line of best fit is about 0.12 m kg^{-1}.

[2]

ii. Using the gradient, determine a value for *k*.
Give your answer to an appropriate number of significant figures and include an appropriate unit.

k = ... unit .... **[2]**

(b).

i. Draw a worst acceptable straight line.

[1]

ii. Determine the gradient of your worst acceptable line.

gradient of worst acceptable line = ... m kg^{-1} **[1]**

iii. Determine the percentage uncertainty in *k*.

percentage uncertainty = ... % **[2]**

30 (a). A student designs an investigation to learn more about an old instrument called a hot wire ammeter. A fine resistance wire stretched between two retort stands sags when heated by the current being measured. This sag is converted into a reading on a non-linear scale.

A current-carrying wire is clamped at each end as shown in Fig. 2.1.

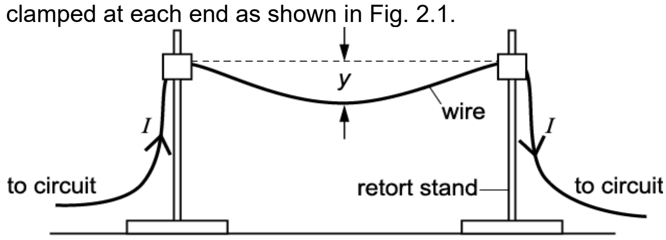


Fig. 2.1

The deflection *y* at the centre of the wire is measured for various currents *I* in the wire.
It is suggested that *y* and *I* are related by the equation

$$y = aI^b$$

where *a* and *b* are constants. This equation can also be written as

$$\lg y = \lg a + b \lg I.$$

A graph is plotted of lg *y* on the *y*-axis against lg *I* on the *x*-axis. State expressions for the gradient and *y*-intercept in terms of *a* and *b*.

gradient = ...

y-intercept = ...

[1]

(b). For different values of the current *I*, the vertical deflection *y* is recorded. A table of results is shown with further columns giving values of lg (I / 10^{-2} A) and lg (*y* / mm), including the absolute uncertainties.

I / 10^{-2} A	y / mm	lg (I / 10^{-2} A)	lg (y / mm)
50	2.6 ± 0.2		
60	3.4 ± 0.2	1.78	0.53 ± 0.03
70	4.4 ± 0.2	1.85	0.64 ± 0.02
80	5.4 ± 0.2	1.90	0.73 ± 0.02
90	6.6 ± 0.2	1.95	0.82 ± 0.01
95	7.2 ± 0.2	1.98	0.86 ± 0.01

i. Complete the missing values in the table, including the absolute uncertainty for lg (*y* / mm).

[2]

ii. Fig. 2.2 shows the axes for a graph of lg (y / mm) on the y-axis against lg (I / 10^{-2} A) on the x-axis. The last four points have been plotted including error bars for lg (y / mm). By plotting the two remaining points, complete the graph. Draw a line of best fit.

[2]

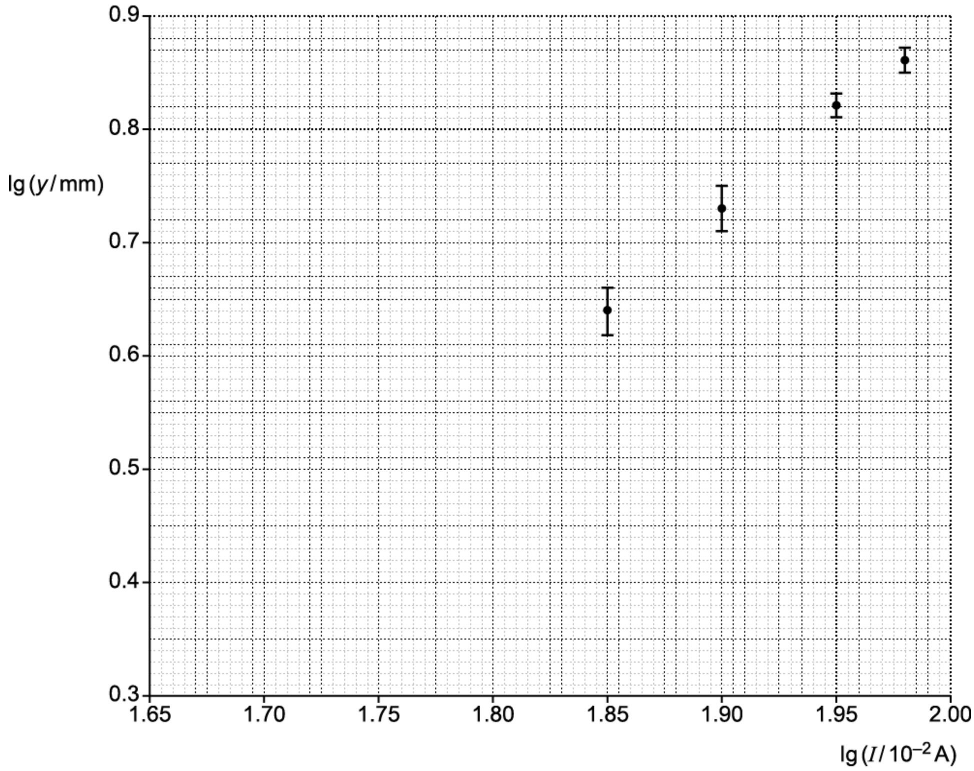


Fig. 2.2

(c).

i. Use the line of best fit through the data points in Fig. 2.2 to determine numerical values of

1 *b*

b = ... **[1]**

2 *a*.

a = ... **[2]**

ii. Determine the absolute uncertainty in the value of *b*.

uncertainty in *b* = ± .... **[2]**

31. Fig. 16.1 shows an arrangement used by a group of students to determine the acceleration of free fall *g* in the laboratory.

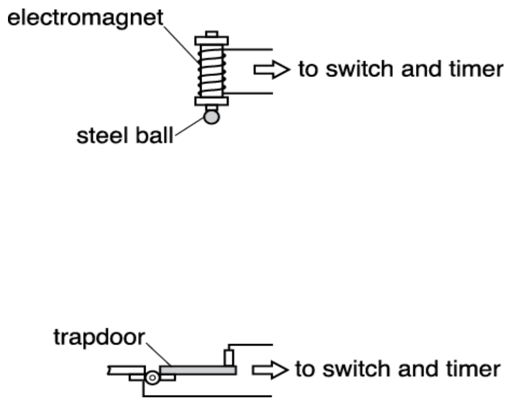


Fig. 16.1

An electromagnet is used to hold a small steel ball in position above a trapdoor. A timer starts as soon as the ball is released, and is stopped when the ball hits and opens the trapdoor. The clamp stands holding the trapdoor mechanism and the electromagnet are not shown in Fig. 16.1.

The distance between the bottom of the steel ball and the top of the trapdoor is 1.200 ± 0.001 m. The steel ball takes 0.50 ± 0.02 s to fall through this distance.

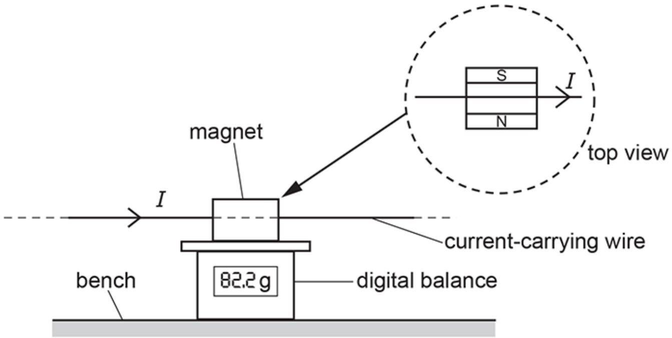
i. Calculate a value for *g* using these results.

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

ii. Determine the percentage uncertainty in the value for *g*.

percentage uncertainty = ... % **[2]**

32. The arrangement shown in the diagram below is used to determine the magnetic flux density between the poles of a permanent magnet



The magnet is placed on the digital balance. The current-carrying wire is horizontal and at right angles to the magnetic field between the poles of the magnet. The wire is fixed.

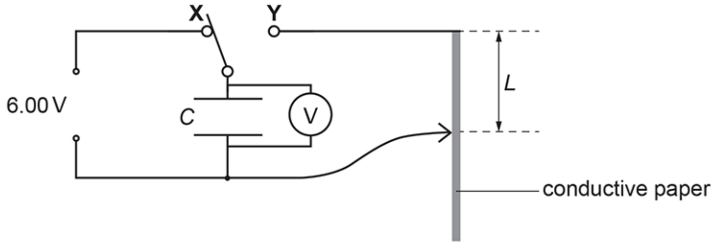
The following results are collected.

- length of the wire in the uniform field of the magnet = 6.0 ± 0.2 cm
- balance reading with no current in wire = 80.0 g
- balance reading with current in wire = 82.2 g
- current in wire = 5.0 ± 0.1 A

Calculate the magnetic flux density *B*, including the absolute uncertainty.
Ignore the absolute uncertainty in the balance readings.
Write your value for *B* to **2** significant figures and the absolute uncertainty to **1** significant figure.

B = ... ± .... T **[4]**

33. A capacitor of capacitance C is connected across a strip of conductive paper.



The switch is moved from **X** to **Y**, and the time *t* for the potential difference across the capacitor to halve is measured.

