Cambridge Assessment International Education

Practical booklet 1

Determination of the spring constant *k* of a spring using the principle of moments

Cambridge International AS & A Level Physics 9702

Version 0.1

Cambridge Pathway

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Introduction

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The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To apply Hooke's Law and the principle of moments to a practical situation.

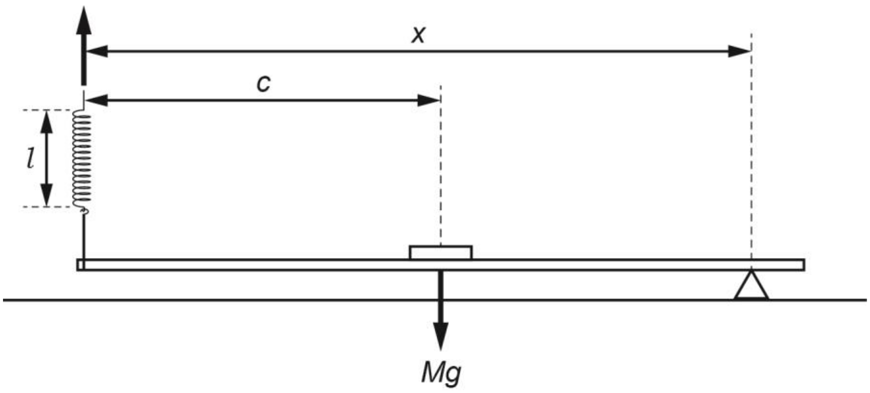
Outcomes

Syllabus sections 1.2e, 2.1a, 5.2a, 5.3a, 9.1b

Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Balance a loaded metre rule Measure the length of a spring using a ruler Measure mass using a balance
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
PDO graph	Draw a graph and determine the gradient and *y*-intercept
ACE interpretation	Interpret the gradient and *y*-intercept
ACE conclusions	Determine the spring constant
ACE limitations	Identify the limitations of the experimental procedure
ACE improvements	Identify possible improvements to the experimental procedure

Theory



A 100 g mass is attached to the mid-point of a metre rule. This makes the rule artificially heavier so that appreciable changes in the length of the spring can be measured later. Learners have to consider the irregular shape of a slotted mass when attaching it to the centre of the rule.

The combined mass of the rule and 100 g mass is M.

The loaded metre rule is supported by the pivot and the spring. The rule is horizontal and the spring is vertical. Assuming that the string is at the end of the rule, then taking moments about the pivot:

Clockwise moment = $k(l - l_0)x$ where l_0 is the unstretched length of the coiled part of the spring.

Anticlockwise moment = $Mg(x - c)$

So, $Mg(x - c) = k(l - l_0)x$ when the rule is balanced

$$Mgx - Mgc = klx - kl_0x$$

$$klx = -Mgc + Mgx + kl_0x$$

$$klx = -\frac{Mgc}{kx} + \frac{Mg}{k} + l_0$$

$$l = -\frac{Mgc}{kx} + \frac{Mg}{k} + l_0$$

$$l = -\frac{Mgc}{k} \cdot \frac{1}{x} + \left(\frac{Mg}{k} + l_0\right)$$

$$l = -\frac{A}{x} + B$$

If the pivot is moved to a new position (x), the height of the spring must be changed for the rule to return to a horizontal position and so the length (l) of the stretched part of the spring changes.

If six sets of readings are taken and a graph is plotted of l on the y-axis against $1/x$ on the x-axis, the gradient = $-A$ and the y-intercept = B.

Since $A = \frac{Mgc}{k}$ and $B = \frac{Mg}{k} + l_0$, two values of k can be determined knowing values for M, c, g and l_0.

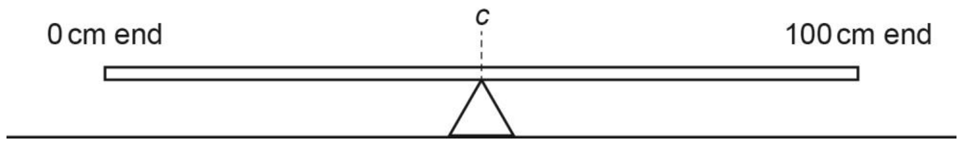
If the graph line through the plotted points is not close to the y-axis, the y-intercept has to be calculated using the equation of straight line $y = mx + c$. This could mean that one value of k is more reliable than the other.

A more direct method for determining k is to find the gradient of a force-extension graph.

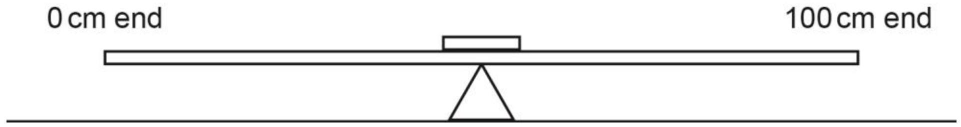
Some physical quantities are often determined in an indirect method e.g. the mass of the Sun is not measured directly but calculated from other measurements such as the time periods of planets.

Method

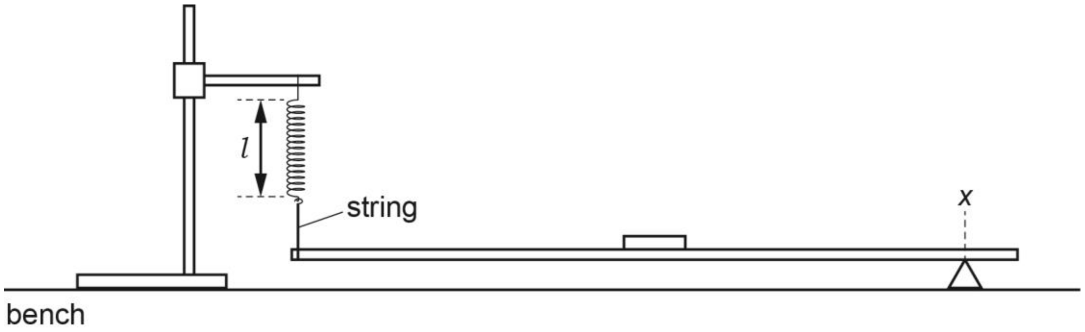
- Learners balance the metre rule as shown and note the reading c of the rule directly above the pivot.



- They then place the 100 g mass over the centre of the rule so that it still balances at c and then they tape the mass to the rule as shown.



- Using an electronic balance, learners will determine the mass M in kg of the combined mass of the rule and the attached mass.
- They then measure and record the length l_0 of the coiled section of the unstretched spring.
- Learners then set up the apparatus as shown with the rule horizontal and the spring vertical. The string should be as close to the end of the rule as possible.



- Learners need to note the reading at x and the length l of the coiled part of the spring.

Results

Learners need to vary the position of the pivot until they have six sets of values of *x* and l and enter them in a table like that below, including values of 1/*x*. All values should be in SI units because later on in the analysis the value of *g* is given in SI units.

All raw values of *x* and *l* should be to the same number of decimal places, i.e. to the nearest mm allowed by the rule.

The number of significant figures for 1/*x* should be the same as, or one more than, the number of significant figures for the corresponding value of *x.*

***x*/m**	***l*/m**	**(1/*x*)/m^{-1}**

Learners then plot a graph of l on the *y*-axis against 1/*x* on the *x*-axis and draw the line of best fit

Interpretation and evaluation

Learners

- determine the gradient and the *y*-intercept of their graph line

$$\text{gradient} = \frac{Mgc}{k}$$ where *k* is the spring constant and *g* = 9.81 m s^{-2}

$$\text{y-intercept} = \frac{Mg}{k} + l_0$$

- use their values of *M*, *c*, l_0, gradient and *y*-intercept to determine values for *k*
- include an appropriate unit for *k*
- discuss whether one determination of *k* is more reliable than the other and explain why
- describe the main sources of uncertainty in this investigation*
- describe how they could improve the investigation.

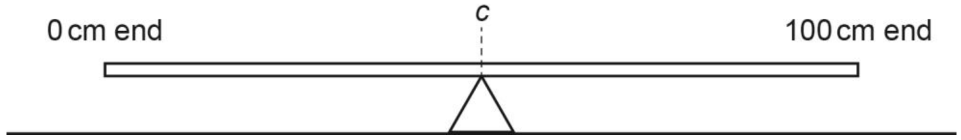
*values of *c* and *x* assume that the bottom of the rubber band is at the 0 cm mark
*the coils of the spring are tilted when l is measured.

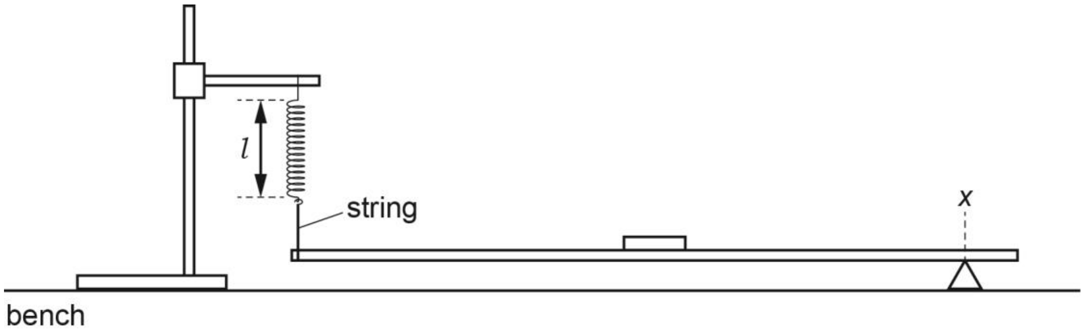
Technician's notes

Each learner will require:

- 1 × stand
- 1 × boss
- 1 × clamp
- 1 × spring
- string of length 1m
- 1 × 100g mass
- 1 × metre rule (with millimetre scale)
- 1 × small roll of adhesive tape
- 1 × triangular glass prism or small triangle pivot
- 1 × 30cm ruler with millimetre scale
- access to an electronic balance

Equipment set-ups





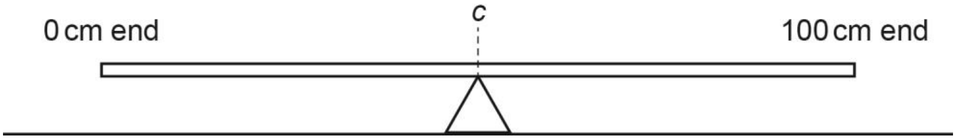
Learner worksheet

Aim

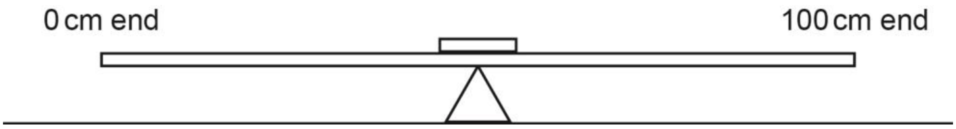
To apply Hooke's Law and the principle of moments to a practical situation.

Method

1. Balance the metre rule as shown and note the reading *c* of the rule directly above the pivot.

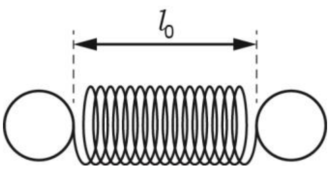


2. Place the 100 g mass over the centre of the rule so that it still balances at *c* and tape the mass to the rule as shown.

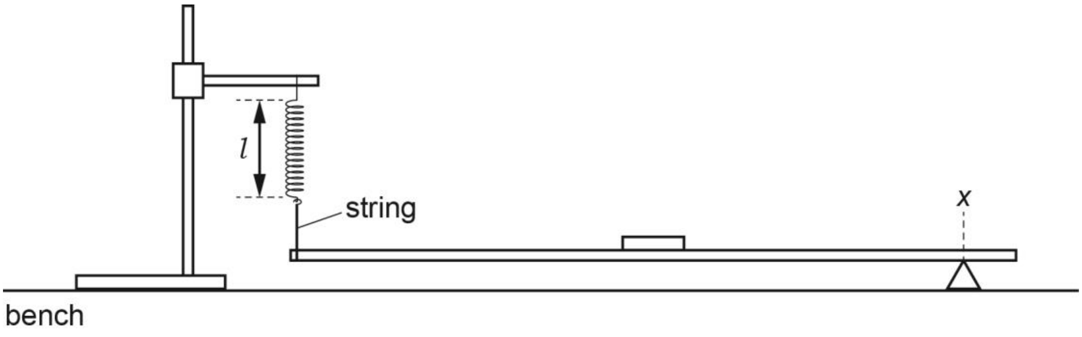


3. Use the electronic balance to find the mass *M* in kg of the combined mass of the rule and the attached mass.

4. Measure and record the length l_0 of the coiled section of the unstretched spring.



5. Set up the apparatus as shown with the rule horizontal and the spring vertical. The string should be as close to the end of the rule as possible.



6. Note the reading at *x* and the length l of the coiled part of the spring.

7. Change the position of the pivot until you have six sets of values of *x* and l.

8. Include values of 1/*x* in the table.

Results

Record all of your results in a table.

x/m	*l*/m	(1/*x*)/m^{-1}

Note

- All values will be in SI units because later on in the analysis the value of *g* is used.
- All raw values of *x* and l should be to the same number of decimal places i.e. to the nearest mm.
- The number of significant figures for 1/*x* should be the same as or one more than the number of significant figures for the corresponding value of *x*.

