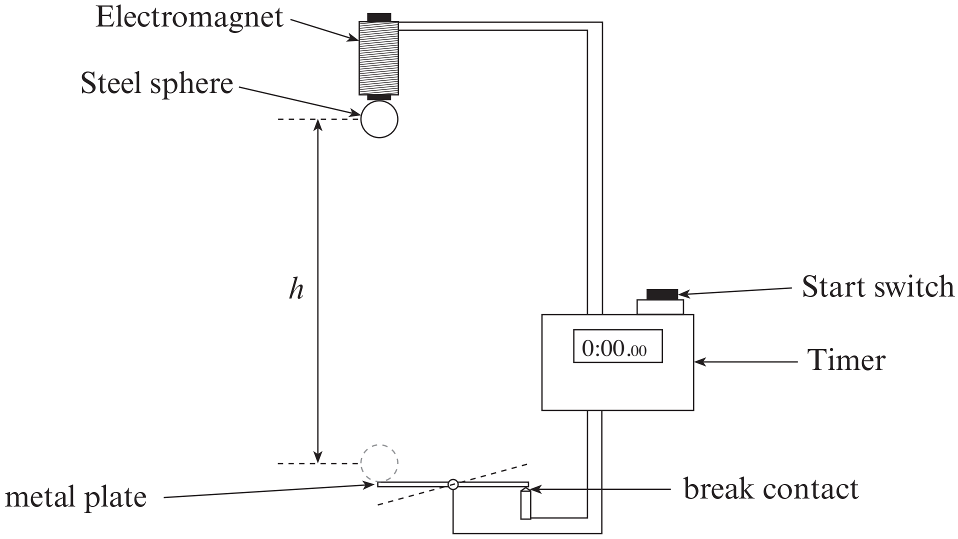
Data analysis task

Several Physics students carry out an experiment to measure the acceleration due to gravity, g, by measuring the time it takes for a steel sphere to fall and break an electrical contact. The following apparatus is used.



When the "Start switch" is pressed it disconnects the electromagnet, releasing the steel sphere. At the same instant the timer starts. When the sphere hits the metal plate it breaks the circuit, stopping the timer, which therefore records the time, t, it takes for the sphere to fall through the height, h.

The students repeat this procedure for a range of heights. The results are shown in the table below.

Height, h ± 0.01	Time, t ± 0.01	Time Squared, t^2 ± 5%	Absolute uncertainty in t^2
(m)	(s)	( )	( )
1.00	0.44		
1.20	0.49		
1.40	0.52		
1.60	0.56		
1.80	0.60		
2.00	0.64		
2.20	0.67		
2.40	0.70		

(a) Complete the two columns for time squared, (t^2) and absolute uncertainty in t^2. Include units at the top of each column. [4]

Examiner only

(b) The following equation of motion can be used to calculate the acceleration due to gravity, g.

$$x = ut + \tfrac{1}{2}at^2,$$

Where u = initial velocity = 0
x = height, h and
a = acceleration due to gravity, g

This gives $$h = \tfrac{1}{2}gt^2$$

Plot a suitable graph to determine the acceleration due to gravity. Include on your graph: error bars; a line of maximum gradient; a line of minimum gradient. [6]

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Examiner only

(c) (i) Determine the maximum and minimum gradients for your graph. [2]

(ii) Calculate the mean (average) gradient and its **percentage** uncertainty. [2]

(iii) Use your answer for the mean gradient to determine a value for the acceleration due to gravity, g. Quote your answer to the correct number of significant figures giving its absolute uncertainty. [4]

Examiner only

(d) The students now decide to use their value for g to estimate the mass of the Earth.

(i) Using Newton's universal law of gravitation, $F = \frac{GMm}{r^2}$, and $F = ma$, show that:

$$M_E = \frac{gR^2}{G}$$ [1]

Where M_E = mass of the Earth
R = Radius of the Earth (6.38×10^6m ± 2%)
G = Gravitational constant $(6.6743 \pm 0.0007) \times 10^{-11}$ N m^2 kg^{-2}

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(ii) Use the above equation, and your value for g to estimate the mass of the Earth, M_E. [1]

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(iii) Calculate the total **percentage** uncertainty in your answer to *(d)*(ii). [3]

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(iv) Hence determine the absolute uncertainty in the mass of the Earth. [2]

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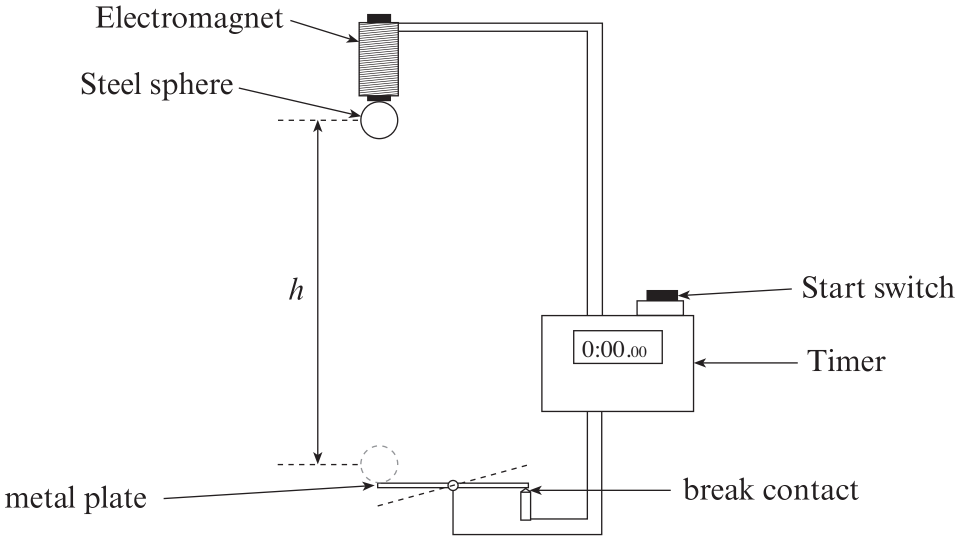
END OF QUESTION PAPER

Data analysis task

Several Physics students carry out an experiment to measure the acceleration due to gravity, g, by measuring the time it takes for a steel sphere to fall and break an electrical contact. The following apparatus is used.