The time *t* is given by the expression

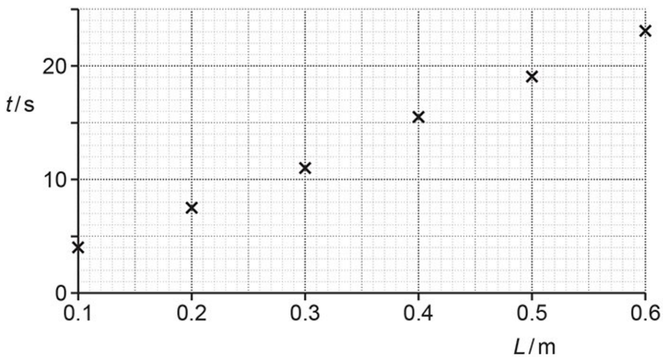
$t = (Ck \ln 2) \times L$

where k is the resistance of the conductive paper per unit length and *L* is the length of the conductive paper.

The value of C is 1.2×10^{-3} F.

In an experiment, *L* is changed and t measured.

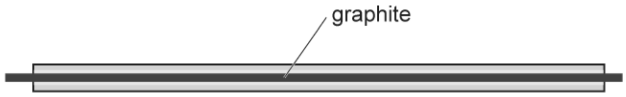
The data points are plotted on a *t* against *L* grid as shown below.



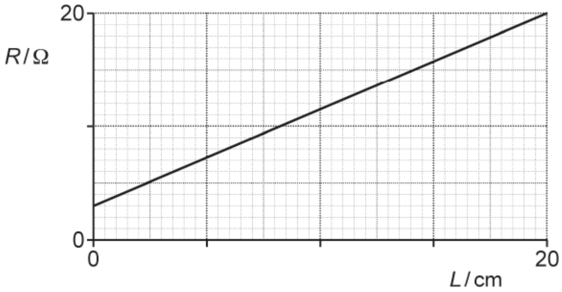
Draw a straight line of best fit through the data points, and use the gradient of this line to determine *k*.

k = ... Ω m^{-1} **[4]**

34. The diagram below shows a pencil cut along its length exposing the graphite.



The resistance of a length *L* of the graphite is *R*. A student directly measures *R* using a multimeter (ohmmeter). The following graph is plotted by the student.



i. Suggest why the graph does not pass through the origin.

[1]

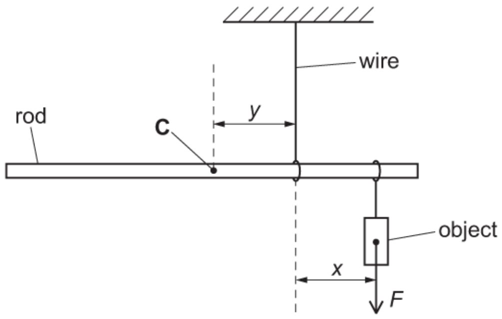
ii. The resistivity of graphite is *ρ*.

Describe how the student can use the graph above, and an additional measuring instrument, to accurately determine *ρ*.
No calculations are required.

[3]

35 (a). A student is doing an experiment in the laboratory to determine the density of a metal rod.

A **uniform** metal rod is suspended horizontally from a wire.
The rod has an object attached to it, as shown in the diagram below.

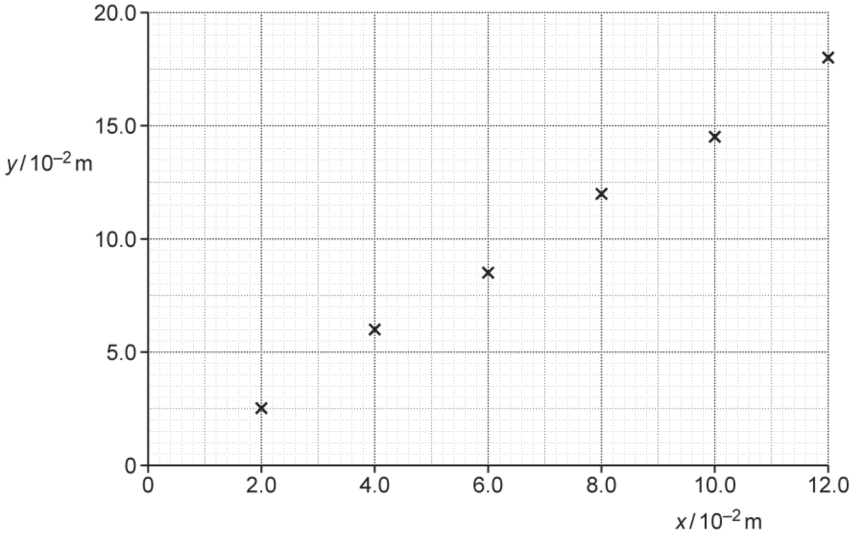


The rod is in equilibrium.
The centre of gravity **C** of the rod is a perpendicular distance *y* from the wire. The line of action of the weight *F* of the object is a perpendicular distance *x* from the wire.
The rod has length *L* and cross-sectional area *A*. The density of the metal rod is ρ.

Show that the distances, *x* and *y*, are given by the expression $y = \left(\frac{F}{AL\rho g}\right)x$, where *g* is the acceleration of free fall.

[2]

(b). The data points shown below are plotted by the student on a *y* against *x* grid.



i. Draw a straight line of best fit through the data points plotted by the student. Determine the gradient of the straight line of best fit.

gradient = ... **[2]**

ii. Use your answer to **(i)** and the data below to determine the density ρ of the metal.

- $F = 6.8$ N
- $L = 0.90$ m
- $A = 6.4 \times 10^{-5}$ m^2

ρ = ... kg m^{-3} **[3]**

36 (a). Fig. 4.1 shows an arrangement used by a student to determine the acceleration of free fall.

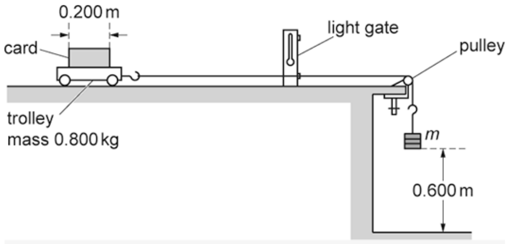


Fig. 4.1

A trolley is attached to a variable mass *m* by a string which passes over a pulley.

The mass *m* is released from rest and falls through a fixed height of 0.600 m accelerating the trolley of mass 0.800 kg. When the mass *m* hits the floor, the trolley then continues to move at a **constant** velocity *v*.

This constant velocity *v* is determined by measuring the time *t* for the card of length 0.200 m to pass fully through a light gate connected to a timer.

Frictional forces on the trolley and the falling mass *m* are negligible.

Show that the relationship between *v* and *m* is

$$v^2 = \frac{1.20mg}{(m + 0.800)}$$

where *g* is the acceleration of free fall.

[2]

(b). The student records the information from the experiment in a table. The column headings and just the last row for *m* = 0.600 kg from this table are shown below.

m / kg	t / 10^{-3} s	$\frac{m}{(m+0.800)}$	v / m s^{-1}	v^2 / m^2 s^{-2}
0.600	90 ± 2	0.429	2.22 ± 0.05	

i. Complete the missing value of v^2 in the table including the absolute uncertainty

[2]

ii. Fig. 4.2 shows some of the data points plotted by the student. Plot the missing data for *m* = 0.600 kg on Fig. 4.2 and draw the straight line of best fit.

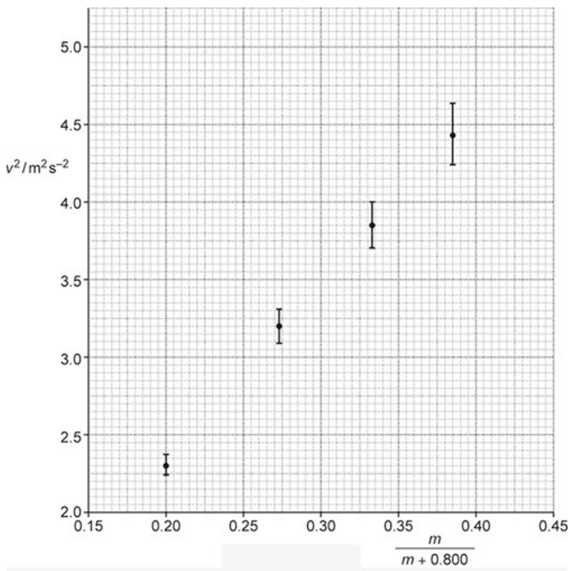


Fig. 4.2

(c).

i. Use the equation given in **(a)** to show that the gradient of the graph of v^2 against $\frac{m}{(m+0.800)}$ is equal to 1.20 *g*.

[1]

ii. Assume that the best-fit straight line through the data points gives 9.5 m s^{-2} for the experimental value of *g*. Draw a worst-fit line through the data points on Fig. 4.2 and determine the absolute uncertainty in the value for *g*.

absolute uncertainty = ± ms^{-2} **[4]**

(d). It is suspected that the card on the trolley did not pass at right angles through the light beam.

Discuss, without doing any calculations, the effect this may have on the experimental value for the acceleration of free fall *g*.

[4]

37 (a). A group of students are conducting an experiment to determine the wavelength of monochromatic light from a laser.
Fig. 24.1 shows the laser beam incident normally at a diffraction grating.

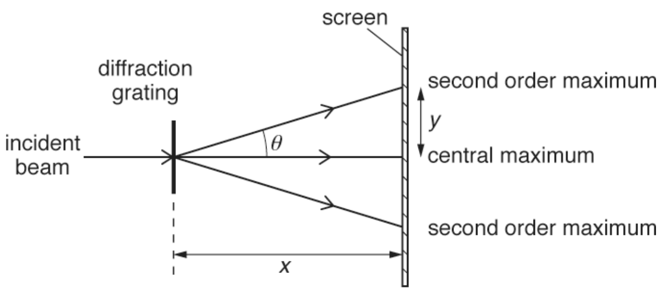


Fig. 24.1

The students use a diffraction grating with 600 lines mm^{-1}. They vary the distance *x* between the grating and the screen from 1.000 m to 2.000 m. They measure the distance y from the *central* maximum to the *second order* maximum.