Interpretation and evaluation

1. Plot a graph of l on the *y*-axis against 1/*x* on the *x*-axis.
2. Draw the line of best fit through your points.
3. Find the gradient of your graph.
4. Find the *y*-intercept of your graph.
5. Theory suggests that l and *x* are related by the equation $l = -\frac{A}{x} + B$ where *A* and *B* are constants.
6. Use your results for the gradient and y-intercept to find values for *A* and *B*. Include appropriate units.
7. $A = \frac{Mgc}{k}$,where *k* is the spring constant and *g* = 9.81 ms^{-2}

   $$B = \frac{Mg}{k} + l_0$$

   Use your values of *M*, *c*, l_0, *A* and *B* to determine values for *k*. Include an appropriate unit for *k*.
8. Discuss whether one determination of *k* is more reliable than the other and explain why.
9. Describe the main sources of uncertainty in this investigation.
10. Describe how you could improve the investigation.

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Practical booklet 2

How the torsional motion of a disc depends on its mass and diameter

Cambridge International AS & A Level

Physics 9702

Version 0.1

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Guidance for teachers

Aim

To investigate the torsional motion of a disc and how this motion depends on the dimensions of the disc. This experiment involves using a stopwatch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations.

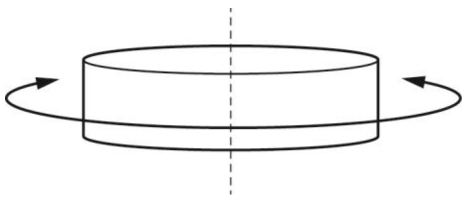
Outcomes

Syllabus sections 1.2e, 2.1a, 2.2c

Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Measure the radius of a mass hanger using a ruler Measure mass using a balance Measure times using a stopwatch
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
ACE conclusions	Draw conclusions relating to the validity, or otherwise, of a given relationship
ACE estimating uncertainties	Estimate the uncertainty in the radius of the disc
ACE limitations	Identify the limitations of the experimental procedure
ACE improvements	Identify possible improvements to the experimental procedure

Theory



When a disc of mass m and radius R undergoes torsional oscillations about a vertical axis the period T is proportional to $\sqrt{mR^2}$ or

$$T^2 = kmR^2 \text{ where } k \text{ is a constant.}$$

The theory is beyond AS Level but relationships like these can be used for AS investigations because they involve measurements that AS students will be expected to make under exam conditions.

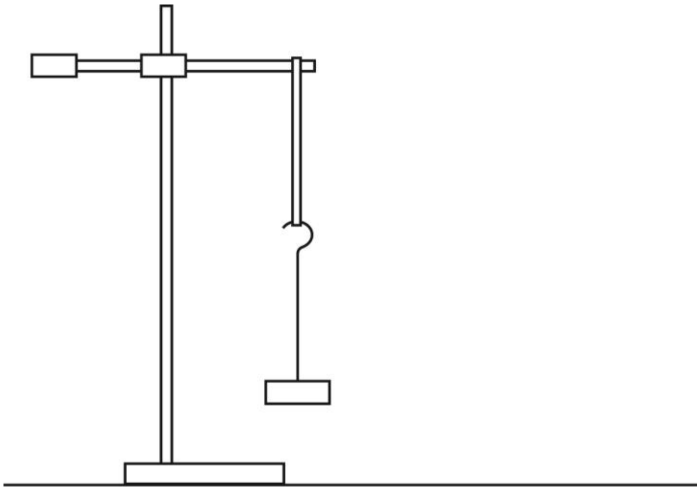
During this investigation, learners will suspend a mass hanger of mass m and radius R and note the time period T for rotational oscillations.

They will do this for two mass hangers of different mass and diameter and investigate the relationship between T, m and R.

Since two results are insufficient to draw a graph, you may wish to encourage learners to plan and carry out further experiments using the modelling clay as an improvement to this experiment.

Method

- For both the 50 g and 100 g mass hangers, learners measure the mass m and the radius R at the widest point.
- They then suspend the 100 g mass hanger from a rubber band and determine the time period T for rotational oscillations, then repeat this for the 50 g mass hanger.
- Learners then investigate the validity of the relationship $T^2 = kmR^2$ where k is a constant.



Results

Learners should record their results in a table like the one below.

			Time for 10 cycles				
***m*/kg**	***R*/m**	**R^2/m²**	**t_1/s**	**t_2/s**	***T*/s**	**T^2/s²**	**k/s² kg⁻¹ m⁻²**

Interpretation and evaluation

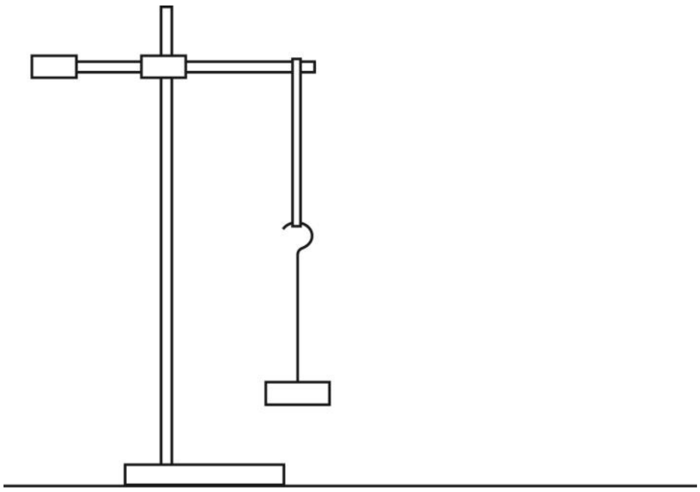
- The validity of the relationship depends on the percentage uncertainty in k.
- Percentage uncertainty in $k = (2\Delta T/T + \Delta m/m + 2\Delta R/R) \times 100\%$
- When the percentage uncertainty is not calculated as above, a statement linking the validity of a relationship to whether the two values are within an arbitrary percentage, e.g. 10% of each other, is sufficient.
- Statements such as 'the relationship is invalid because the two k values are different' are insufficient.

Technician's notes

Each learner will require:

- 1 × stand
- 1 × boss
- 1 × clamp
- 1 × 100g mass hanger
- 1 × 50g mass hanger
- 1 × metre rule with a millimetre scale
- 1 × rubber band
- 1 × stopwatch reading to 0.1s or better
- access to an electronic balance
- 50g of modelling clay

Equipment set-up



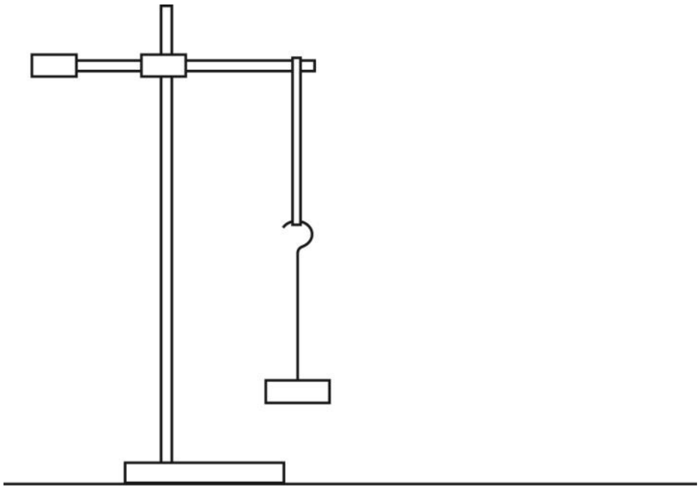
Learner worksheet

Aim

To use a stopwatch to measure intervals of time, including the period of an oscillating system by timing an appropriate number of consecutive oscillations.

Method

1. Determine the radius *R* of the 100 g mass at its widest point.
2. Estimate the percentage uncertainty in *R*.
3. Determine the mass *m* of the 100 g mass.
4. Suspend the rubber band from the stand and hang the 100 g mass hanger from the rubber band as shown.



5. Twist the mass hanger through about half a turn and release it.
6. Measure the time for ten complete cycles and determine the time *T* for one complete cycle.
7. Calculate mR^2.
8. Repeat for the 50 g mass hanger.

Results

Record all of your results in a table.

			Time for 10 cycles				
***m*/kg**	***R*/m**	**R^2/m^2**	**t_1/s**	**t_2/s**	***T*/s**	**T^2/s^2**	**k/s^2 kg^{-1} m^{-2}**

Note

- All raw values of *m* should be to the same number of decimal places i.e. to the nearest g or 0.1 g.
- All raw values of *R* should be to the same number of decimal places i.e. to the nearest mm.
- All raw values of *t* should be to the same number of decimal places i.e. to the nearest 0.1 s or 0.01 s.
- The number of significant figures for R^2 should be the same as or one more than the number of significant figures for the corresponding value of *R*.
- The number of significant figures for T^2 should be the same as or one more than the number of significant figures for the corresponding values of *t*.

Interpretation and evaluation

Investigate the validity of the relationship $T^2 = kmR^2$ where *k* is a constant.

The relationship is valid if the two values of *k* are the same within the bounds of experimental uncertainty.

The percentage uncertainty in $k = (2\Delta T/T + \Delta m/m + 2\Delta R/R) \times 100\%$

1. Calculate the percentage uncertainty in *k*.

   When the percentage uncertainty is not calculated as above, a statement linking the validity of a relationship to whether the two values are within an arbitrary percentage, e.g. 10% of each other, is sufficient. Statements such as ‘the relationship is invalid because the two *k* values are different’ are insufficient.

2. Explain whether your results support the relationship.

3. Justify the number of significant figures that you have given for your values of *k*.

4. Describe two sources of uncertainty or limitations of the experiment.

5. Describe two improvements that could be made to this experiment. You may suggest the use of other apparatus or different procedures.

Note

- A source of uncertainty is measuring *R* with a metre rule. An improvement would be to use Vernier calipers instead of a metre rule.
- Measuring radius directly is uncertain. Measuring diameter and halving it to get radius reduces uncertainty. Do not simply state ‘measuring radius’ as a source of uncertainty because you can reduce this uncertainty yourself without additional equipment.

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Cambridge Assessment International Education

Practical booklet 3

Determination of the acceleration of free fall g using the motion of two connected masses

Cambridge International AS & A Level

Physics 9702

Version 0.1

Cambridge Pathway

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Guidance for teachers

Aim

To apply Newton's laws of motion and the equations of uniformly accelerated motion to a practical situation.

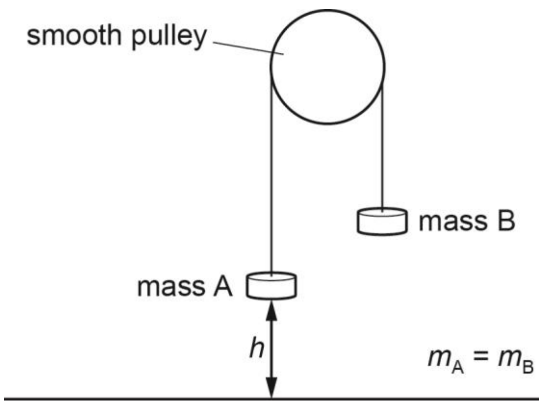
Outcomes

Syllabus sections 1.2e, 2.1a, 3.1g, 3.1h, 4.1b, 5.1c

Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Measure the height of a mass above the floor using a ruler Measure times using a stopwatch
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
ACE interpretation	Relate results to AS theory
ACE conclusions	Draw conclusions relating to the validity, or otherwise, of a given relationship
ACE estimating uncertainties	Estimate uncertainty in times
ACE limitations	Identify the limitations of the experimental procedure
ACE improvements	Identify possible improvements to the experimental procedure

Theory



When mass A of mass m_A is released it will fall through a distance h to the floor and mass B of mass m_B will move upwards. Both masses will have an acceleration of a. The tension in the string is T.

Applying Newton's laws to mass A and to mass B

$$m_A g - T = m_A a \quad \text{....(i)}$$

$$T - m_B g = m_B a \quad \text{....(ii)}$$

where T is the tension in the string.

Since $s = ut + ½at^2$ and $u = 0$ it follows that $h = ½at^2$ and therefore $a = 2h/t^2$.

Adding (i) and (ii) and substituting for a: $(m_A - m_B)g = 2h(m_A + m_B)/t^2$.

So $(m_A - m_B) = k/t^2$ where k is a constant and $k = 2h(m_A + m_B)/g$.

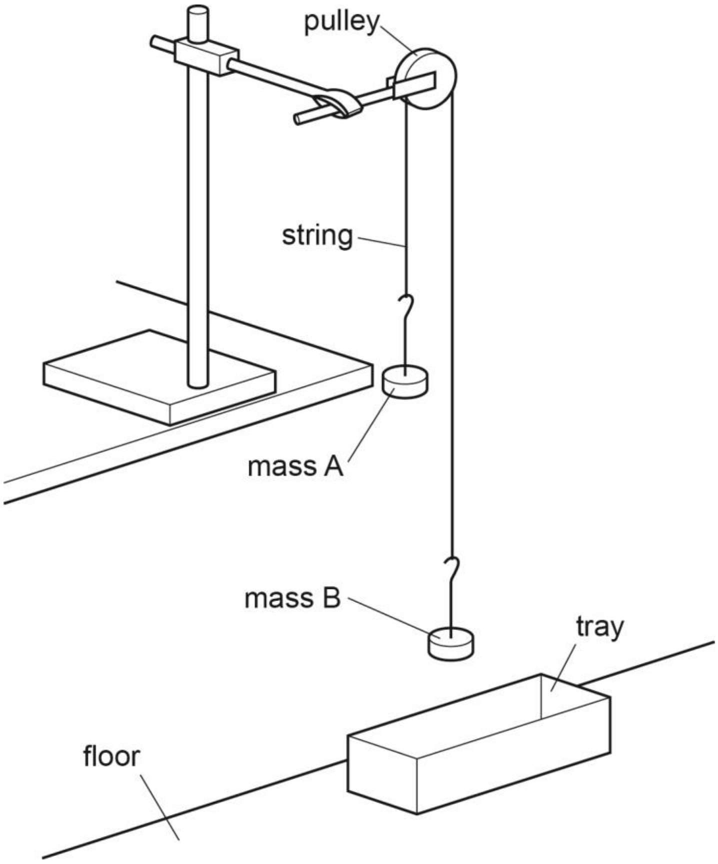
The value of g is given by $g = 2h(m_A + m_B)/k$.