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The students repeat this procedure for a range of heights. The results are shown in the table below.

Height, h ± 0.01	Time, t ± 0.01	Time Squared, t^2 ± 5%	Absolute uncertainty in t^2
(m)	(s)	**(s^2)**	**(s^2)**
1.00	0.44	***0.19 (4)***	***0.01 (0)***
1.20	0.49	***0.24 (0)***	***0.01 (2)***
1.40	0.52	***0.27 (0)***	***0.01 (4)***
1.60	0.56	***0.31 (4)***	***0.01 (6)***
1.80	0.60	***0.36 (0)***	***0.01 (8)***
2.00	0.64	***0.41 (0)***	***0.02 (1)***
2.20	0.67	***0.44 (9)***	***0.02 (2)***
2.40	0.70	***0.49 (0)***	***0.02 (5)***

(a) Complete the two columns for time squared, (t^2) and absolute uncertainty in t^2. Include units at the top of each column. [4]

See answers in table

Units correct [s^2 in both t and Δt^2] (1)
all t^2 calculated correctly (1)
t^2 quoted to 2 or 3 d.p. (1)
Uncertainties calculated correctly and expressed to 1 s.f. [accept 2 s.f.] (1)

(b) The following equation of motion can be used to calculate the acceleration due to gravity, g.

$$x = ut + \tfrac{1}{2}at^2,$$

Where u = initial velocity = 0
x = height, h and
a = acceleration due to gravity, g

This gives $h = \tfrac{1}{2}gt^2$

Plot a suitable graph to determine the acceleration due to gravity. Include on your graph: error bars; a line of maximum gradient; a line of minimum gradient. [6]

- *Suitable scales [points occupy more than ½ extent and not awkward sales – e.g. multiples of 3 (1) [apply e.c.f. if t^2 calculated incorrectly]*
- *All points plotted correctly to within ½ division (2) [Penalise 1 mark per error: max penalty 2]*
- *Error bars plotted correctly (1)*
- *Steepest line drawn correctly consistant with error bars (1)*
- *Least steep line drawn correctly consistent with error bars (1)*

(c) (i) Determine the maximum and minimum gradients for your graph. [2]

- *Suitable triangles shown on graph [or equiv, e.g. 2 points shown on each line] with h separation ≥ 1m (1)*
- *Both calculations correct [no s.f. penalty] (1)*

(ii) Calculate the mean (average) gradient and its **percentage** uncertainty. [2]

- *Mean gradient correctly calculated, e.c.f. (1)*
  [No s.f. penalty. Units not required]
- *% uncertainty correct, e.c.f. (1)* $[= \frac{\text{max grad} - \text{min grad}}{\text{mean grad}} \times 100]$

(iii) Use your answer for the mean gradient to determine a value for the acceleration due to gravity, *g*. Quote your answer to the correct number of significant figures giving its absolute uncertainty. [4]

- *g calculated correctly (e.c.f.) [from 2 × mean gradient] (1)*
  [No s.f. or unit penalty]
- *Absolute uncertainty correct and express to 1 s.f. (1)*
- *g quoted to precision consistent with uncertainty (1)*
  [e.g. if uncertainty s.f. is in 1^{st} decimal place, g quoted to 1 d.p.]
- *Unit for g given as* ms^{-2} *(1) [Accept* Nkg^{-1}*]*
  [Accept $cm\,s^{-2}$ *if apropriate]*

(d) The students now decide to use their value for g to estimate the mass of the Earth.

(i) Using Newton's universal law of gravitation, $F = \frac{GMm}{r^2}$, and $F = ma$, show that:

$$M_E = \frac{gR^2}{G}$$ [1]

Where M_E = mass of the Earth
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G = Gravitational constant $(6.6743 \pm 0.0007) \times 10^{-11}$ N m^2 kg^{-2}

- $mg = \frac{GMm}{r^2}$ ***and convincing manipulation*** *(1)*

(ii) Use the above equation, and your value for g to estimate the mass of the Earth, M_E. [1]

- *Mass calculated correctly (e.c.f.) and expressed in kg (1)*

(iii) Calculate the total **percentage** uncertainty in your answer to *(d)*(ii). [3]

- *% uncertainty in R^2 given as 2 × 2% [=4%]*
  [can be awarded by implication if the final answer is correct]
- *Comment that % uncertainty in G is irrelevant [or very small]*
- *Total % uncertainty calculated correctly from 4% + % uncertainty in g [from (c)(ii)] (1)*

(iv) Hence determine the absolute uncertainty in the mass of the Earth. [2]

- *Absolute uncertainty calculated correctly and expressed to 1 s.f. (1)*
  [From (c)(i) × (c)(ii) / 100]
- *mass quoted with a precision consistent with uncertainty (1)*