The students decide to plot a graph of *y* against $\sqrt{x^2 + y^2}$.

Show that the gradient of the graph is equal to sin *θ*, where *θ* is the angle between the central maximum and the *second* order maximum.

[1]

(b). Fig. 24.2 shows the graph plotted by the students.

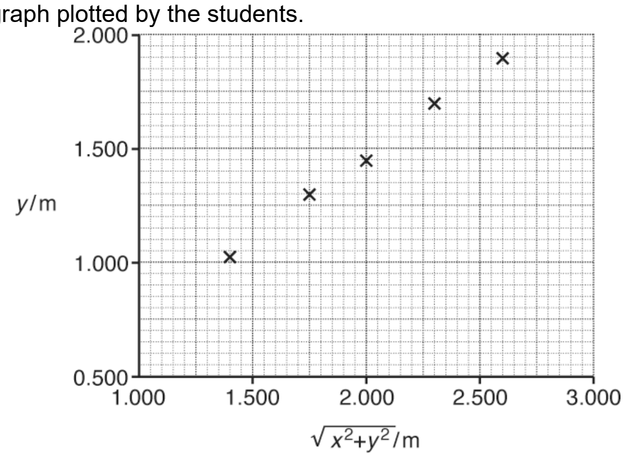


Fig. 24.2

i. Use Fig. 24.2 to determine an accurate value of the wavelength λ of the light from the laser.

λ = m **[2]**

ii. Suggest why there are no error bars shown in Fig. 24.2.

[1]

iii. Suggest how the precision of this experiment may be affected by using a protractor to measure the angle θ.

[1]

38. The gravitational field strength at a distance *r* from the centre of Mars is *g*.

The table below shows some data on Mars.

g / N kg^{-1}	r / km	lg (g / N kg^{-1})	lg (r / km)
1.19	6000	0.076	3.78
0.87	7000		
0.67	8000	−0.174	3.90
0.53	9000	−0.276	3.95
0.43	10000	−0.367	4.00

i. Complete the table by calculating the missing values.

[1]

ii. Fig. 17.2 shows the graph of lg (g / N kg^{-1}) against lg (r / km).

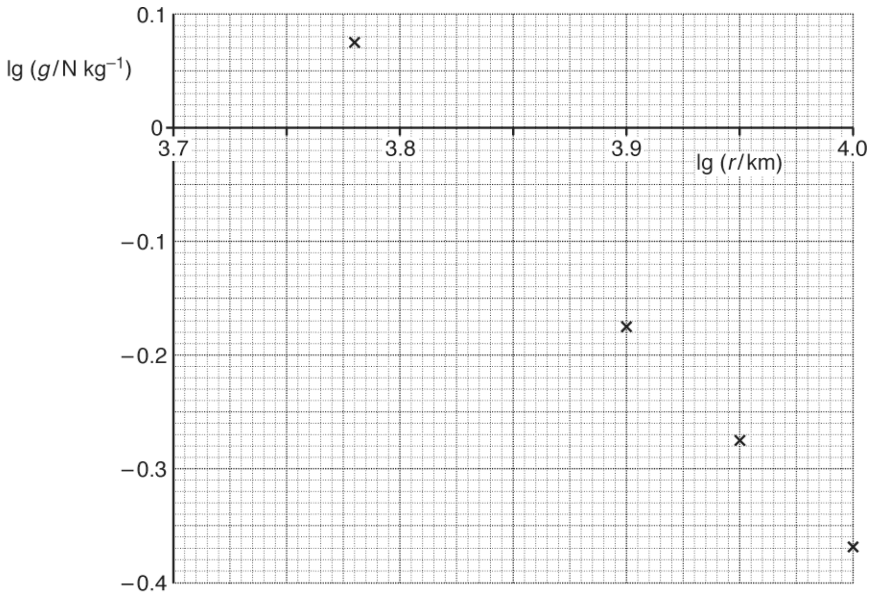


Fig. 17.2

1 Plot the missing data point on the graph and draw the straight line of best fit.

[2]

2 Use Fig. 17.2 to show that the gradient of the straight line of best fit is −2.

[1]

3 Explain why the gradient of the straight line of best fit is −2.

[2]

39. Hydrogen atoms excited in a discharge tube only emit four different discrete wavelengths of visible photons.

*In a semi-darkened room, a single slit is placed in front of the discharge tube. A student holds a diffraction grating which has 300 lines per millimetre.
The student looks through the grating at a 15 cm plastic ruler placed 0.50 m away, as shown in Fig. 5.1.
The paths of the different colours of light from the slit to the student's eye are shown in Fig. 5.2.

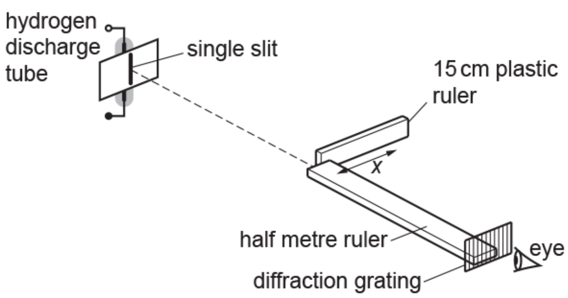


Fig. 5.1 (not to scale)

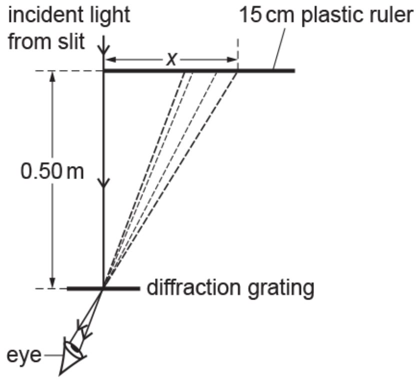


Fig. 5.2 (not to scale)

Four **first** order images of the slit, one at each photon wavelength, are observed as vertical lines against the background of the plastic ruler, as shown in Fig. 5.3.

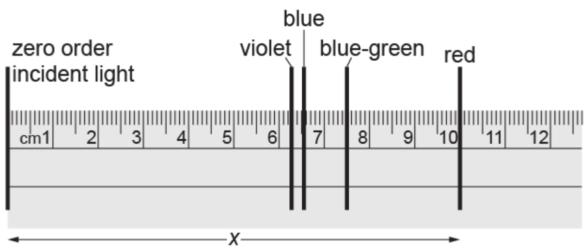


Fig. 5.3

The student decides to determine the wavelength of the photons which form the red line observed at x = 10 cm on the ruler.

- Describe how the information that has been given can be used to determine the wavelength of the red photons.
- Estimate the percentage uncertainty in the measured value of the wavelength.

----

[6]

40. A researcher is investigating the work function of metals using the photoelectric effect.
The table below shows the threshold frequency f_0 and the work function φ for various metals.

metal	**A**	**B**	**C**	**D**	**E**
f_0 / 10^{14} Hz	4.5	5.6	6.5	8.0	9.7
φ / eV	1.9	2.3	2.7	3.4	4.1

Fig. 27 shows the data points for the metals **A**, **B**, **D** and **E** plotted on a φ against f_0 grid.

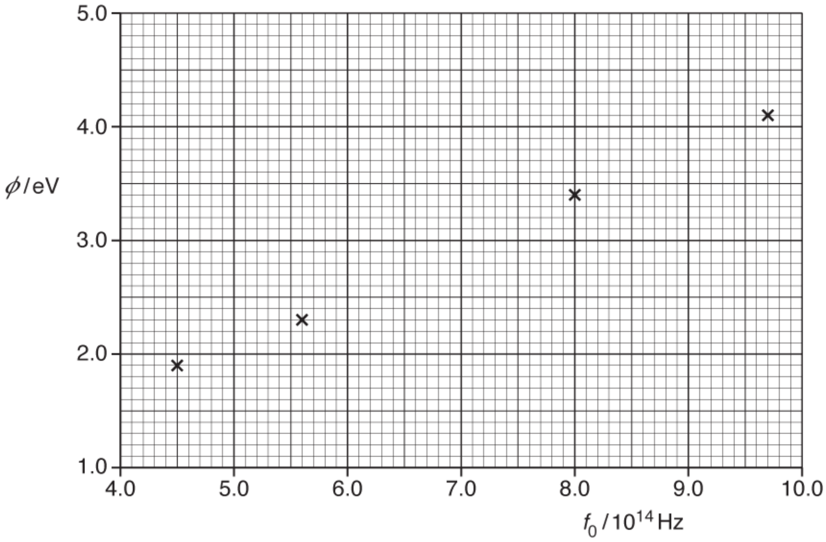


Fig. 27

i. Use Einstein's photoelectric equation to show

$$\varphi = hf_0$$

where h is the Planck constant.

[1]

ii. Plot the data point for **C** on Fig. 27 and draw the straight line of best fit

. **[1]**

iii. Use Fig. 27 to determine the experimental value for h.

h = ... J s **[2]**

iv. Explain, without doing any calculations, how you could use Fig. 27 to determine the percentage uncertainty in *h*.

[2]

41 (a). A student wishes to investigate how the terminal velocity *v* of a metal sphere varies with the radius *r* of the sphere as it travels through a liquid.
It is suggested that

$$v = Kr^2$$

where *K* is a constant.