The calculated value of g will be less than $9.81\,\mathrm{m\,s^{-2}}$ due to friction in the pulley.

Method

Learners

- set up the apparatus as shown.



- make both the mass m_A of A and the mass m_B of B equal to 100 g. It must be possible to transfer masses from B to A.
- adjust the height of the apparatus so that the distance h between the bottom of mass A and the floor is approximately 1 metre.
- transfer 10 g from mass B to mass A
- record the mass m_A of mass A and the mass m_B of mass B.
- calculate the difference in mass ($m_A - m_B$).
- release mass A from height h and determine the time t it takes to reach the floor.
- estimate the percentage uncertainty in their value of t.
- transfer another 10 g from mass B to mass A and repeat

It is suggested that the relationship between ($m_A - m_B$) and t is

$$(m_{\mathrm{A}} - m_{\mathrm{B}}) = \frac{k}{t^2}$$

where k is a constant.

Interpretation and evaluation

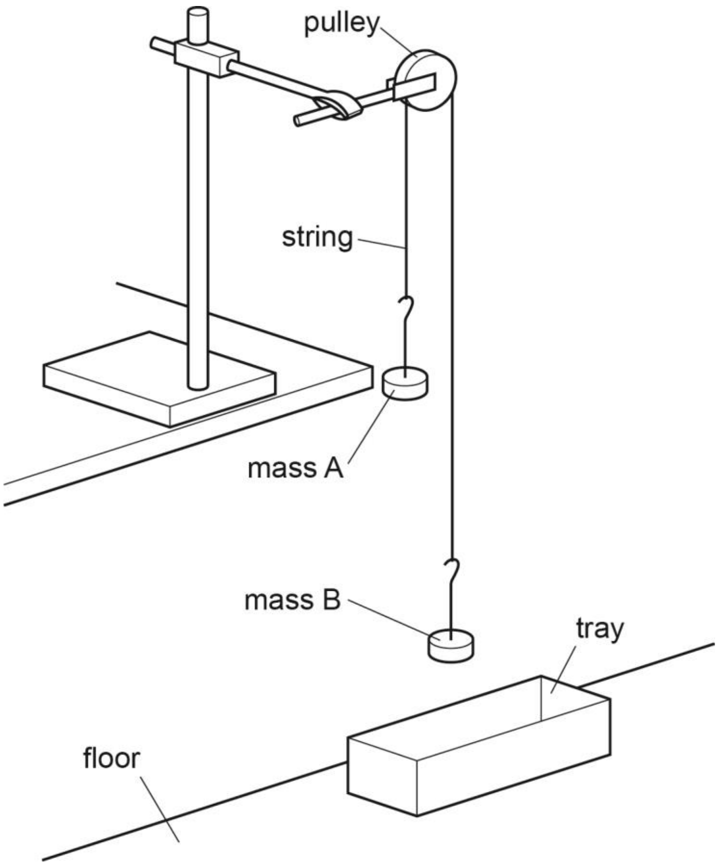
- Learners use their value of k to determine g using $k = 2h(m_A - m_B)/g$.
- They then comment on any difference between their value for g and the accepted value of $9.81\,\mathrm{m\,s^{-2}}$.
- Learners should then explain this difference in terms of the experimental conditions, e.g. friction in the pulley or air resistance.

Technician's notes

Each learner will require:

- 1 × stand
- 1 × boss
- 1 × clamp
- 1 × 100g mass hanger
- 1 × 50g mass hanger
- 5 × 10g slotted masses which must fit both hangers
- 1 × pulley
- 1 × metre rule
- string
- 1 × stopwatch
- 1 × shallow tray
- access to a balance

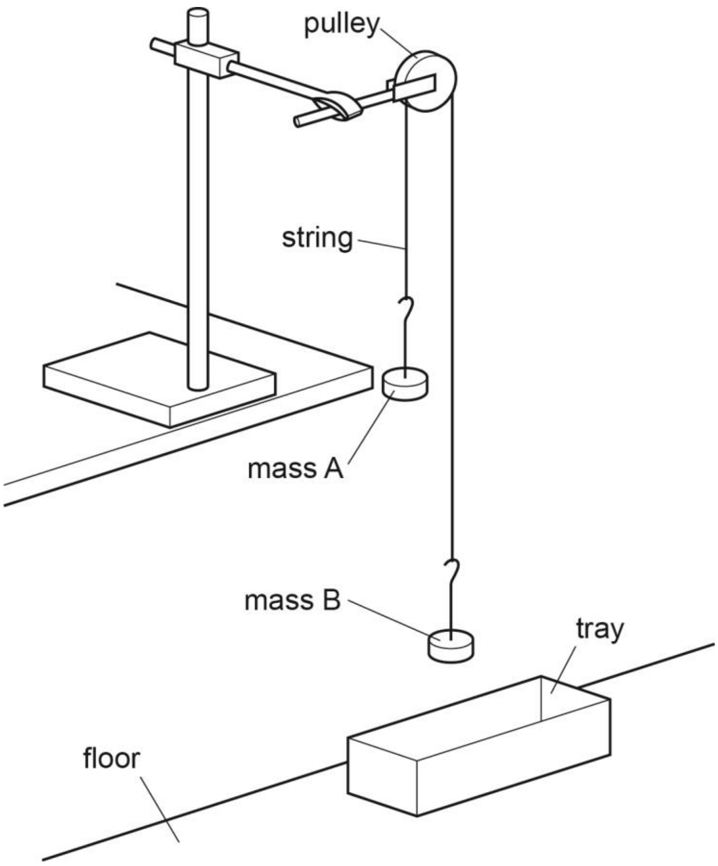
Equipment set-up



Learner worksheet

Method

1. Set up the apparatus as shown.



2. Make both the mass m_A of A and the mass m_B of B equal to 100 g. It must be possible to transfer masses from B to A.

3. Adjust the height of the apparatus so that the distance h between the bottom of mass A and the floor is approximately 1 metre.

4. Transfer 10 g from mass B to mass A.

5. Record the mass m_A of mass A and the mass m_B of mass B.

6. Calculate the difference in mass ($m_A - m_B$).

7. Release mass A from height h and determine the time t it takes to reach the floor.

8. Estimate the percentage uncertainty in your value of t.

9. Transfer another 10 g from mass B to mass A and repeat 3, 4, 5, 6 and 7.

Results

Record your results.

m_A	m_B	$m_A - m_B$	t_1/s	t_2/s	$t_{average}$/s	t^2/s^2

Interpretation and evaluation

1. It is suggested that the relationship between ($m_A - m_B$) and t is $(m_A - m_B) = \frac{k}{t^2}$ where k is a constant.
   - Investigate the validity of the relationship by calculating two values of k.
   - The relationship is valid if the two values of k are the same within the bounds of experimental uncertainty.
   - When the percentage uncertainty is not calculated as above, a statement linking the validity of a relationship to whether the two values are within an arbitrary percentage, e.g. 10% of each other is sufficient. Statements such as 'the relationship is invalid because the two k values are different' are insufficient.

2. Explain whether your results support the relationship.

3. Justify the number of significant figures that you have given for your values of k.

4. $k = \frac{2h(m_A+m_B)}{g}$ so $g = \frac{2h(m_A+m_B)}{k}$. Calculate g.

5. Calculate the percentage uncertainty in g.

6. Comment on your value of g compared to the accepted value of $9.81\,\text{m}\,\text{s}^{-2}$.

7. If your value of g is not within the percentage uncertainty of 9.81, suggest why your value is different.

Planning

One source of uncertainty is that only two results are obtained. This is insufficient evidence and no graph can be drawn.

Using the apparatus provided, collect sufficient results so that the following graph can be drawn: ($m_A - m_B$) against $1/t^2$

If the relationship is valid then the graph should be a straight line through the point (0,0).

Note

- For every set of readings ($m_A + m_B$) must be constant
- As ($m_A - m_B$) increases the values of t may become too small to measure. Could the range of the experiment be extended by using 5 g msses instead of 10 g masses?

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Cambridge Assessment International Education

Practical booklet 4

Determination of the resistivity of a metal

Cambridge International AS & A Level

Physics 9702

Version 0.1

Cambridge Pathway

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Introduction

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The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To set up a circuit including an ammeter, voltmeter and resistors in series and use Ohm's Law.

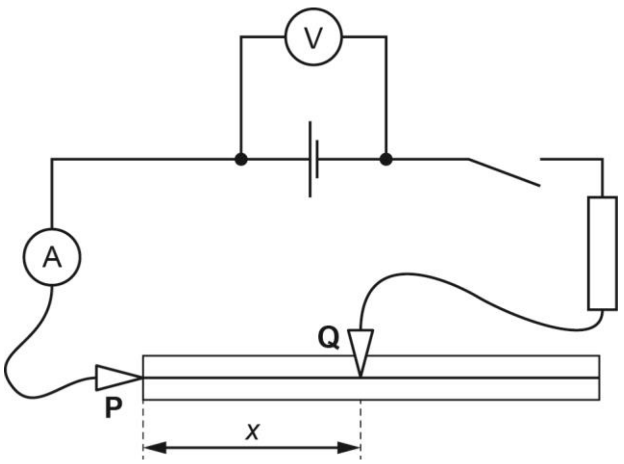
Outcomes

Syllabus sections 1.2e, 2.1a, 2.1b, 19.3b, 19.3e, 20.1b, 20.2d

Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Construct a circuit from a circuit diagram Use an ammeter and a voltmeter Use a micrometer screw gauge Measure length using a metre rule
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
PDO graph	Draw a graph and determine the gradient and *y*-intercept
ACE interpretation	Interpret the gradient and *y*-intercept
ACE conclusions	Determine the resistivity of the metal

Theory



P and **Q** are the crocodile clips

Diameter of constantan wire = d, so cross section area of wire = $\pi d^2/4$
Voltmeter reading = V; Ammeter reading = I
Distance between crocodile clips along wire = x
Resistance of resistor = R
Resistance of wire between crocodile clips = $\rho x/A$
where ρ = resistivity of constantan, and A = cross-sectional area of constantan wire

Total resistance in series = $R + \rho x/A$

Using Ohm's Law:

$$\frac{V}{I} = R + \frac{\rho x}{A}$$

so

$$\frac{1}{I} = \frac{\rho x}{AV} + \frac{R}{V}$$

Therefore $\frac{1}{I} = Mx + N$ where $M = \frac{\rho}{AV}$ and $N = \frac{R}{V}$.

A graph of $1/I$ on the *y*-axis against *x* on the *x*-axis will have a gradient = *M* and y-intercept = *N*.

Method

Learners

- measure the diameter *d* of the wire using the micrometer screw gauge.
- calculate the cross-sectional area *A* of the wire.
- connect the circuit with the crocodile clip **Q** half way along the wire.
- close the switch and read *V*, I and *x.*
- increase *x* and note I until they have six sets of values of *x* and I.

Results

- Learners should record values of *x* to the same number of decimal places, i.e. to the nearest mm allowed by the rule, and I to the precision allowed by the ammeter. They should include values of $1/I$ in the table. Appropriate units should be added to the column headings.

- The number of significant figures for $1/I$ should be given to the same as, or one more than, the number of significant figures for the corresponding value of I.

x	I	$1/I$

- Learners then plot a graph of $1/I$ on the *y*-axis against *x* on the *x*-axis and draw the line of best fit.

Interpretation and evaluation

Learners

- determine the gradient and *y*-intercept of the graph line
- use the gradient and values of *A* and *V* to determine ρ
- use the *y*-intercept and *V* to determine *R*
- compare their value of ρ with the accepted value of $4.9 \times 10^{-7}\,m^2$
- compare their value of *R* with 10 Ω

Note

- Any of the wires in the table are suitable:

material	swg	diameter/mm	resistivity/Ω m
constantan	32	0.27	4.9×10^{-7}
constantan	34	0.23	4.9×10^{-7}
constantan	36	0.19	4.9×10^{-7}
nichrome	26	0.46	1.5×10^{-6}
nichrome	28	0.38	1.5×10^{-6}
nichrome	30	0.32	1.5×10^{-6}

- Learners are asked to increase *x*. For very small values of *x* the resistance of the connecting wires is significant and the graph is not linear.
- Allow learners to use any unit e.g. A or mA or cm or m and discuss at the end if their value of ρ is consistent with the value of ρ in SI units.

The theory assumes that *V* remains constant. If the results deviate from a straight line graph it could be because *V* has decreased because the dry cell has remained connected for a long period or that the cell has significant internal resistance.

