Measurement of *g* by freefall

Practical question — PH6 2010 Data analysis task

Total	/25

INSTRUCTIONS

The candidates will be expected to determine the density of aluminium foil.

Test 1

Apparatus required:

- 1 × rectangular sheet of aluminium (cooking) foil approximately 30 cm wide and 100 cm long. 1 × metre ruler.
- 1 × digital vernier callipers [or a micrometer] of resolution 0·01 mm.
- 1 × 50 ml measuring cylinder.
- 1 × balance of resolution 0·1 g or 0·01 g.
- 1 × water bottle or beaker containing at least 50 cm^3 of water.

All the above apparatus should be available to the candidate at the start of the experiment. The micrometer/vernier callipers could be shared between candidates, as could the balance.

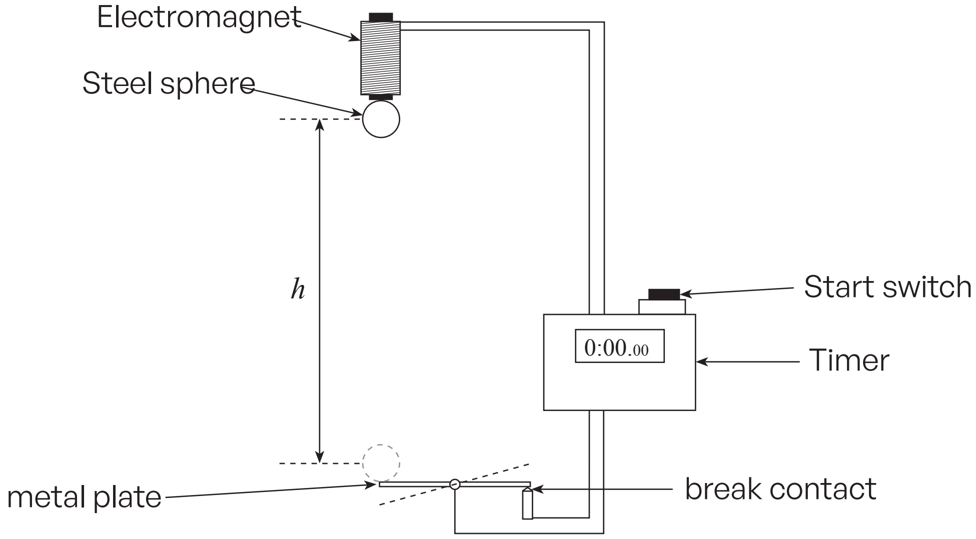
Test 2

The apparatus is as for Test 1, except that the sheet of aluminium foil should be approximately 30cm × 80cm.

You are going to use a sheet of aluminium foil to determine the density of aluminium by two different methods.

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		

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

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

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

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

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

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]

3. (a) Determine the maximum and minimum gradients for your graph. [2]

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

(c) 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]

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

(a) 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 (6.38×10^6 m ± 2%)
G = Gravitational constant $(6.6743 \pm 0.0007) \times 10^{-11}$ N m^2 kg^{-2}

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

(c) Calculate the total **percentage** uncertainty in your answer to **4.**(b). [3]

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

MARK SCHEME

<table>
<tr><th colspan="2">Question</th><th></th><th>Marks available</th></tr>
<tr><td>1.</td><td></td><td>
<table>
<tr><th>Height, h
± 0.01</th><th>Time, t
± 0.01</th><th>Time Squared, t^2
± 5%</th><th>Absolute uncertainty in t^2</th></tr>
<tr><td>(m)</td><td>(s)</td><td>(s^2)</td><td>(s^2)</td></tr>
<tr><td>1.00</td><td>0.44</td><td>0.19 (4)</td><td>0.01 (0)</td></tr>
<tr><td>1.20</td><td>0.49</td><td>0.24 (0)</td><td>0.01 (2)</td></tr>
<tr><td>1.40</td><td>0.52</td><td>0.27 (0)</td><td>0.01 (4)</td></tr>
<tr><td>1.60</td><td>0.56</td><td>0.31 (4)</td><td>0.01 (6)</td></tr>
<tr><td>1.80</td><td>0.60</td><td>0.36 (0)</td><td>0.01 (8)</td></tr>
<tr><td>2.00</td><td>0.64</td><td>0.41 (0)</td><td>0.02 (1)</td></tr>
<tr><td>2.20</td><td>0.67</td><td>0.44 (9)</td><td>0.02 (2)</td></tr>
<tr><td>2.40</td><td>0.70</td><td>0.49 (0)</td><td>0.02 (5)</td></tr>
</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)</td><td>4</td></tr>
<tr><td>2.</td><td></td><td>Suitable scales [points occupy more than 1⁄2 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 1⁄2 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)</td><td>6</td></tr>
<tr><td>3.</td><td>(a)</td><td>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)</td><td>2</td></tr>
<tr><td></td><td>(b)</td><td>Mean gradient correctly calculated, e.c.f. (1)
[No s.f. penalty. Units not required]
% uncertainty correct, e.c.f. (1) $[= \frac{max\ grad - min\ grad}{mean\ grad} \times 100]$</td><td>2</td></tr>
</table>

Question			Marks available
	(c)	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 1st decimal place, g quoted to 1 d.p.] Unit for g given as ms^{-2}(1) [Accept Nkg^{-1}] [Accept cms^{-2} if appropriate]	4
4.	(a)	$mg = \frac{GMm}{r^2}$ ***and convincing manipulation** (1)*	1
	(b)	Mass calculated correctly (e.c.f.) and expressed in kg (1)	1
	(c)	% uncertainty in R2 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 [3(b)] (1)	3
	(d)	Absolute uncertainty calculated correctly and expressed to 1 s.f. (1) [From 3.(a) × 3.(b) / 100] mass quoted with a precision consistent with uncertainty (1)	2