Describe with the aid of a suitable diagram how an experiment can be safely conducted, and how the data can be analysed to determine *K*.

[6]

(b). A solid wooden sphere of density 650 kg m^{-3} has a diameter of 2.8 cm.

i. Describe and explain how the student can measure precisely the diameter of the sphere.

[2]

ii. Show that the mass of the sphere is 0.0075 kg.

[2]

iii. The sphere is pushed below the surface of water as shown in Fig. 3.

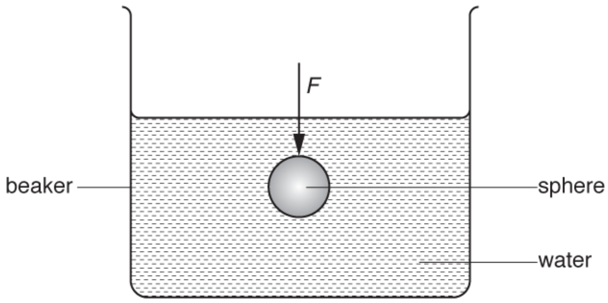


Fig. 3

Determine the force *F* that needs to be applied to the sphere to keep the wooden sphere stationary in this position.
density of water = 1000 kg m^{-3}

F = ... N **[2]**

42 (a). A tennis ball is struck with a racket.
The initial velocity v of the ball leaving the racket is 30.0 m s^{-1} and it makes an angle of 70° to the horizontal as shown in Fig. 16.
Air resistance is negligible

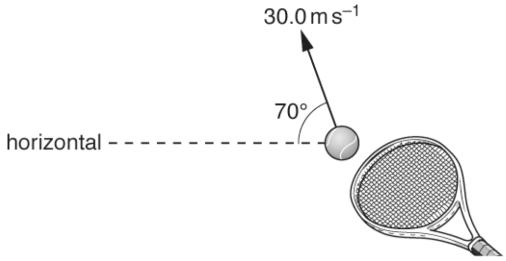


Fig. 16

i. Calculate the vertical component of the initial velocity of the ball.

vertical component = m s^{-1} **[1]**

ii. Use your answer in (**i**) to show that the ball reaches a maximum height *h* of about 40 m.

h = m **[2]**

iii. Explain why the kinetic energy of the ball is not zero at maximum height.

[1]

iv. The mass *m* of the ball is 57.0 g.
Calculate the kinetic energy E_k of the ball when it is at its maximum height.

E_k = J **[2]**

(b). A metal ball is rolled off the edge of a horizontal laboratory bench. The initial horizontal velocity of the ball is *v*. The ball travels a horizontal distance *x* before it hits the level floor.

Use your knowledge of projectile motion to suggest the relationship between *v* and *x*. Describe how an experiment can be safely conducted to test this relationship and how the data can be analysed.

[6]

43. *Two groups of researchers, **A** and **B**, conduct photoelectric effect experiments on a new material. The maximum kinetic energy KE_{max} of the photoelectrons emitted from the material is determined for different frequencies f of the electromagnetic radiation incident on the material.

Fig. 19 shows incomplete graphs of KE_{max} against f from the groups **A** and **B**.

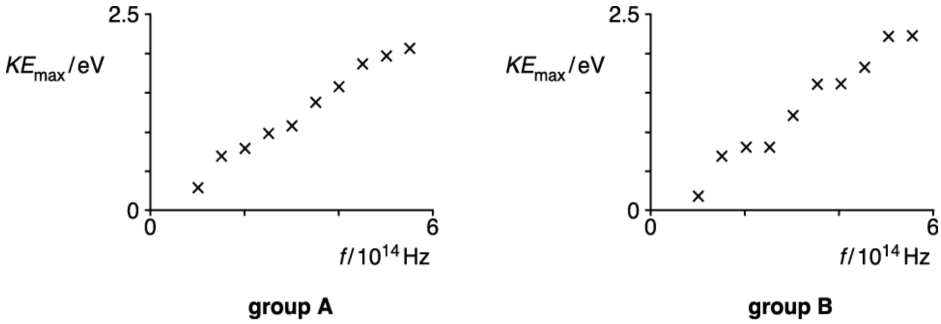


Fig. 19

The value of the Planck constant h is determined from the completed KE_{max} against f graphs.
The result from each group is shown below.

group A: $h = (6.3 \pm 0.3) \times 10^{-34}$ J s
group B: $h = (6.6 \pm 0.6) \times 10^{-34}$ J s

Explain how a graph of KE_{max} against f can be used to determine h. Discuss the accuracy and precision of the results from each group.

[6]

44 (a).

A student conducts an experiment to confirm that the uniform magnetic flux density *B* between the poles of a magnet is 30 mT.

A current-carrying wire of length 5.0 cm is placed perpendicular to the magnetic field.

The current *I* in the wire is changed and the force *F* experienced by the wire is measured. Fig. 22.1 shows the graph plotted by the student.

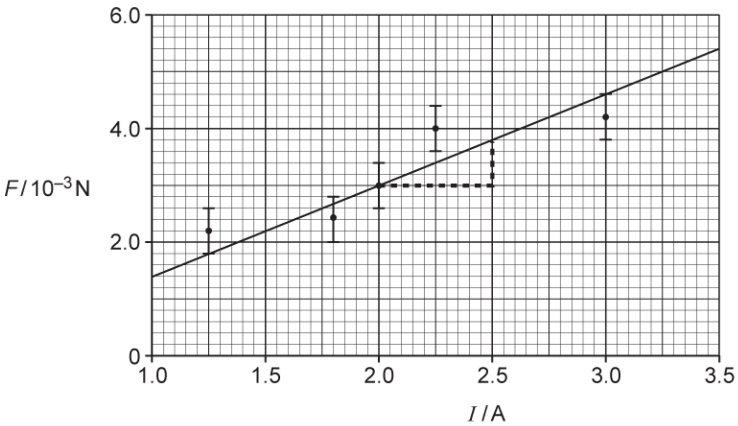


Fig. 22.1

The student's analysis is shown on the graph of Fig. 22.1 and in the space below.

$F = BIL$

$$\text{gradient} = BL = \frac{(3.8 - 3.0) \times 10^{-3}}{2.5 - 2.0} = 0.0016$$

$$B = \frac{0.0016}{0.05} = 0.032\,\text{T} = 32\,\text{mT}$$

This is just 2 mT out from the 30 mT value given by the manufacturer, so the experiment is very accurate.

Evaluate the information from Fig. 22.1 and the analysis of the data from the experiment. No further calculations are necessary

[6]

(b). Fig. 22.2 shows a transformer circuit.

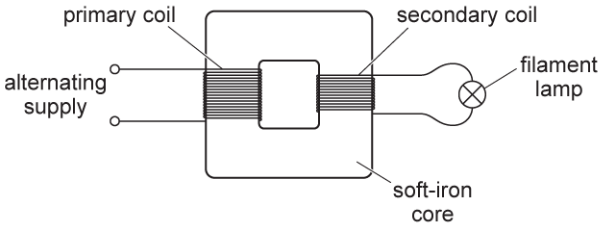


Fig. 22.2

The primary coil is connected to an alternating voltage supply. A filament lamp is connected to the output of the secondary coil.

i. Use Faraday's law of electromagnetic induction to explain why the filament lamp is lit.

[3]

ii. The primary coil has 400 turns and the secondary coil has 20 turns. The potential difference across the lamp is 12 V and it dissipates 24 W. The transformer is 100% efficient.

1. Calculate the current in the primary coil.

current = ... A **[2]**

2. The alternating voltage supply is replaced by a battery and an open switch in series. The switch is closed. The lamp is lit for a short period of time and then remains off. Explain this observation.

[2]

45. This question is about a space probe which is in orbit around the Sun.

The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α-particle emission with a half-life of 88 years.
The kinetic energy of each α-particle is 8.8×10^{-13} J.

i. Calculate the number N of plutonium-238 nuclei needed to provide the power of 470 W.

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

ii. Calculate the power P still available from the plutonium-238 source 100 years later.

P = ... W**[3]**

46 (a). This question is about a laser pen.

Green light from the laser pen passes through a pair of narrow slits **S_1** and **S_2** as shown in Fig. 5.1.

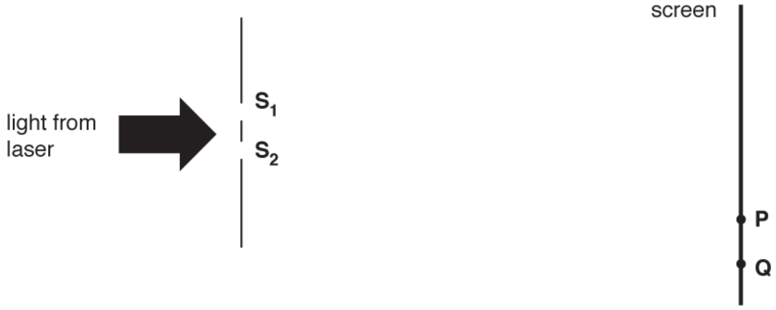


Fig. 5.1

A pattern is produced on a screen consisting of regularly spaced bright and dark lines as shown in Fig. 5.2.