Technician's notes

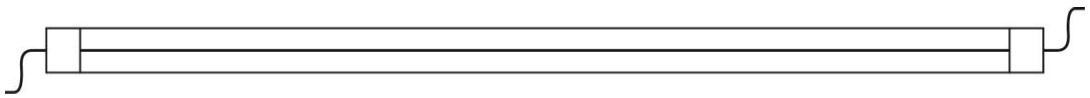
Each learner will require:

- 1 × 1.5V dry cell
- 1 × ammeter
- 1 × voltmeter
- 1 × switch
- 7 × connecting leads
- 2 × crocodile clips
- 110 cm of constantan wire swg 34*
- 1 × 10Ω resistor
- Access to a micrometer screw gauge

Additional instructions

* any of the following wires would be suitable:
    constantan 32, 34, 36 swg
    nichrome 26, 28, 30 swg

The wire should be taped to the metre rule as shown in the diagram:



Learner worksheet

Aim

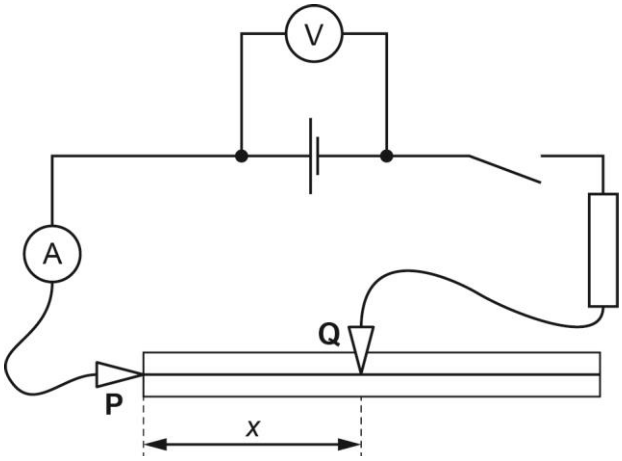
To set up a circuit including an ammeter, voltmeter and resistors in series, take readings from the circuit and use Ohm's Law.

Method

1. Use the micrometer to measure the diameter d of the thin wire that is attached to the metre rule. You should be able to use the short length at each end on the other side of the tape.

2. Calculate the cross section area A of the wire using the equation $\pi d^2/4$.

3. Set up the circuit shown:



4. Connect crocodile clip **P** to the short length of wire overhanging the metre rule.

5. Connect crocodile clip **Q** to the wire about half way along it (close to the 50 cm mark)

6. Close the switch and record values of
   - length x
   - ammeter reading I
   - voltmeter reading V.

7. Increase x until you have six sets of values for x and I.

Results

Record your results. Include values of $1/I$, and each column heading should have a suitable unit

x	I	$1/I$

Interpretation and evaluation

1. Plot a graph of $1/I$ on the y-axis against x on the x-axis.

2. Draw the line of best fit through your points.

3. Find the gradient of your graph.

4. Find the y-intercept of your graph.

5. Theory suggests that I and x are related by the equation $1/I = Mx + N$ where M and N are constants.

6. Use your results from to find values for M and N. Include appropriate units.

   $M = \frac{\rho}{AV}$ where ρ is the resistivity of the material of the wire

   and $N = \frac{R}{V}$ where R is the resistance of the resistor R in the circuit.

7. Use your values of M, N, A and V to determine values for ρ and R. Include appropriate units.

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Practical booklet 5

How the loss of gravitational potential energy of a rolling ball depends on its initial height

Cambridge International AS & A Level Physics 9702

Version 0.1

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Guidance for teachers

Aim

To determine the gravitational potential energy of an object and the efficiency of a system.

Outcomes

Syllabus sections 1.2e, 2.1a, 6.2c, 6.2d, 6.3f

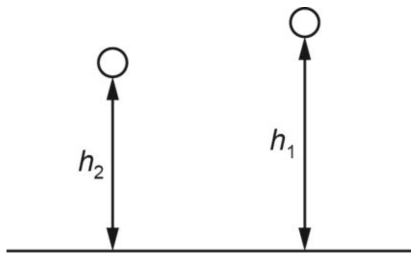
Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Measure the height of an object above the bench with a ruler
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
PDO graph	Draw a graph to investigate a relationship
ACE limitations	Identify the limitations of the experimental procedure
ACE improvements	Identify possible improvements to the experimental procedure

Theory

When an object of mass m is at a height h above the bench its gravitational potential energy is given by

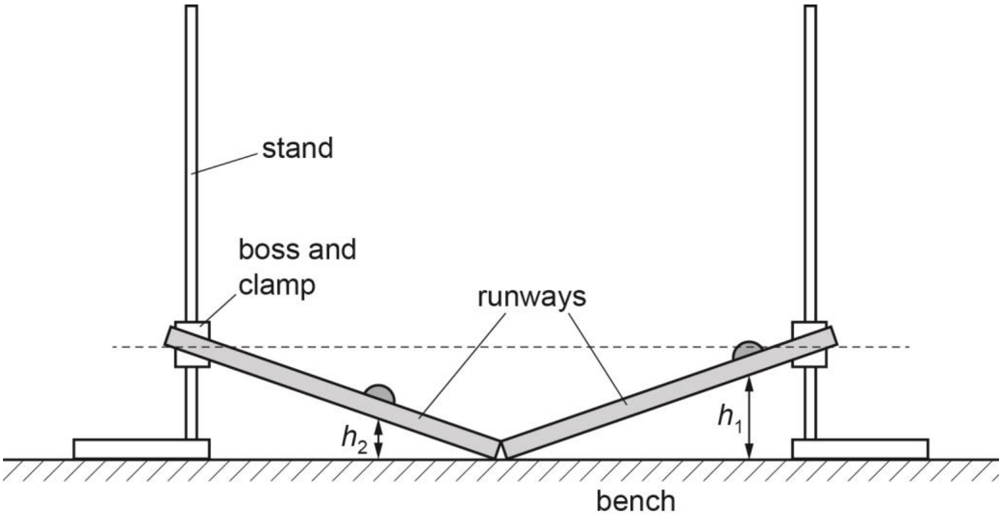
$E_{GPE} = mgh$ where g is the gravitational field strength.



If the object is at a height of h_1 before a collision and h_2 after the collision, the efficiency of the system is

$$\text{efficiency} = \frac{\text{remaining } E_{GPE}}{\text{original } E_{GPE}} = \frac{mgh_2}{mgh_1} = \frac{h_2}{h_1}$$

Method



Learners set up the runways as shown and place a marble near the top of one runway, measuring the height h_1 of the bottom of the marble above the bench.

They release the marble then measure the height h_2 to the bottom of the marble when it reaches its maximum height on the other runway.

Learners then estimate the percentage uncertainty in their value of h_2.

This is then repeated using a different value of h_1.

Results

Learners record all of their results

h_1/cm	h_2/cm	h_2/cm	h_2/cm	$h_{2\ average}$/cm	h_2/h_1

Interpretation and evaluation

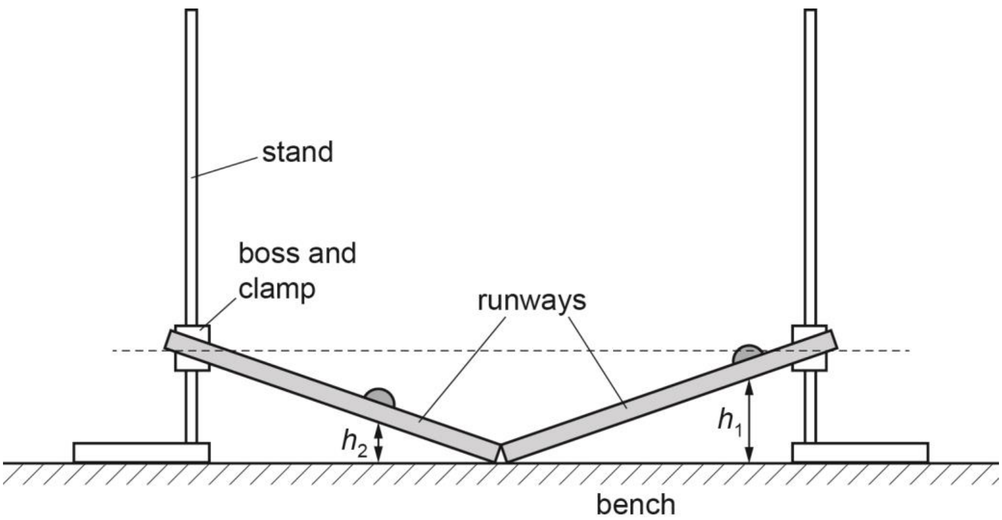
- Learners should consider how reliable their measurements are.
- The runways might move between readings and therefore will not be lined up correctly.
- The measurement to the bottom of the ball is difficult.
- A graph could be drawn of h_2/h_1 against h_1 to observe any trend.
- There is scope for further investigation.
- Learners could repeat the investigation with the runways inclined at a different angle or use a marble with a different mass.

Technician's notes

Each learner will require:

- 2 × stands
- 2 × bosses
- 2 × clamps
- 1 × marble
- 2 × rigid runways of approximate length 40cm with a V-shaped groove. It should be possible for the marble to run easily along the groove
- 1 × metre rule
- access to a balance

Equipment set-up



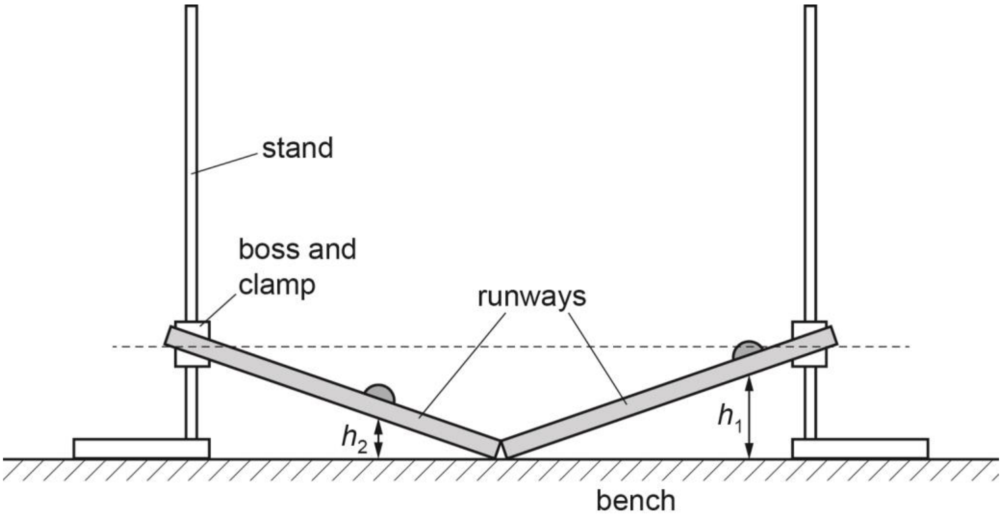
Learner worksheet

Aim

To calculate the gravitational potential energy of an object and the efficiency of a system.

Method

1. Set up the apparatus as shown. The marble should be able to roll down one runway and up the other one.



2. Place the marble so that the bottom of the marble is at a height h_1 above the bench. Record h_1 and remove the marble from the track.

3. Measure the mass m of the marble and calculate the change in gravitational potential energy ΔE of the marble when it is raised from the bench to its position on the track. Use the equation $\Delta E = mg\Delta h$.

4. Replace the marble on the track and measure h_1.

5. Release the marble. Measure and record the maximum height h_2 that the marble reaches on the other track.

6. Change h_1 and repeat.

Results

Record your results

h_1/cm	h_2/cm	h_2/cm	h_2/cm	$h_{2\ \text{average}}$/cm	h_2/h_1

Interpretation and evaluation

If the marble rolled up the same height as it was released from (i.e. $h_2 = h_1$) then it would not have lost any energy and the process would be '100% efficient'.

The value of h_2/h_1 represents the efficiency of the process.

1. Complete the table with calculated values of h_2/h_1.
2. Do you notice a trend?
3. Consider a range of readings and draw a graph of h_2/h_1 against h_1.
4. What are the sources of uncertainty in the experiment?
5. Can you suggest and perform further investigations? For example, use a marble with a different mass, change the angle of the runways.

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Practical booklet 6

Determination of the centre of gravity of a shape

Cambridge International AS & A Level

Physics 9702

Version 0.1

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Guidance for teachers

Aim

To determine the centre of gravity of a shape. Learners will consider the range of an investigation and practise using a trigonometric function.

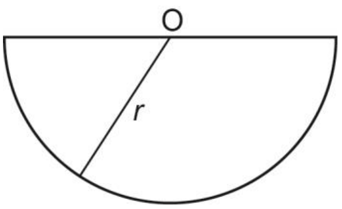
Outcomes

Syllabus sections 1.2e, 2.1a, 5.d

Skills included in the practical

AS Level skills	How learners develop the skills
MMO collection	Measure length using a ruler Measure angle using a protractor
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
PDO graph	Draw a graph and determine the gradient
ACE interpretation	Interpret the gradient

Theory and method



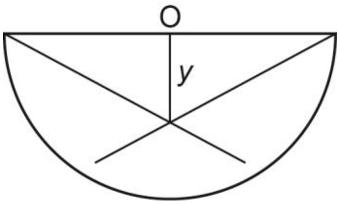
The cardboard shape is a semicircle with radius *r* and the centre of the circle is at O.

The centre of gravity of the shape can be found by:

- placing a pin through a hole in the shape close to a corner
- suspending the shape and a plumbline from the pin
- drawing a line along the plumbline on the shape
- repeating from the other corner
- noting the point where the two lines cross

Learners should be familiar with this experiment. A fun way of introducing this topic to beginners is to use an atlas to cut out shapes of different countries (photocopy or trace and cut out the shape, don't cut up the atlas) and find the name of the place that is at its centre of gravity. Some capital cities are at the centre of gravity of their country.

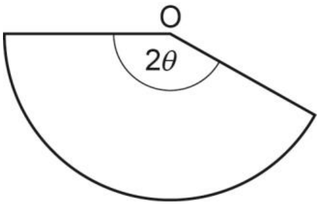
The result will be that the centre of gravity is at distance *y* from O.



If the card is cut to the shape shown below and the experiment is repeated, the relationship between *y* and θ is

$$y = \frac{120r \sin\theta}{\pi\theta}$$

where θ is in degrees.



Results

Learners record all of their results.

2θ	θ	$\sin\theta$	$(\sin\theta)/\theta$

A graph of *y* against $\frac{\sin\theta}{\theta}$ should be a straight line through (0,0) with $\text{gradient} = \frac{120r}{\pi}$.

Learners can then see if the measured value of *r* is consistent with the value calculated from their gradient.

Note

- The shape will end up with a lot of lines on it and care must be taken to use the correct lines for the measurement of *y* for a particular value of θ.
- Learners are expected to plan an experiment so that at least six sets of readings are taken at regular intervals over a reasonable range.
- Learners have to decide what the smallest value of 2θ to use is.
- Once the card is cut it will not be possible to go back to an intermediate angle or repeat readings for the larger angles.
- Learners should have access to a new card if they make a mistake early on.
- The graph should be a straight line through (0,0) but the plotted points will not be close to (0,0).

Technician's notes

Each learner will require:

- 1 × semi-circular card of radius 145 mm and thickness 0.2 mm
- 1 × pair of scissors
- 1 × 30cm rule
- 1 × optical pin
- 1 × stand
- 1 × boss
- 1 × clamp
- 1 × protractor
- 50cm cm length of thin thread with a loop at one end and a 10 g mass attached to the other end

Learner worksheet

Aim

To determine the centre of gravity of a shape.

Method

1. Measure the radius *r* of the semi-circular card.

2. Use the pin to make a hole close to a corner of the card. The hole should be big enough for the card to be able to swing freely when the card is suspended from the pin

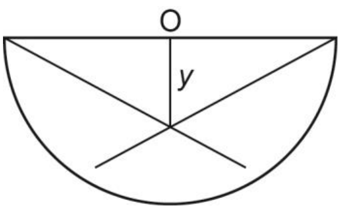
3. Clamp the pin and suspend the card and plumbline from the pin.

4. Draw a line on the card along the line of the plumbline.

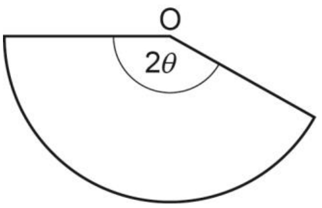
5. Repeat 1, 2 and 3 using a hole close to the other corner of the card.

6. The point where the lines cross is the centre of gravity of the card.

7. Measure the distance *y* between the centre of gravity and the centre of the semicircle O as shown.



8. Cut the card as shown.



9. Note the value of 2θ and calculate θ.

10. Repeat all the steps so that you have a new value for *y* the distance between O and the centre of gravity of the new shape

11. Change the shape of the card so that you have a set of values for *y* and θ.

12. Calculate values for $\sin\theta$ and $(\sin\theta)/\theta$.

Results

Record all of your results.

2θ	θ	$\sin\theta$	$(\sin\theta)/\theta$

Interpretation and evaluation

1. y and θ are related by the expression

$$y = \frac{120r\sin\theta}{\pi\theta}$$

   where θ is in degrees.

2. Plot a graph of y on the y-axis against $\frac{\sin\theta}{\theta}$ on the x-axis.

3. The graph should be a straight line through (0,0) although your plotted points will not be close to (0,0).

4. Determine the gradient of your graph line and use the expression for gradient $120r/\pi$ to calculate a value for r. Compare this value to your measured value.

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Cambridge Assessment International Education

Practical booklet 7

Discharge of a capacitor through a resistor

Cambridge International AS & A Level

Physics 9702

Version 0.1

Cambridge Pathway

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Introduction

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The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To investigate the characteristics of exponential decay and calculate the charge stored in a capacitor.

Outcomes

Syllabus sections 1.2e, 2.1a, 2.1b, 18.1a, 18.1b, 19.1d, 19.3b, 26.4d, 26.4f

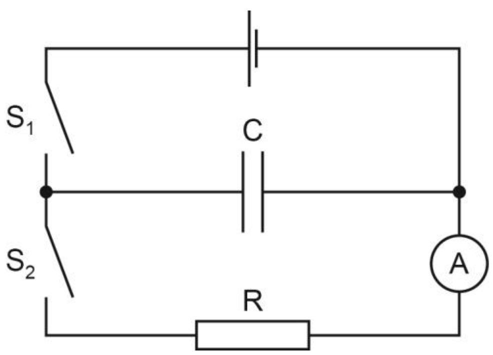
Skills included in the practical

A Level skills	How learners develop the skills
Planning	Consider further investigations with different components
Analysis	Collect and record data in a table
Conclusions	Determine and interpret the gradient of a graph

This practical provides an opportunity to build on essential skills introduced at AS Level.

AS Level skills	How learners develop the skills
MMO collection	Set up a set up a circuit from a circuit diagram Use an ammeter to measure current
MMO values	
MMO quality of data	

Theory



The discharge of the capacitor through the resistor is exponential since the rate of flow of charge from the capacitor is proportional to the charge on the capacitor.

$I = \frac{V}{R}$ and $Q = CV$

Therefore $I = \frac{dQ}{dt} \propto Q$ since *R* and *C* are constant.

This leads to $I = I_0 e^{-t/RC}$ from which $\ln I = \ln I_0 - \frac{t}{RC}$ where I_0 is the current at *t*=0.

A graph of ln I against t

- has gradient = $-1/RC$ and y-intercept = ln I_0

A graph of I against t

- will show an exponential decay from which 'half-life' can be found
- enables Q (= CV) to be found from the area under the curve

Similarities with radioactive decay:

Radioactive decay follows $x = x_0 e^{-\lambda t}$ where $\lambda = \frac{0.693}{t_{1/2}}$

so $\frac{1}{RC} = \lambda = \frac{0.693}{t_{1/2}}$

The quantity $1/RC$ is analogous to the decay constant in radioactive decay, and is related to the decay half-life.

Method

Learners set up the circuit. First they close S_1 and take readings, then open S_1 and close S_2 and take readings.

Results

Learners record values of current I and time t and include values of ln I in their table

Interpretation and evaluation

- draw a graph of ln I against t which will have gradient = $-1/RC$ and y-intercept = ln I_0
- draw a graph of I against t and find the area under the graph, which is the charge Q

Further work

Using a *smaller* resistor, e.g. 47 kΩ, will result in:

- bigger I_0 because $I = V/R$
- smaller 'half-life' because $t_{½} \propto CR$
- same area under graph because $Q = CV$

Using a *bigger* resistor, e.g. 220 kΩ, will result in:

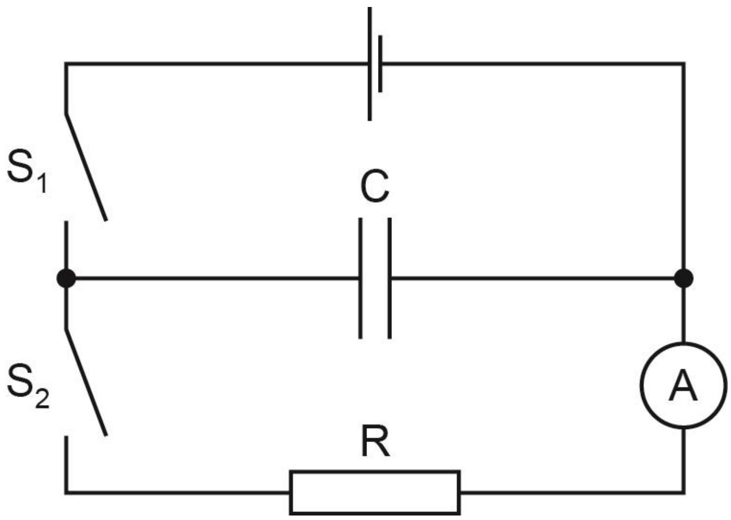
- smaller I_0 because $I = V/R$
- bigger 'half-life' because $t_{½} \propto CR$
- same area under graph because $Q = CV$

Technician's notes

Each learner will require:

- 1 × 1.5v dry cell
- 1 × 1000µF capacitor
- 1 × 100 kΩ resistor
- 1 × 0-200 µA ammeter
- 2 × switches
- 8 × connecting leads
- 1 × stopwatch

Equipment set-up



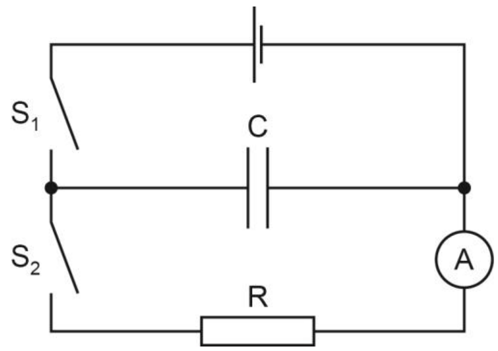
Learner worksheet

Aim

To investigate the characteristics of exponential decay and calculate the charge stored in a capacitor.

Method

1. Connect the circuit shown.



2. Close switch S_1 to charge the capacitor C.
3. Open S_1 and close S_2 to discharge the capacitor through the resistor R.
4. Record values of current I with time t.

Results

Record all of your results.

t/s	I/μA	ln (I/μA)

Interpretation and evaluation

- Include values of ln I in the table.
- From $I = I_0 e^{-t/RC}$, $\ln I = \ln I_0 - \frac{t}{RC}$ where I_0 is the current at time t = 0.
- Draw a graph of ln I against t, and use the gradient to determine RC. Compare this with the nominal values from the components.
- Draw a graph of I against t and find the area under the graph.
- The area under the I-t graph represents the charge Q (= It) stored on the plates of the capacitor.
- Consider what will happen to the characteristics of both graphs if the experiment is repeated with a 47 kΩ resistor replacing the 100 kΩ resistor.

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Cambridge Assessment International Education

Practical booklet 8

Investigating how the force between magnetic poles depends on their separation

Cambridge International AS & A Level

Physics 9702

Version 0.1

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Introduction

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The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

Using a log-log graph to investigate the relationship between two variables.

Outcomes

Syllabus sections 1.2e, 2.1a, 22.1a

Skills included in the practical

A Level skills	How learners develop the skills
Analysis	Investigate a relationship by drawing a log-log graph
Conclusions	Determine and interpret the gradient of a graph

This practical provides an opportunity to build on essential skills introduced at AS Level.

	How learners develop the skills
MMO collection	Measure lengths using a micrometer Measure force using a newton-meter (force meter)
MMO values	
MMO quality of data	
ACE limitations	Identify the limitations of the experimental procedure
ACE improvements	Identify possible improvements to the experimental procedure

Learners will be familiar with the inverse square law that applies to forces between point masses (syllabus 8.2b) and point charges (syllabus 17.3b).

If the force of attraction F between two magnets depends on their separation d according to

$$F = kd^n$$

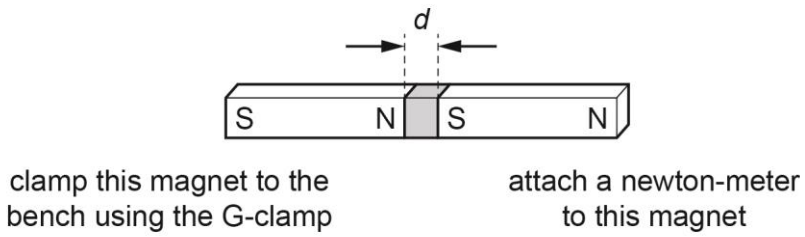
and the inverse square law is obeyed then $n = -2$.

Since $\lg F = n \lg d + \lg k$, a graph of $\lg F$ against $\lg d$ has a gradient of n.

The y-intercept is $\lg k$ so $k = 10^{y\text{-intercept}}$.
Values of n and k can be used to find the force at a distance outside the experimental range, e.g. for $d = 20$ cm.

The uncertainty about the existence and location of a ‘point magnetic pole’ means that the situation is more complicated than it is for electric and gravitational forces.

Method



- Learners set up the magnets as above, using the cards to separate the magnets and then measure the distance *d* of that separation.
- They then gently pull the newton-meter (force meter) until the magnets separate and record the maximum reading *F* on the newton-meter.
- This is repeated for different separations.

Results

Learners record all of their results in a table, such as that below.

d/m	*F*/N	lg(*d*/m)	lg(*F*/N)

Interpretation and evaluation

With the results, learners plot a graph of lg *F* on the *y*-axis against lg *d* on the *x*-axis to find the gradient = *n*.

A more sensitive method might use a precision digital balance that can measure to 0.1 g or 0.01 g.

One magnet is fixed vertically on the balance and the other magnet is clamped vertically above it with a known separation. This time the magnets repel so that the two magnets do not come into contact.
Readings from the balance indicate the force of repulsion and can be converted from g to N.

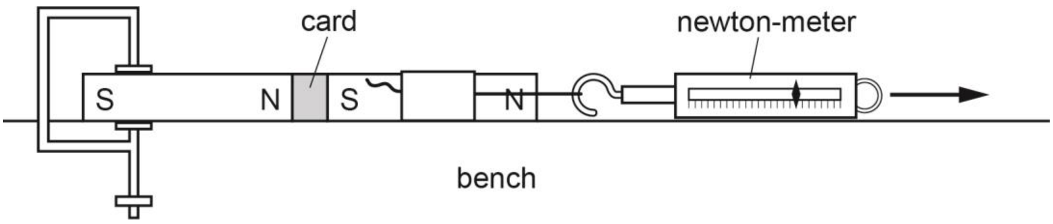
The power law governing the force and the separation varies for different regions of separation.