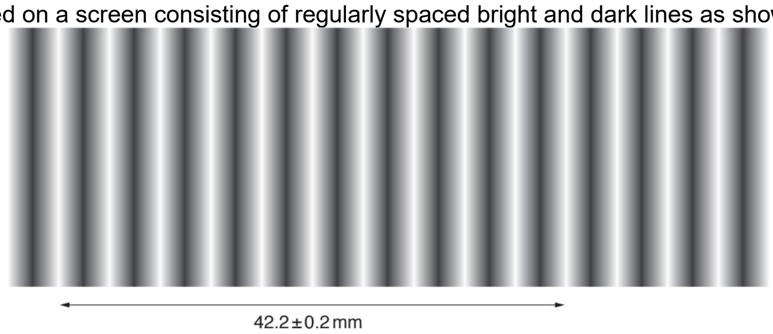


Fig. 5.2

i. Fig. 5.1 shows two points, **P** and **Q**, on the screen. Explain in terms of path difference why point **P** is a bright line and point **Q** is a dark line.

[2]

ii. The screen is at a distance of 4.50 ± 0.02 m from the slits and the slit separation is 0.56 ± 0.02 mm.

1. Use Fig. 5.2 to determine the wavelength λ of the light.

λ = ... m **[3]**

2. Determine the percentage uncertainty in λ.

percentage uncertainty = ... % **[2]**

(b). The power of the green light from the laser pen is 50.0 mW. It is now used in a demonstration of the photoelectric effect.

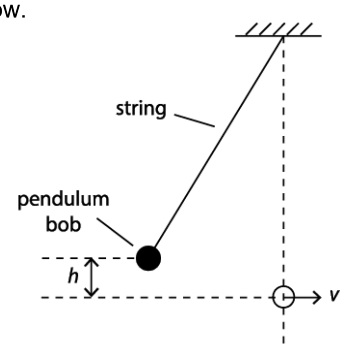
i. Calculate the number of photons *n* that the laser emits per second.

n = ... **[2]**

ii. The green light falls on a negatively charged metal plate with a work function of 2.6 eV. Explain whether photoelectrons will be emitted.

[2]

47 (a). A group of students are conducting an experiment in the laboratory to determine the acceleration of free *g* using a simple pendulum as shown below.



The pendulum bob is released from **rest** from a height *h.* The speed of the pendulum bob as it passes through the vertical position is *v.* The speed *v* is measured using a light-gate and a computer.
The results from the students are shown in a table.

h / m	v / m s^{-1}	v^2 / m^2 s^{-2}
0.052	1.0 ± 0.1	1.0 ± 0.2
0.100	1.4 ± 0.1	2.0 ± 0.3
0.151	1.7 ± 0.1	2.9 ± 0.3
0.204	1.9 ± 0.1	
0.250	2.2 ± 0.1	4.8 ± 0.4
0.302	2.4 ± 0.1	5.8 ± 0.5

Complete the missing value of v^2 in the table.

[1]

(b). Fig. 24 shows the graph of v^2 against h.

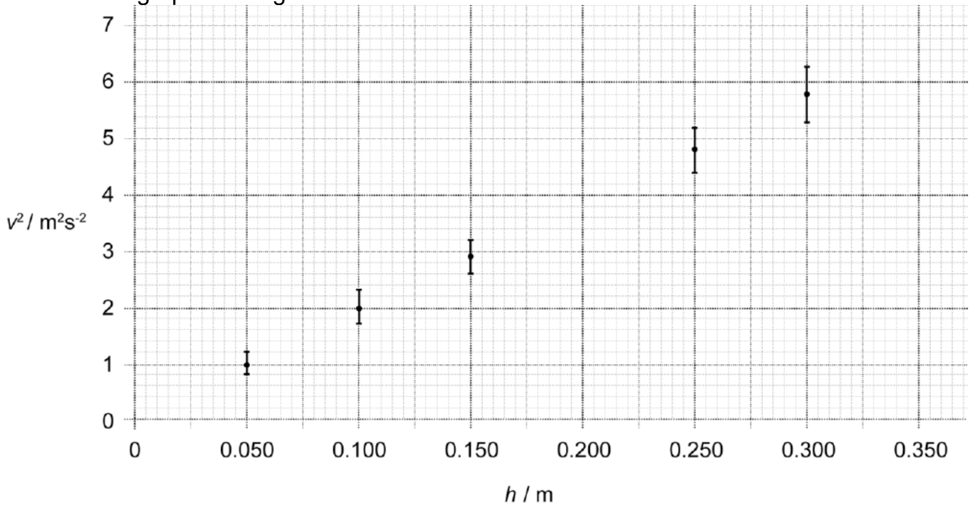


Fig. 24

i. Plot the missing data point and error bar on Fig. 24.

[1]

ii. * Explain how Fig. 24 can be used to determine the acceleration of free fall g. Find the value of g and include the uncertainty in your answer.

[6]

48 (a). A student carries out an experiment to measure *g*, the acceleration due to gravity, by measuring the time *t* for a steel ball to fall a distance *s*.
The method is shown in **Fig. 2.1**

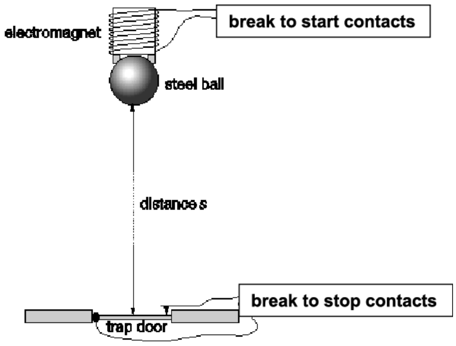


Fig 2.1

The break-to-start and break-to-stop contacts are connected to an electronic timer. As the steel ball is released from the electromagnet, the electronic timer starts. The ball falls a distance *s* before it hits a hinged metal 'trap door'. The trap door opens, breaks the circuit and stops the timer.

The student records the following data for a range of distances *s*, averaging the time *t* at each distance over several drops. He intends to plot a graph of *s* against t^2 so adds a third column to his table of results.

s/m	mean *t*/s	t^2/s^2
0.40	0.31	0.10
0.60	0.38	0.14
0.80	0.42	0.18
1.00	0.47	
1.20	0.51	
1.40	0.55	0.30

i. Complete the table. Add the final two points to the graph of **Fig. 2.2**. Draw a straight line of best fit on **Fig. 2.2**.

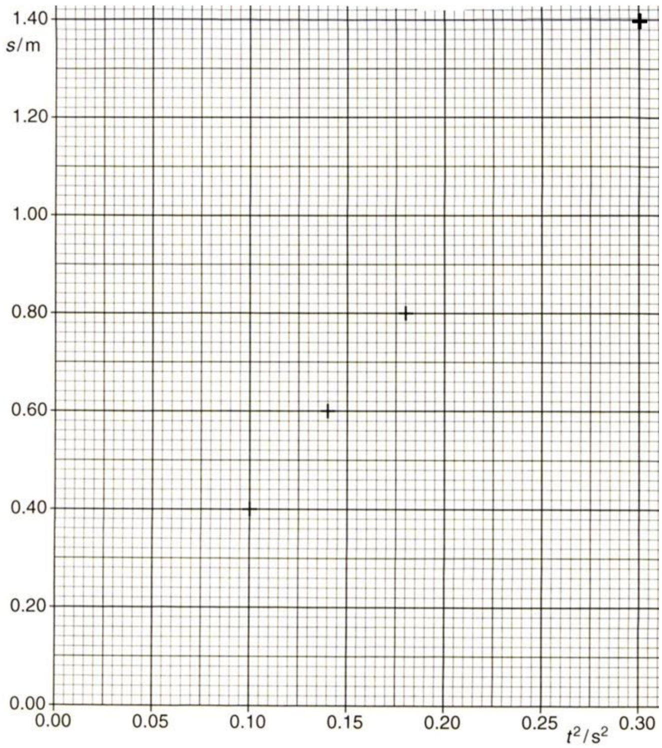


Fig. 2.2. **[3]**

ii. Determine the gradient of the line. Show clearly your working.

gradient = ... $m\ s^{-2}$ **[2]**

(b). The student expected the line to go through the origin and have a gradient of *g*/2. The timing device he used measures to within 0.01 s and the distance *s* was measured to within 0.01 m.

i. The fact that the line of best fit does not pass through the origin is unlikely to have been caused by random errors in his measurements. Justify this statement.

[2]

ii. Explain how a systematic error in each of the measured quantities could contribute to the line not passing through the origin and what effect, if any, each would have on the gradient of the line.

[4]

iii. Suggest one source of possible systematic error in the experiment.

[1]

49. The speed of sound in air can be determined by forming stationary waves in the laboratory. Fig. 24.1 shows an arrangement used by a student to determine the speed of sound v.

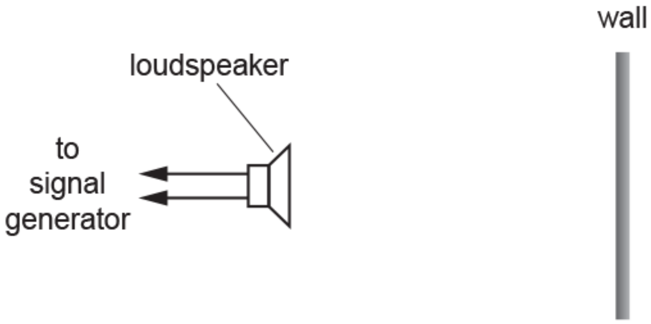


Fig. 24.1

A loudspeaker is placed in front of a smooth vertical wall in the laboratory. The loudspeaker is connected to a signal generator.
Stationary waves of frequency f are formed in the space between the wall and the loudspeaker.

A microphone is used to determine the mean separation L between adjacent nodes.

Fig. 24.2 shows the data plotted by the student.