Technician's notes

Each learner will require:

- 2 × bar magnets
- 1 × newton meter (force meter)
- access to a micrometer screw gauge
- 6 × cards 2cm × 2cm × 1mm
- string
- 1 × G-clamp
- adhesive tape
- log-log graph paper

Equipment set-up



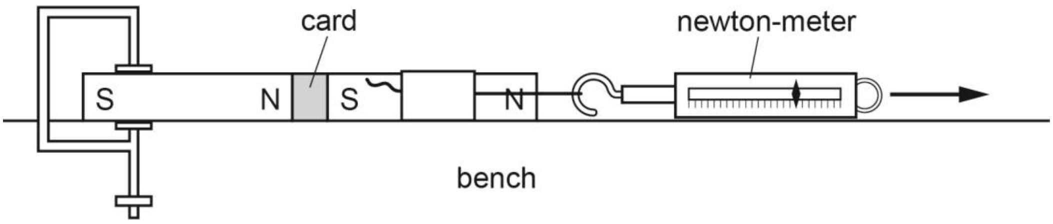
Learner worksheet

Aim

Using a log-log graph to investigate the relationship between two variables.

Method

1. Use the micrometer screw gauge to measure the thickness *d* of one of the cards.
2. Clamp one of the magnets to the bench.
3. Use string and tape to attach a newton-meter (force meter) to the other magnet.
4. Place the card between the magnets.
5. Gently pull the newton-meter until the magnets separate.
6. Read the maximum value of force *F* at separation.
7. Change the separation using more cards.
8. Repeat for further values of *d* and *F*.



Results

Record all of your results

d/m	*F*/N	lg (*d*/m)	lg (*F*/N)

Interpretation and evaluation

Investigate the relationship $F = kd^n$ (lg $F = n$ lg d + lg k).

1. Plot a graph with lg F on the y-axis against lg d on the x-axis.
2. The gradient = n.
3. The y-intercept = lg$k$ so $k = 10^{y\text{-intercept}}$.
4. Use your values of n and k to calculate F when d = 20 cm.
5. Describe the main sources of uncertainty in this investigation.
6. Describe how you could improve this investigation.

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Practical booklet 9

Determination of the spring constant *k* of a spring using an oscillating system

Cambridge International AS & A Level

Physics 9702

Version 0.1

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Guidance for teachers

Aim

To apply simple harmonic theory and use error bars, best straight lines and worst acceptable straight lines.

Outcomes

Syllabus sections 1.2e, 2.1a, 13.1a, 13.1b, 13.1c, 13.1d

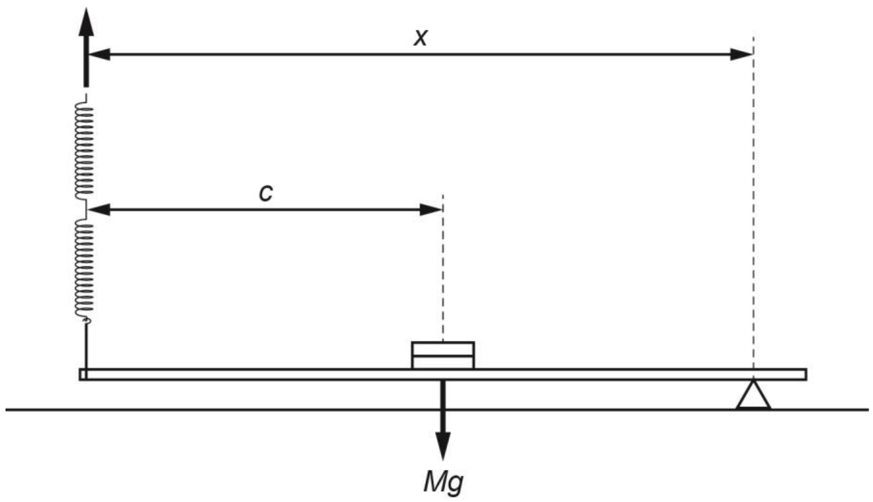
Skills included in the practical

A Level skills	How learners develop the skills
Analysis	Collect and record data in a table Draw a graph with error bars
Conclusions	Determine and interpret the gradient and *y*-intercept of a graph with both a line of best fit and a worst acceptable line
Evaluation	Determine uncertainties using best and worst acceptable straight lines

This practical provides an opportunity to build on essential skills introduced at AS Level.

AS Level skills	How learners develop the skills
MMO collection	Time oscillations using a stopwatch
MMO values	
MMO data	

Theory



This has similar apparatus and theory to Practical 1. This time the left-hand end of the metre rule is pulled down and released and the period T of the oscillations is measured.

To obtain values of T that are large enough to measure, it is necessary to increase T by

- using two springs
- adding another 100 g mass to the centre of the metre rule

Two 100 g masses are attached to the mid-point of a metre rule. This makes the rule artificially heavier so that appreciable values of T can be measured later. Learners have to consider the irregular shape of a slotted mass when attaching it to the centre of the rule. The combined mass of the rule and two 100 g masses is M.

The loaded metre rule is supported by the pivot and the springs. The rule is horizontal and the springs are vertical. Assuming that the string is at the end of the rule, then taking moments about the pivot:

Clockwise moment = $k(l - l_0)x$ where l_0 is the unstretched length of the coiled part of the spring.

Anticlockwise moment = $Mg(x - c)$

So, $Mg(x - c) = k(l - l_0)x$ when the rule is balanced.

$$(l - l_0) = \frac{Mg(x - c)}{kx}$$

The period T is given by $T = 2\pi\sqrt{\frac{l - l_0}{g}}$.

$$T^2 = \frac{4\pi^2 Mg(x - c)}{kgx} = \frac{4\pi^2 Mgx}{kgx} - \frac{4\pi^2 Mc}{kgx}$$

$$T^2 x = \frac{4\pi^2 M}{k}x - \frac{4\pi^2 Mc}{k} = Ax + B$$

If a graph is plotted of T^2x against x, the gradient = A and the y-intercept = B.

Since $A = \frac{4\pi^2 M}{k}$ and $B = -\frac{4\pi^2 Mc}{k}$ two values of k can be found knowing values of M and c (or use $B/A = -c$ and determine both c and k).

Further graph work

Learners should be able to:

- include error bars with each plotted point
- draw a best straight line (BSL) through their plotted points
- draw a worst acceptable straight line (WASL) through their points
- determine the uncertainty in their value of gradient
- determine the uncertainty in their value of y-intercept.

Error bars can be connected with the variable on the x-axis or y-axis or both.

A simple way to deal with error bars in this experiment is to suppose that there is an uncertainty of 2 mm in each value of x so that a point plotted at x = 72.0 cm would be a horizontal line spreading from 71.8 cm to 72.2 cm.

A more challenging task would be to draw the error bars for T^2x.

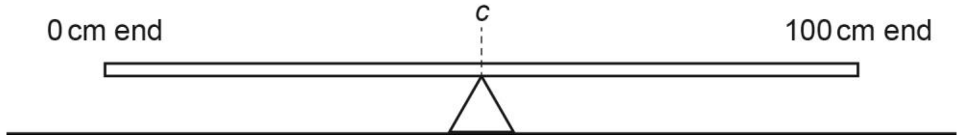
The uncertainties in M and c could also be considered.

The BSL should be the best line through the points regardless of error bars.

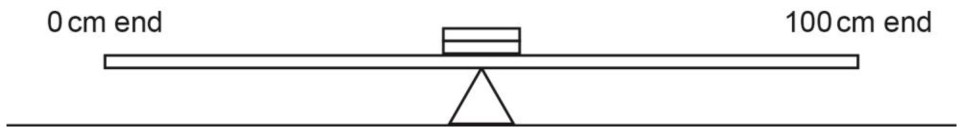
The WASL should be the most extreme line that still passes through all the error bars.

Method

- Learners balance the metre rule as shown and record the reading *c* of the rule directly above the pivot.

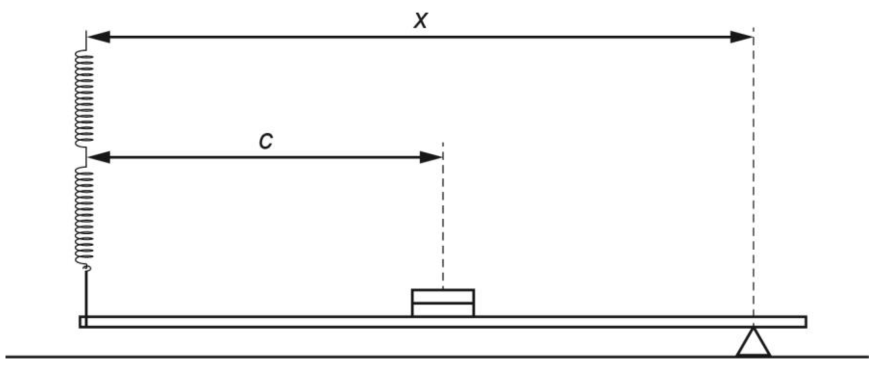


- They then place two 100 g masses over the centre of the rule so that it still balances at *c* and then tape the masses to the rule as shown.



- Using an electronic balance, learners then determine the mass *M* in kg of the combined mass of the rule and the attached masses.

- Learners then set up the apparatus as shown below with the rule horizontal and the springs vertical. The string should be as close to the end of the rule as possible.



- They then place the pivot, measure *x*, pull down the left hand end of the rule and determine the period *T* of the oscillations.

- This is repeated with different values of *x*.

Results

Learners record the different measures of x and the corresponding T period of oscillation, and also include values of T^2x in the table.

	Time for 10 cycles				
x/m	t_1/s	t_2/s	$t_{average}$/s	T/s	T^2x / s^{2}m

Interpretation and evaluation

Learners plot a graph of T^2x on the y-axis against x on the x-axis, and include error bars (as previously mentioned).

They then draw the BSL and WASL and find both gradient and y-intercept and their uncertainties

$\text{gradient} = \frac{4\pi^2 M}{k}$ and $\text{y-intercept} = -\frac{4\pi^2 Mc}{k}$

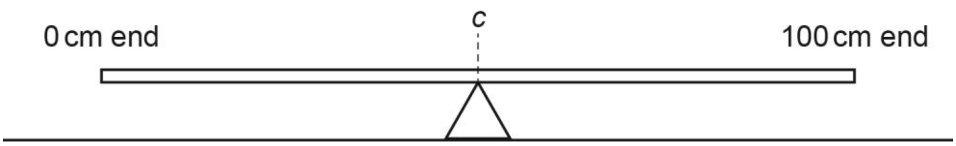
They then use their values of M, c, gradient and y-intercept to determine values for k, and find the uncertainty in k in each case.

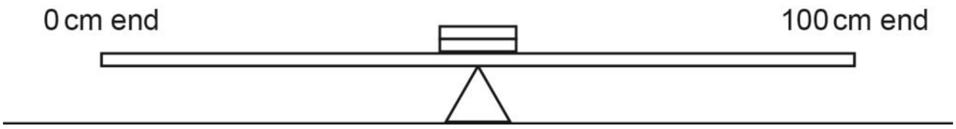
Technician's notes

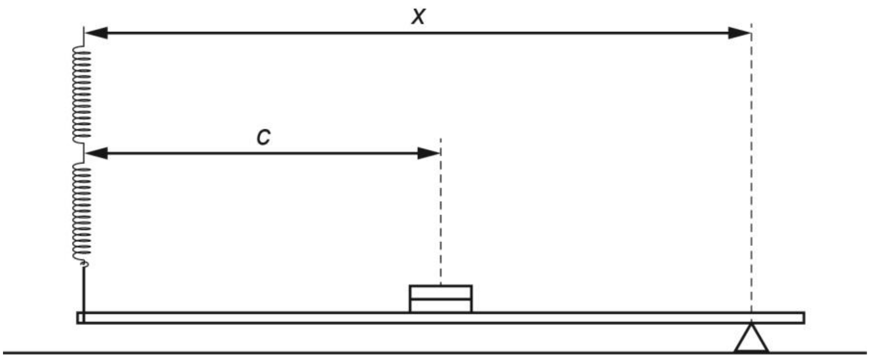
Each learner will require:

- 1 × stand
- 1 × clamp
- 1 × boss
- 2 × springs
- string
- 1 × metre rule with millimetre scale
- adhesive tape
- 1 × triangular glass prism or small triangular pivot
- 1 × stopwatch
- access to an electronic balance

Equipment set-ups







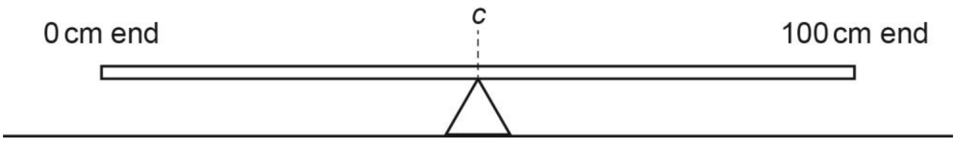
Learner worksheet

Aim

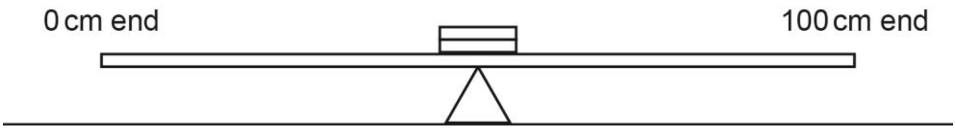
To apply simple harmonic theory and use errors bars, best straight lines and worst acceptable straight lines.

Method

1. Balance the metre rule as shown and will note the reading *c* of the rule directly above the pivot.



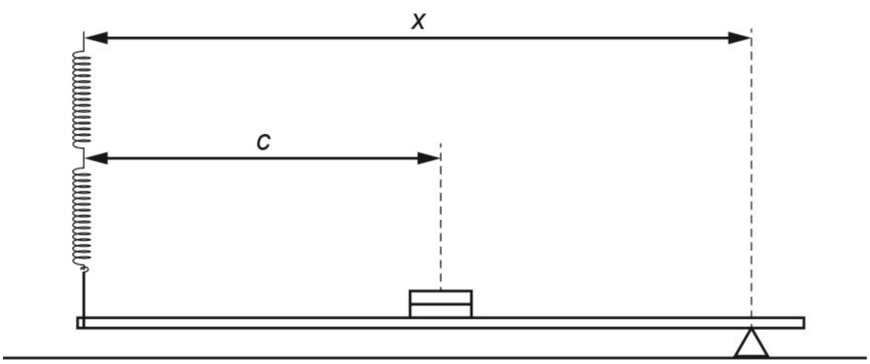
2. Place two 100 g masses over the centre of the rule so that it still balances at *c* and tape the masses to the rule as shown.



3. Using an electronic balance, determine the mass *M* in kg of the combined mass of the rule and the attached masses.

4. Set up the apparatus as shown below with the rule horizontal and the springs vertical. Use the stand, boss and clamp to support the top spring.

   The string should be as close to the end of the rule as possible.



5. Measure *x*.

6. Pull down the left hand end of the rule and determine the period *T* of the oscillations.

7. Change the position of the pivot and take six sets of readings for *x* and *T.*

8. Include values of T^2x in the table.

Results

Learners record the different measures of x and the corresponding T period of oscillation, and also include values of T^2x in the table.

	Time for 10 cycles				
x/m	t_1/s	t_2/s	$t_{average}$/s	T/s	T^2x / s^{2}m

Interpretation and evaluation

1. Plot a graph of T^2x on the y-axis against x on the x-axis.

2. Include error bars for x (± 2 mm).

3. Draw the best straight line (BSL) and the worst acceptable straight line (WASL) and find both gradient and y-intercept and their uncertainties.

4. Use your values of M, c, gradient and y-intercept to determine values for k.

$gradient = \frac{4\pi^2 M}{k}$ and $\text{y-intercept} = -\frac{4\pi^2 Mc}{k}$

5. Find the uncertainty in k in each case.

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Cambridge Assessment International Education

Practical booklet 10

Determination of specific heat capacity using a cooling curve

Cambridge International AS & A Level Physics 9702

Version 0.1

Cambridge Pathway

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Introduction

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The science syllabuses address practical skills that contribute to the overall understanding of scientific methodology. Learners should be able to:

1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To use theory from electricity and heat and apply a cooling correction.

Outcomes

Syllabus sections 1.2e, 2.1a, 12.1b

Skills included in the practical

A Level skills	How learners develop the skills
Planning	Plan an experiment

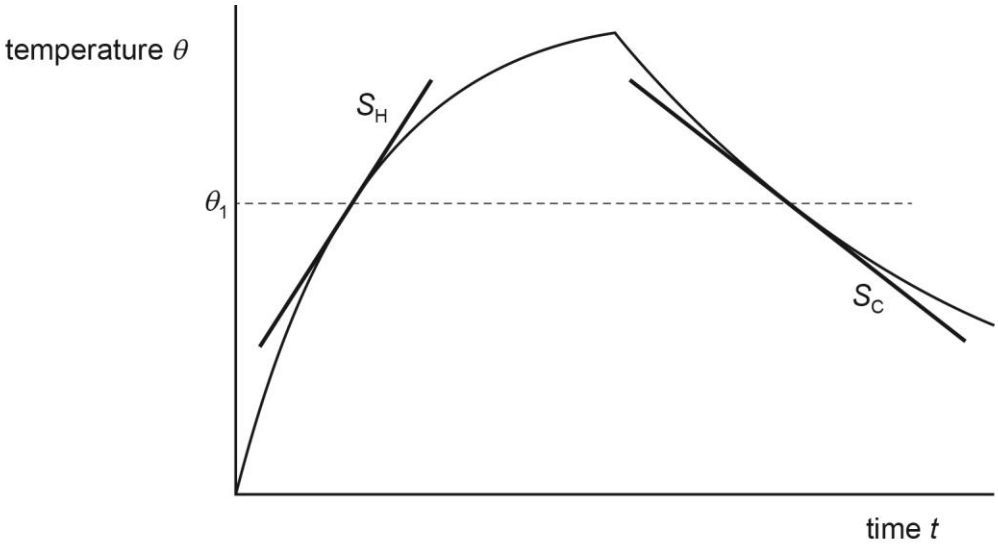
This practical provides an opportunity to build on essential skills introduced at AS Level.

AS Level skills	How learners develop the skills
MMO collection MMO values MMO quality of data	Measure mass using a balance Measure temperature using a thermometer
PDO table PDO recording	Collect and record data in a table
PDO graph	Draw a graph Draw a tangent to a curve to find a rate of change

Theory

When some water in a beaker is heated up the graph of temperature against time is not a straight line. This is because the greater the temperature difference between the water and the surroundings, the greater the rate of loss of heat to the surroundings.

When the heating stops the graph is not a straight line because the rate of cooling decreases as the temperature of the water approaches room temperature.



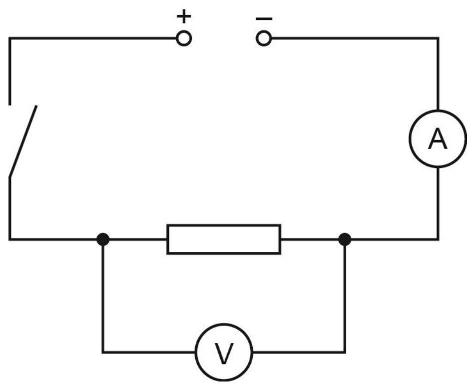
At a particular temperature θ_1, the rate of temperature increase S_H is the gradient of the curve at θ_1 as the water is increasing in temperature, and the rate of temperature decrease S_C is the positive gradient of the curve at θ_1 where the water is decreasing in temperature.

If the water is heated electrically then $VI = (M_W C_W + M_G C_G)(S_H + S_C)$
where:

V = voltmeter reading	C_W = specific heat capacity of water
I = ammeter reading	C_G = specific heat capacity of glass
M_W = mass of water	M_G = mass of glass

Method

- Learners set up the circuit shown below.



- They record the mass of the beaker and add 75 cm^3 of water to it, then record the mass of the beaker plus water and calculate the mass of water. They also record the temperature of the water in the beaker.

- Learners place the resistor in the water, close the switch and start the stopwatch, recording values of time t and temperature θ until the temperature has risen by 15°C.

- When the temperature has risen by 15°C they open the switch and continue to take readings until the temperature has dropped to 6°C below the maximum temperature reached.

Results

Learners record all of their readings in a table, such as that below.

t/s	θ/°C

Interpretation and evaluation

Learners draw graphs of the results. At a temperature 4°C *below the maximum temperature reached* they draw tangents to both the heating and cooling curves. They then find the gradients of both tangents, S_H and S_C.
Learners then determine C_W from $VI = (M_W C_W + M_G C_G)(S_H + S_C)$.

Planning

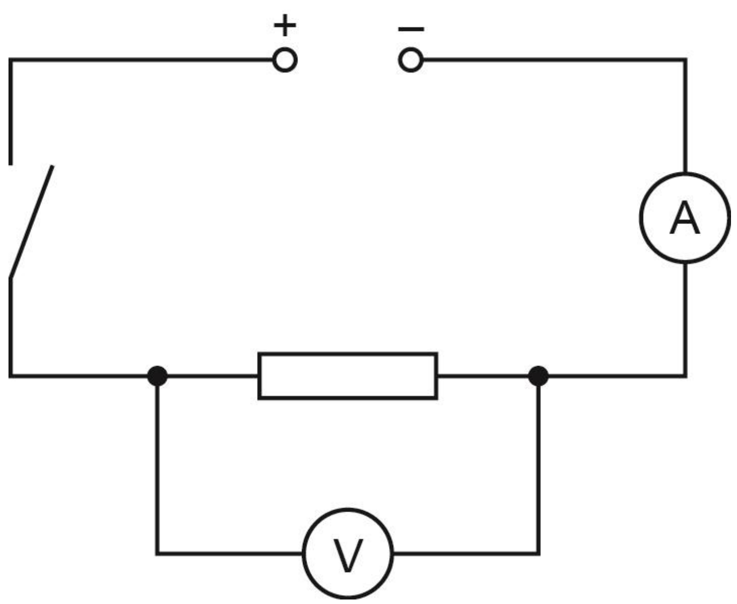
A planning task is also given, in which learners consider an extension to the experiment by using the same apparatus to investigate Newton's law of cooling.

Technician's notes

Each learner will require:

- 1 × 12 V d.c. power supply
- 1 × ammeter with range 0-10A reading to 0.01 A
- 1 × voltmeter with range 0-20 V
- 1 × 15 Ω resistor with a wire of length 15 cm soldered to each end. The other end of each wire should be bared
- 1 × switch
- 1 × thermometer
- 1 × 250 ml beaker with markings every 50 ml
- 1 × measuring cylinder and supply of water at room temperature
- 1 × stirrer
- 6 × connecting wires
- 1 × stopwatch
- access to a balance
- paper towels

Equipment set-up



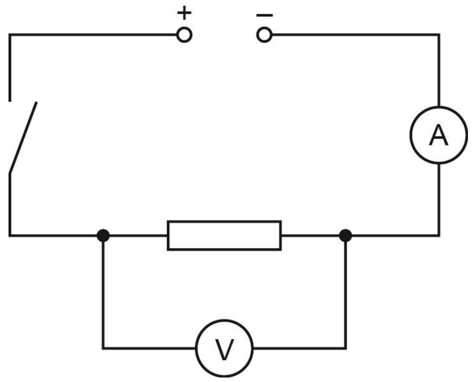
Learner worksheet

Aim

To use theory from electricity and heat and apply a cooling correction.

Method

1. Set up the circuit shown below.



2. Record the mass M_G of the glass beaker.

3. Add approximately 75 cm^3 of water to the beaker (about half way between the 50 and 100 cm^3 markings).

4. Record the mass M_T of the beaker and water and calculate the mass of water M_W using $M_W = M_T – M_G$.

5. Record the temperature θ_R of the water in the beaker.

6. Place the resistor below the surface of the water in the beaker.

7. Close the switch.

8. Start the stopwatch.

9. Record the ammeter reading I and the voltmeter reading V.

10. Record values of time t and temperature θ every minute until the temperature has risen by 15 °C above θ_R.

11. Open the switch and continue to take readings until the temperature has dropped to 6 °C below the maximum temperature reached.

Results

Record all of your readings.

t/s	θ/°C

Interpretation and evaluation

When the water is heated up the graph of temperature against time is not a straight line because the greater the temperature difference between the water and θ_R, the greater the rate of loss of heat to the surroundings.

When the water cools the graph is not a straight line because the rate of cooling decreases as the temperature of the water approaches θ_R.

At a particular temperature θ_1, the rate of temperature increase S_H is the gradient of the curve at θ_1 as the water is increasing in temperature, and the rate of temperature decrease S_C is the positive gradient of the curve at θ_1 where the water is decreasing in temperature.

1. Draw a graph of your results.

2. At a temperature θ_1 where θ_1 is 4 °C *below the maximum temperature reached,* draw tangents to both the heating and cooling curves.

3. Find the gradients of both tangents, S_H and S_C.

4. Determine C_W from $VI = (M_W C_W + M_G C_G)(S_H + S_C)$ where the specific heat capacity of glass C_G = 840 J/(kg K).

Planning

It is suggested that the cooling of hot water is described by the equation

$$\theta = \theta_R + (\theta_H - \theta_R)e^{-\alpha t}$$

where θ_H is the initial temperature of the hot water, θ_R is room temperature, t is time and α is a constant.

Design a laboratory experiment, using the apparatus provided, to test the relationship between θ and t and determine a value for α. You should pay particular attention to the experimental procedure, the measurements to be taken, the control of variables, the analysis of the data and any safety precautions to be taken.

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Cambridge Assessment International Education

Practical booklet 11

Making and using a thermocouple

Cambridge International AS & A Level

Physics 9702

Version 0.1

Cambridge Pathway

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1. plan experiments and investigations
2. collect, record and present observations, measurements and estimates
3. analyse and interpret data to reach conclusions
4. evaluate methods and quality of data, and suggest improvements.

The practical skills established at AS Level are extended further in the full A Level. Learners will need to have practised basic skills from the AS Level experiments before using these skills to tackle the more demanding A Level exercises. Although A Level practical skills are assessed by a timetabled written paper, the best preparation for this paper is through extensive hands-on experience in the laboratory.

The example experiments suggested here can form the basis of a well-structured scheme of practical work for the teaching of AS and A Level science. The experiments have been carefully selected to reinforce theory and to develop learners' practical skills. The syllabus, scheme of work and past papers also provide a useful guide to the type of practical skills that learners might be expected to develop further. About 20% of teaching time should be allocated to practical work (not including the time spent observing teacher demonstrations), so this set of experiments provides only the starting point for a much more extensive scheme of practical work.

Guidance for teachers

Aim

To establish a temperature scale and use it to estimate an unknown temperature.