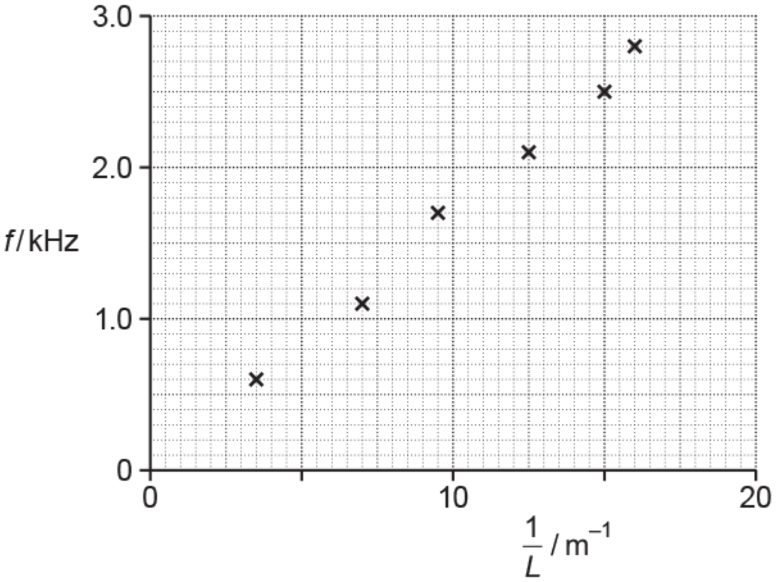


Fig. 24.2

i. Draw a straight line of best fit and determine the gradient of this line.

gradient = ... Hzm **[2]**

ii. Explain why the gradient of the line is $\frac{v}{2}$, where *v* is the speed of sound.

[2]

iii. Use your answer in part **(i)** and the information given in **(ii)** to determine *v*.

v = ... m s^{-1} **[1]**

iv. The smaller values of *L* are much more difficult to determine with the microphone in this experiment and this produces large percentage uncertainty in the values of $\frac{1}{L}$.
Suggest how this percentage uncertainty may be reduced in this experiment.

[2]

50. Fig. 1 shows a high-speed electric train.

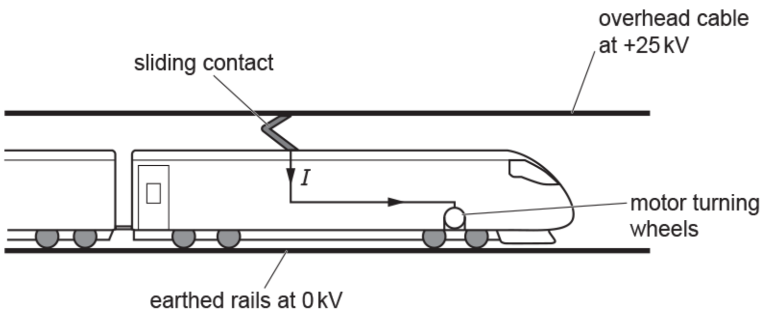


Fig. 1

The potential difference between the overhead cable and the rails on the ground is 25 kV.
The sliding contact on the top of the train constantly touches the overhead cable.
The overhead cable supplies a current I to the electric motor of the train.
The motor turns the wheels. The train experiences a **resultant** forward force *F*.

The total mass of the train is 2.1×10^5 kg.

The train accelerates from rest. The value of F is 190 kN for speeds less than 6.0 m s^{-1}.

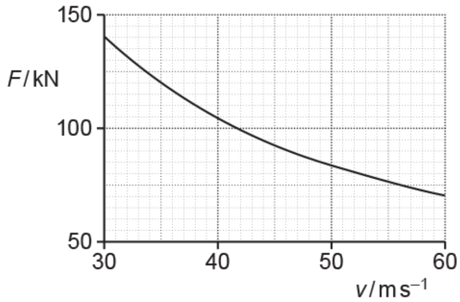
i. Show that the train's acceleration is about 1 m s^{-2}.

[1]

ii. Calculate the distance s that the train travels to reach a speed of 6.0 m s^{-1}.

s = ... m**[2]**

iii. The speed of the train is v.
During one period of its journey, the train accelerates from v = 30 m s^{-1} to v = 60 m s^{-1}.
The graph of *F* against v for this period is shown below.



1. Use the graph to show that output power of the electric motor during this period is constant at about 4 MW.

[3]

2. Calculate the current *I* in the electric motor when the train is travelling at 50 m s^{-1} .

I = ... A**[2]**

51 (a).

State **one** S.I. base quantity other than length, mass and time.

[1]

(b). Fig. 17 shows two resistors **X** and **Y** connected in series.

Fig. 17

The resistors are wires. Both wires have the same length *L* and diameter *d*. The material of **X** has resistivity *ρ* and the material of **Y** has resistivity 2*ρ*.

i. Show that the total resistance *R* of the wires is given by the equation

$$R = \frac{12\rho L}{\pi d^2}.$$

[2]

ii. A student uses the equation in **(i)** to determine *R*.
The table below shows the data recorded by the student in her lab book.

Quantity	Value
ρ	4.7×10^{-7} Ωm
L	9.5 ± 0.1 cm
d	0.270 ± 0.003 mm

1. Name the likely instruments used by the student to measure *L* and *d*.

L:

d:

[1]

2. Use the data in the table and the equation in **(i)** to determine *R* and the absolute uncertainty.
Write your answer to the correct number of significant figures.

R = ... ± .... Ω **[4]**

3. The instrument used to measure *d* has a zero-error. The measured *d* is much **larger** than the actual value.
Discuss how the actual value of *R* compares with the value calculated above.

[1]

52. A student is carrying out an experiment in the laboratory to determine the capacitance *C* of a capacitor. Fig. 20.2 shows the circuit used by the student.

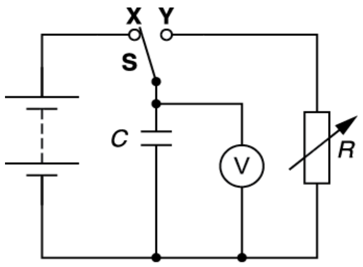


Fig. 20.2

The switch **S** is first connected to **X** to charge the capacitor. The switch is then moved to **Y** at time $t = 0$. The time *T* taken for the potential difference *V* across the capacitor to halve is determined for different values of resistance *R*.

i. Fig. 20.3 shows the graph of *T* against *R* as plotted by the student.

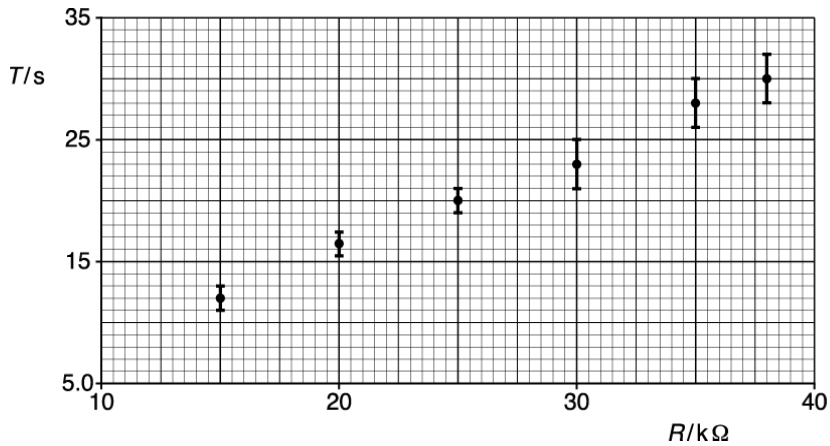


Fig. 20.3

1 Draw a straight line of best fit.

[1]

2 Use $V = V_0e^{-t/CR}$ to show that $T = -\ln(0.5)CR$.

[2]

3 Determine a value for the capacitance *C*.

C = ... F **[3]**

ii. Describe, without doing any calculations, how you can use Fig. 20.3 to determine the percentage uncertainty in *C*.

[2]

53. Fig. 18.1 shows a circuit used by a student to determine the resistivity of the material of a wire.

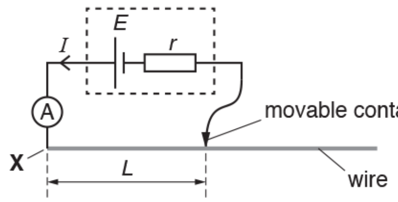


Fig. 18.1

The wire is uniform and has diameter 0.38 mm. The cell has electromotive force (e.m.f.) E and internal resistance r. The length of the wire between **X** and **Y** is L.

The student varies the length L and measures the current I in the circuit for each length.

Fig. 18.2 shows the data points plotted by the student.

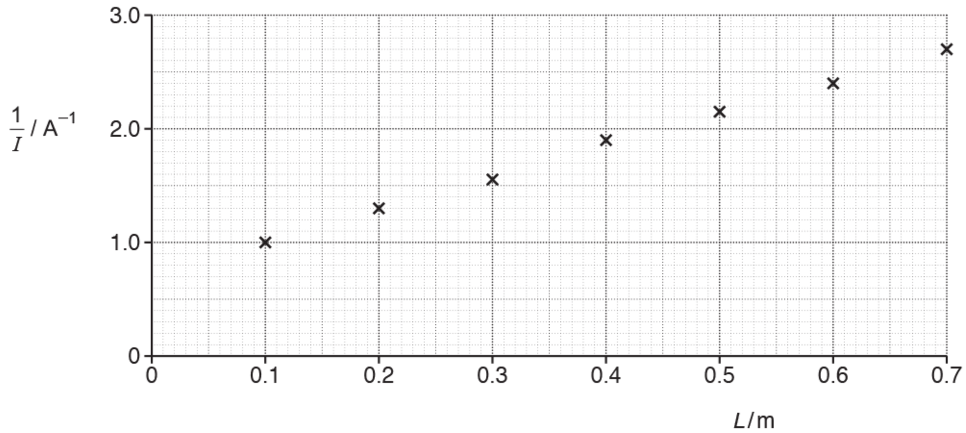


Fig. 18.2

i. On Fig. 18.2 draw the straight line of best fit. Determine the gradient of this line.

gradient = ... $A^{-1}\ m^{-1}$ **[2]**

ii. Show that the gradient of the line is $\frac{\rho}{AE}$, where ρ is the resistivity of the material of the wire, A is the area of cross-section of the wire and E is the e.m.f. of the cell.

[2]

iii. The e.m.f. E of the cell is 1.5 V. The diameter of the wire is 0.38 mm.

Use your answer to **(i)** and the equation given in **(ii)** to determine ρ.

ρ = ... Ωm **[2]**

iv. Fig. 18.3 illustrates how the student had incorrectly measured all the lengths L of the wire.

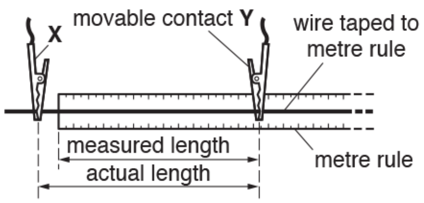


Fig. 18.3

According to the student, re-plotting the data points using the **actual** lengths of the wire will not affect the value of the resistivity obtained in **(iii)**.

Explain why the student is correct.

[2]

54 (a). A student measures the diameter of a ball in different directions.

The student's results are:

2.43 cm 2.54 cm 2.59 cm

i. State the name of a suitable measuring instrument to measure the diameter of the ball.

[1]

ii. Calculate the mean diameter d of the ball.
Include the absolute uncertainty in d.

d = ... ± .... cm **[2]**

iii. Show that the volume of the ball is about 8.4×10^{-6} m^3.

[1]

iv. The mass of the ball is 23 ± 1 g.
Determine the density ρ of the ball.
Give your answer to an appropriate number of significant figures.

ρ = ... kg m^{-3} **[2]**

v. Determine the percentage uncertainty in ρ.

percentage uncertainty = ... % **[2]**

(b). The 23 g mass ball from **(a)** is used in an experiment with a spring.

The student measures the unstretched length L_0 of a spring as shown in Fig. 3.1.

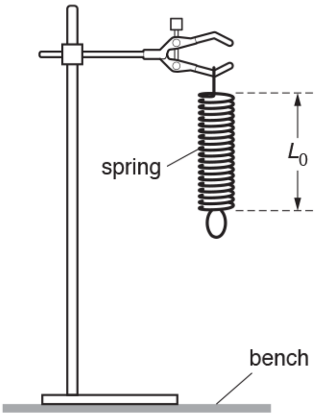


Fig. 3.1

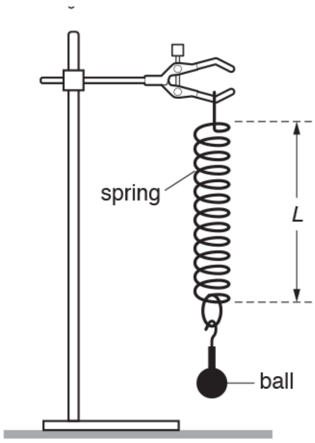


Fig. 3.2

The student then attaches the ball to the spring and measures the length L of the spring as shown in Fig. 3.2.

The student's results are:

L_0 = 0.078 m and L = 0.096 m

Calculate the force constant k of the spring.

k = ... N m^{-1} **[3]**

(c). The 23 g mass ball from **(a)** and the spring from **(b)** are now used in an experiment to investigate upthrust.

The ball attached to the spring is lowered into a beaker containing a liquid so that it is totally submerged. The student measures the new length L_N of the spring, as shown in Fig. 3.3.

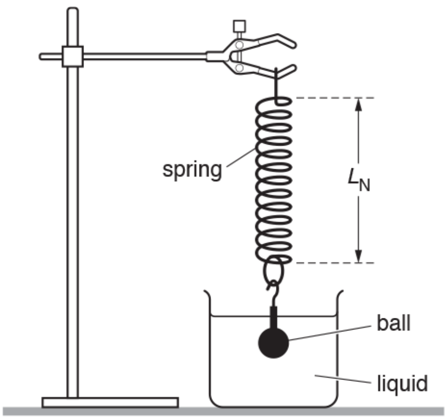


Fig. 3.3

The length L_N of the spring is now 0.088 m.

i. Calculate the upthrust on the submerged ball.

upthrust = ... N **[2]**

ii. Calculate the density of the liquid.

density of liquid = ... kg m^{-3} **[2]**

55. A researcher is investigating the de Broglie wavelength of charged particles.

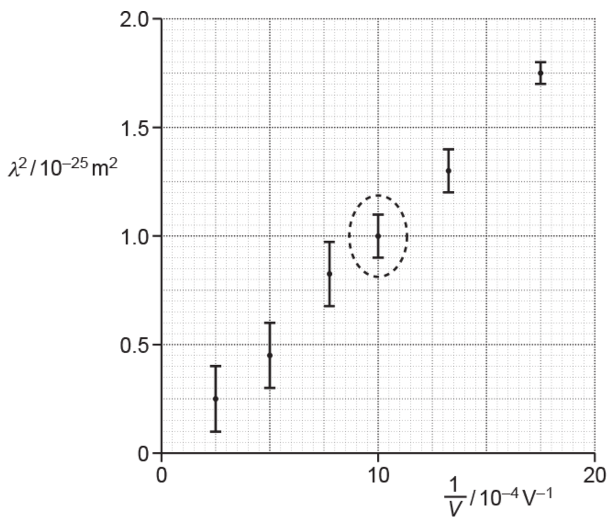
The charged particles are accelerated through a potential difference *V*. The de Broglie wavelength *λ* of these particles is then determined by the researcher.

Each particle has mass *m* and charge *q*.

i. Show that the de Broglie wavelength *λ* is given by the expression $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$.

[2]

ii. The researcher plots data points on a λ^2 against $\frac{1}{V}$ grid, as shown below.



Calculate the percentage uncertainty in λ for the data point circled on the grid.

1

percentage uncertainty = ... % **[2]**

2 Draw a straight line of best fit through the data points. **[1]**

The charge q on the particle is $2e$, where e is the elementary charge.

Use your best fit straight line to show that the mass m of the particle is about 10^{-26} kg.

3

[4]

56. An approximate value of the Planck constant *h* can be determined in the laboratory using light-emitting diodes (LEDs). An LED suddenly starts to conduct and emit monochromatic light when the potential difference across an LED exceeds a minimum value V_0.
The potential difference V_0 and the wavelength λ of the emitted light are related by the equation

$$V_0 = \left(\frac{hc}{e}\right) \times \frac{1}{\lambda}$$

where *e* is the elementary charge and *c* is the speed of light in a vacuum.

Fig. 20.1 shows some data points plotted by a student on a V_0 against $\frac{1}{\lambda}$ graph for five different LEDs.

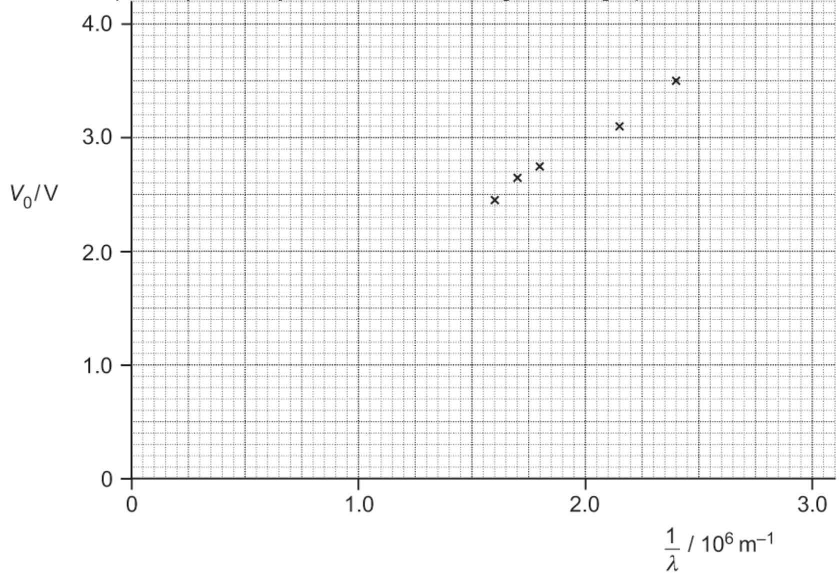


Fig. 20.1

The potential difference across each LED was measured using a digital voltmeter with divisions ± 0.01 V. The values for the wavelengths are accurate and were provided by the manufacturer of the LEDs.

The value of V_0 was determined by directly observing the state of the LED in the **brightly** lit laboratory.

i. Draw the straight line of best fit on Fig 20.1 and determine the gradient of the line.

gradient = V m **[2]**

ii. Use your answer in **(i)** and the equation above to determine a value for *h* to 2 significant figures. Show your working.

h = J s **[3]**

iii. Calculate the percentage difference between your value in **(ii)** and the accepted value of the Planck constant.

difference = % **[1]**

iv. Identify the two types of errors shown by the data in Fig. 20.1 and suggest how you could have refined the experiment to reduce or eliminate these errors.

[4]

57 (a). The ball-release mechanism of a pinball machine is shown in Fig. 17.1.