Outcomes

Syllabus sections 1.2e, 2.1a, 11.2a

Skills included in the practical

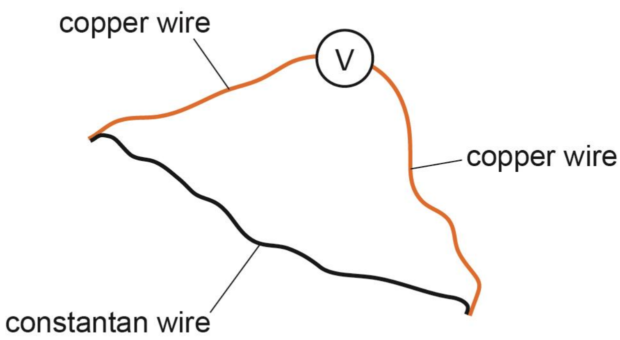
A Level skills	How learners develop the skills
Planning	Plan and then carry out an experiment
Analysis	Collect and record data in a table
Conclusions	Determine and interpret the gradient and *y*-intercept of a graph Use the results of the experiment to estimate an unknown temperature

This practical provides an opportunity to build on essential skills introduced at AS Level.

AS Level skills	How learners develop the skills
MMO collection	Measure temperature using a thermometer Use a voltmeter with an appropriate scale
MMO values	
MMO data	
ACE limitations	Identify the limitations of the experimental procedure

Theory

The e.m.f. of the thermocouple circuit shown depends on the temperature difference $(\theta - \theta_0)$ between the two metal junctions.



$$V = a(\theta - \theta_0) + b \text{ where } a \text{ and } b \text{ are constants}$$

Method

Learners are given the circuit diagram and equation above, and should plan and then carry out an experiment to determine the constants *a* and *b* in the equation.

The planning of the experiment should follow the principles assessed in Paper 5, i.e. considering the experimental procedure, the measurements to be taken, the control of variables, the analysis of the data and any safety precautions to be taken.

The expected experimental procedure is:

- Learners construct a thermocouple as shown above.
- Room temperature θ_0 is measured using the mercury-in-glass thermometer.
- One junction is kept at room temperature while the other is placed in boiling (or very hot) water.
- As the water cools, readings of water temperature θ and the voltmeter V are recorded.

Learners' proposed experimental procedures should be checked before they attempt to carry out the experiment, paying particular attention to safety.

Results

All water temperature θ and voltmeter V readings should be recorded.

θ /°C	V/mV	$(\theta - \theta_0)$ /°C

Interpretation and evaluation

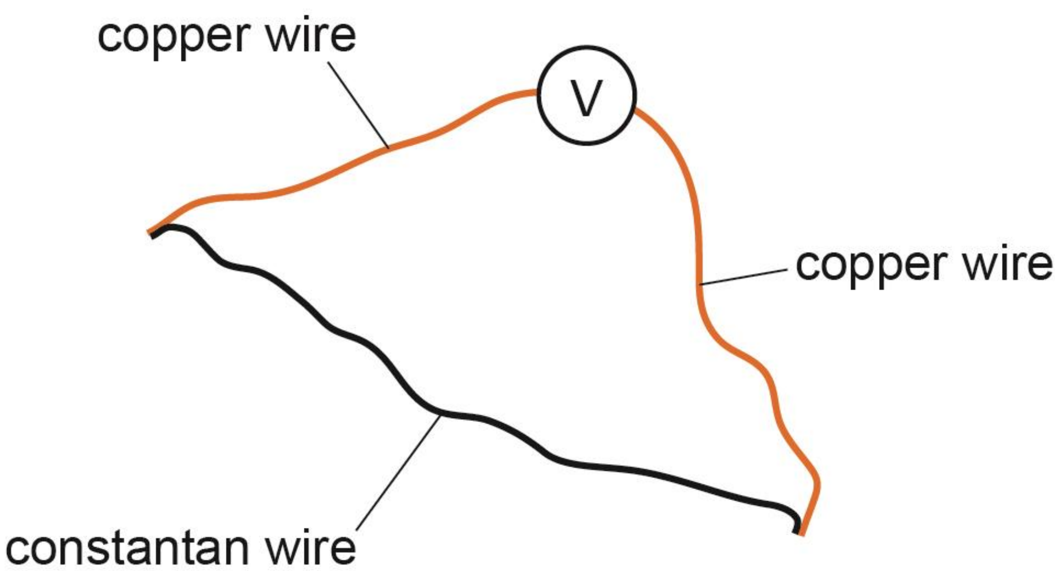
- Using $V = a(\theta - \theta_0) + b$ the values of a and b are determined from a graph of V against $(\theta - \theta_0)$.
- The results are used to estimate the temperature of a lit match.
- Learners should be encouraged to question this method of temperature measurement or temperature estimate. Some issues for discussion are:
  - the expansion of mercury is not uniform
  - the graph should go through (0,0) and not have an intercept. When both junctions are at room temperature the voltmeter reading is zero.

Technician's notes

Each learner will require:

- 1 × liquid-in-glass 0–100°C thermometer reading to the nearest 1°C
- 1 × digital voltmeter set to 0–200 mV scale reading to the nearest 0.1 mV
- 1 × bare 26 swg constantan wire of length 50 cm
- 2 × bare 26 swg copper wires each of length 50 cm. One end of each wire should have a 4 mm plug attached
- 1 × beaker
- source of boiling water
- box of matches

Equipment set-up



Learner worksheet

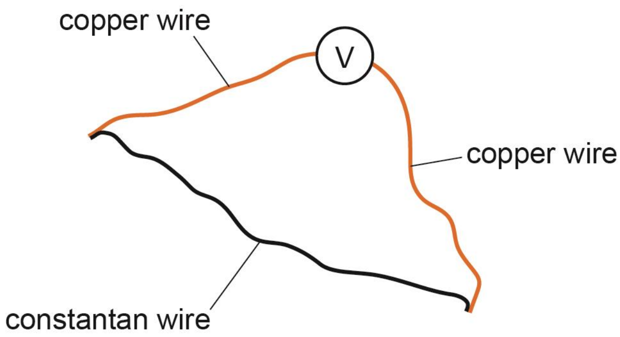
Aim

To establish a temperature scale and use it to estimate an unknown temperature.

Method

A thermocouple thermometer can be created by connecting metals of different types. Copper wire and constantan wire are available.

Connect the circuit shown below. The junctions should be formed by twisting the ends of the wire together. The length of each junction should be about 2 cm and it must not be possible to separate the wires by gentle pulling.



The e.m.f. V measured by the voltmeter is given by:

$V = a(\theta - \theta_0) + b$

where θ and θ_0 are the temperatures of the two junctions of the thermocouple.

Using the apparatus provided, plan an experiment to test the relationship between V and θ, and determine values for a and b.

Check with your teacher that your planned experiment is appropriate, and then carry out the experiment.

Results

Draw a table of results with appropriate column headings and use it to record your results.

Interpretation and evaluation

1. Determine the values of *a* and *b* from your experiment. This will require plotting a graph.

2. Use your results to estimate the temperature of the flame from a lit match.

3. State two sources of uncertainty.

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Practical booklet 12

Determination of acceleration of free fall *g* using a V-shaped pendulum

Cambridge International AS & A Level

Physics 9702

Version 0.1

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Guidance for teachers

Aim

An opportunity to plan an entire experiment given the theory only.

Outcomes

Syllabus sections 1.2e, 2.1a, 13.1b

Skills included in the practical

A Level skills	How learners develop the skills
Planning	Plan an experiment

This practical provides an opportunity to build on essential skills introduced at AS Level.

AS Level skills	How learners develop the skills
MMO collection	Measure lengths using a rule Measure angles using a protractor Measure time intervals using a stopwatch
MMO values	
MMO quality of data	
PDO table	Collect and record data in a table
PDO recording	
PDO graph	Draw a graph and determine the gradient and y-intercept
ACE interpretation	Interpret the gradient and y-intercept

Method

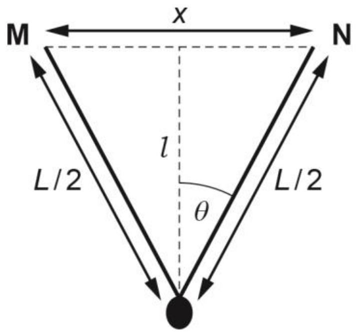
Give each learner a copy of one of the theories for a V-shaped pendulum and ask them to plan an experiment to find g. The instructions in red are optional.

Results

The results tables are optional. More able learners may be able to construct their own tables of results including all required column headings.

Theory 1

Total length of string = *L*.
String supported at M and N.
Vary 2θ and measure *T*.



$$\frac{l}{L/2} = \cos\theta$$

$$l = \frac{L\cos\theta}{2}$$

Substituting into $T = 2\pi\sqrt{\frac{l}{g}}$ and squaring gives:

$$T^2 = \frac{2\pi^2 L\cos\theta}{g}$$

Squaring again and using the trigonometric identity $\sin^2\theta + \cos^2\theta = 1$:

$$T^4 = \frac{4\pi^4 L^2 \cos^2\ \theta}{g^2} = -\frac{4\pi^4 L^2 \sin^2\ \theta}{g^2} + \frac{4\pi^4 L^2}{g^2}$$

$$T^4 = -A\sin^2\theta + B$$

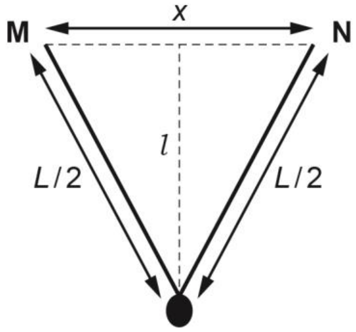
A graph of T^4 against $\sin^2\theta$ should be a straight line with:

$$A = -\text{gradient} = \frac{4\pi^4 L^2}{g^2}$$

$$B = A = \text{y-intercept} = \frac{4\pi^4 L^2}{g^2}$$

Theory 2

Total length of string = *L*.
String supported at M and N.
Vary *x* and measure *T*.



$T = 2\pi\sqrt{\frac{l}{g}}$ raised to the power 4 gives:

$$T^4 = 16\pi^4\left(\frac{l}{g}\right)^2$$

Using Pythagoras's Theorem: $l^2 = (L/2)^2 - (x/2)^2$

therefore

$$T^4 = \frac{16\pi^4}{g^2}\left(\frac{L^2}{4} - \frac{x^2}{4}\right) = -\frac{4\pi^4 x^2}{g^2} + \frac{4\pi^4 L^2}{g^2}$$

$$T^4 = -Cx^2 + D$$

A graph of T^4 against x^2 should be a straight line with:

$$C = -\text{gradient} = \frac{4\pi^4}{g^2}$$

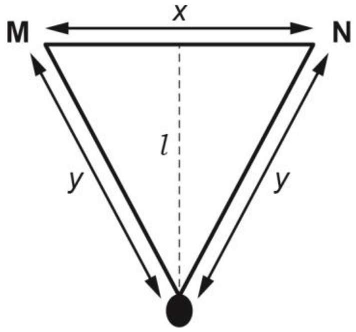
$$D = \text{y-intercept} = \frac{4\pi^4 L^2}{g^2}$$

Also:

$$\sqrt{\frac{D}{C}} = L$$

Theory 3

Total length of string = *L*.
String supported at M and N but is continuous.
Vary *x* and measure *y* and *T*.



$T = 2\pi\sqrt{\frac{l}{g}}$ raised to the power 4 gives:

$$T^4 = 16\pi^4\left(\frac{l}{g}\right)^2$$

Length of string = *y* + *y* + *x* = 2*y* + *x* = *L*

By Pythagorus:

$$l^2 = y^2 - \left(\frac{x}{2}\right)^2$$

so

$$T^4 = 16\pi^4\left(\frac{l}{g}\right)^2 = \frac{4\pi^4}{g^2}(4y^2 - x^2)$$

$$4y^2 - x^2 = (2y - x)(2y + x) = (2y - x)L$$

Therefore:

$$T^4 = \frac{4\pi^4}{g^2}(4y^2 - x^2) = \frac{4\pi^4(2y - x)L}{g^2}$$

$$T^4 = \frac{8\pi^4 Ly}{g^2} - \frac{4\pi^4 Lx}{g^2}$$

$$\frac{T^4}{x} = \frac{8\pi^4 L}{g^2}\cdot\frac{y}{x} - \frac{4\pi^4 L}{g^2}$$

$$\frac{T^4}{x} = E\cdot\frac{y}{x} - F$$

A graph of T^4/x against *y*/*x* should be a straight line with

$E = \text{gradient} = \frac{8\pi^4 L}{g^2}$

$F = -\text{y-intercept} = \frac{4\pi^4 L}{g^2}$

Theory 1 results table

L = ………………m

			Time for 10 cycles				
θ/°	sin θ	$\sin^2 \theta$	t_1/s	t_2/s	$t_{average}$/s	T/s	T^4/s^4

Theory 2 results table

L = ………………m

		Time for 10 cycles				
x/m	x^2/m^2	t_1/s	t_2/s	$t_{average}$/s	T/s	T^4/s^4

Theory 3 results table

L = ……………..m

			Time for 10 cycles					
x/m	y/m	y/x	t_1/s	t_2/s	$t_{average}$/s	T/s	T^4/s^4	(T^4/x)/ s^{4}m^{-1}

Technician's notes

Each learner will require:

- 2 × stands
- 2 × bosses
- 2 × clamps
- 1 × pendulum bob
- string of length 1m
- 1 × stopwatch
- 1 × metre rule
- 1 × protractor

Learner worksheet

Aim

An opportunity to plan an entire experiment given the theory only.

Method

You have been given the theory for a V-shaped pendulum. Plan an experiment to determine *g* by:

- measuring *L*
- drawing up a table for your results
- recording your results in the table
- drawing an appropriate graph
- using the values of the gradient and *y*-intercept

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