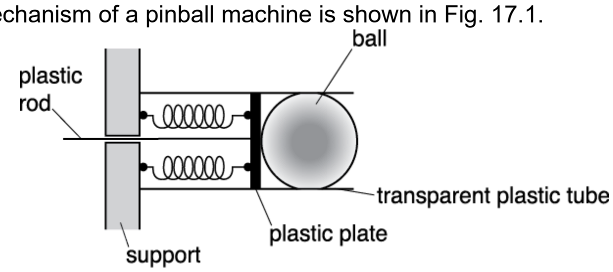


Fig. 17.1

A pair of identical compressible springs are fixed between a plastic plate and a support. The springs are in parallel. A plastic rod attached to the plate is pulled to the left to compress the springs. A ball, initially at rest, is fired when the plate is released.

A group of students are conducting an experiment to investigate the ball-release mechanism shown in Fig. 17.1. The students apply a force *F* and measure the compression *x* of the springs.
The table below shows the results.

***F* / N**	***x* / cm**
1.1 ± 0.2	2.0
2.0 ± 0.2	4.0
2.9 ± 0.2	6.0
4.0 ± 0.2	8.0
5.1 ± 0.2	10.0

Fig. 17.2 shows four data points from the table plotted on a *F* against *x* graph.

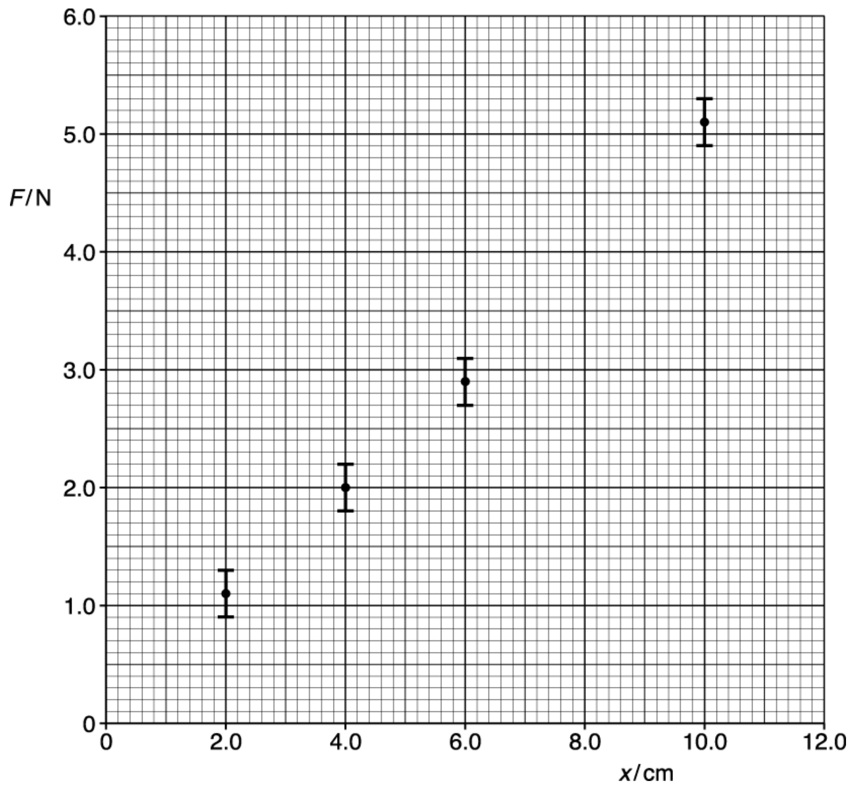


Fig. 17.2

i. Plot the missing data point and the error bar on Fig. 17.2.

[1]

ii. Describe how the data shown in the table may have been obtained in the laboratory.

[2]

iii. Draw the best fit and the worst fit straight lines on Fig. 17.2.
Use the graph to determine the force constant *k* for a **single** spring and the absolute uncertainty in this value.

k = ... ± .... N m^{-1} **[4]**

iv. State the feature of the graph that shows Hooke's law is obeyed by the springs.

[1]

v. The mass of the ball is 0.39 kg.

Use your answer from **(iii)** to calculate the launch speed *v* of the ball when the plastic plate shown in Fig. 17.1 is pulled back 12.0 cm.

v = ... m s^{-1} **[3]**

(b). A new arrangement for the ball-release mechanism using three identical springs is shown in Fig. 17.3.

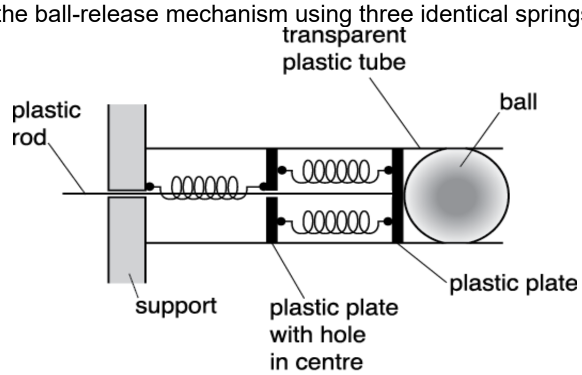


Fig. 17.3

The force constant of each spring is *k*.
The same ball of mass 0.39 kg is used. The plastic rod is pulled to the left by a distance of *x*.

Show that initial acceleration *a* of this ball is given by the equation

$$a = 1.7\,kx.$$

[2]

58. $^{60}_{27}Co$ is produced by irradiating the stable isotope $^{59}_{27}Co$ with neutrons.

Each nucleus of $^{60}_{27}Co$ then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.

Students want to carry out an investigation into gamma photon absorption using a source of $^{60}_{27}Co$.
They add sheets of lead between the source **S** and a radiation detector **T**, to give a total thickness *d* of lead. **S** and **T** remain in fixed positions, as shown in Fig. 2.1.

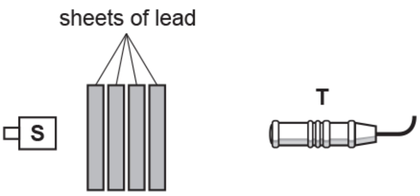


Fig. 2.1

i. The $^{60}_{27}Co$ source emits beta radiation as well as gamma radiation.

Explain why this would not affect the experiment.

[1]

ii. The students record the number *N* of gamma photons detected by **T** in 10 minutes for each different thickness *d* of lead. The background count is negligible.

The results are shown in a table. The table includes values of ln *N*, including the absolute uncertainties.

N	***d / mm***	***ln N***
4300 ± 440	0	8.37 ± 0.10
2500 ± 250	0	7.82 ± 0.10
1400 ± 150	20	7.24 ± 0.11
800 ± 90	30	6.68 ± 0.11
500 ± 60	40	6.21 ± 0.12
300 ± 40	50	

N and *d* are related by the equation $N = N_0 e^{-\mu}$ where N_0 and μ are constants.

1. The students decide to plot a graph of ln *N* against *d*.

Show that this should give a straight line with gradient = $-\mu$ and *y*-intercept = $\ln N_0$.

[1]

2. Complete the missing value of ln *N* in the table, including the absolute uncertainty.

Show your calculation of the absolute uncertainty in the space below.

[2]

3. In Fig. 2.2, five of the data points have been plotted, including error bars for ln *N*

- Plot the missing data point and error bar.
- Draw a straight line of best fit and one of worst fit.

[2]

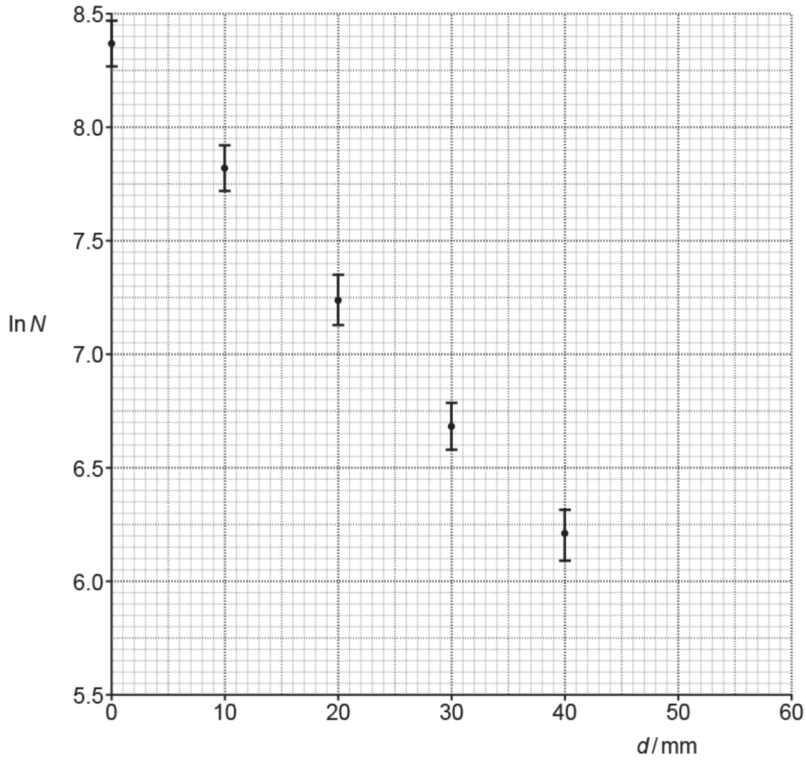


Fig. 2.2

4. Use Fig. 2.2 to determine the value of μ in m^{-1}, including the absolute uncertainty.

μ =.....................± .... m^{-1} **[4]**

5. Determine the thickness, $d_{½}$, of lead which halves the number of gamma photons reaching **T**.

$d_{½}$ = ... m **[2]**

END OF QUESTION PAPER