# Using y = mx + c in physics

35–40 minutes independent work + 15–20 minutes review | 38 marks

AQA A Level 7408 and OCR A A Level H556 | Mathematical skills

## Skills practised

Choose axes; compare equations with a straight line; plot data; interpret gradients, intercepts and their units.
AQA maths MS 2.2, 2.3, 3.1–3.4; selected applications 3.4.2.1; 3.5.1.1, 3.5.1.3, 3.5.1.6; 3.6.1.3.
OCR A maths M2.2, M2.3, M3.1–M3.4; selected applications 3.4.1(b), (c), (d)(i); 4.2.3(a); 4.2.4(a)(i); 4.3.2(a)–(c)(i); 5.3.1(a), (c)(ii).

An engineering laboratory commissions an inspection gantry. You will calibrate its spring load sensor, a portable battery supply and a mass–spring mount. The models you need are supplied. Use a calculator and ruler; give numerical results to a sensible precision.

## 1 Read a straight-line equation [3 marks]

Compare the physical equation with y = mx + c. First name the vertical and horizontal quantities; then identify their coefficients. In this familiar form m means gradient. In Questions 4–5, m means mass, so we call the graph gradient G.
Worked example: F = kx. For F against x, gradient = k and intercept = 0. For x against F, first write x = (1/k)F: gradient = 1/k, not k.
Find a gradient using changes: G = Δy/Δx. Its unit is the vertical-axis unit divided by the horizontal-axis unit. A straight line shows direct proportionality only if it passes through the origin.

(a) For V = E − rI, a graph has V vertically and I horizontally. State its gradient and vertical intercept. [1 mark]

(b) A force sensor has output S = αF + $S_0$. Output S is measured in volts and force F in newtons. State the SI unit of α. [1 mark]

(c) The graph of S against F is straight but has a non-zero vertical intercept. Is S directly proportional to F? Justify your answer. [1 mark]

## 2 Calibrate the spring load sensor [9 marks]

The spring obeys Hooke's law. A pointer gives a length reading d, with an arbitrary zero-force reading $d_0$. The actual extension is $d - d_0$. Table 1 gives the calibration data.

Model: $d = d_0 + F/k$, where F is force and k is stiffness. Use metres for d and $d_0$ when k is in N $m^{-1}$. The graph uses mm so the small movements are easy to plot.

**Table 1**

| F / N | 0 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|---|
| d / mm | 2.0 | 6.2 | 9.8 | 14.2 | 17.8 | 22.0 |

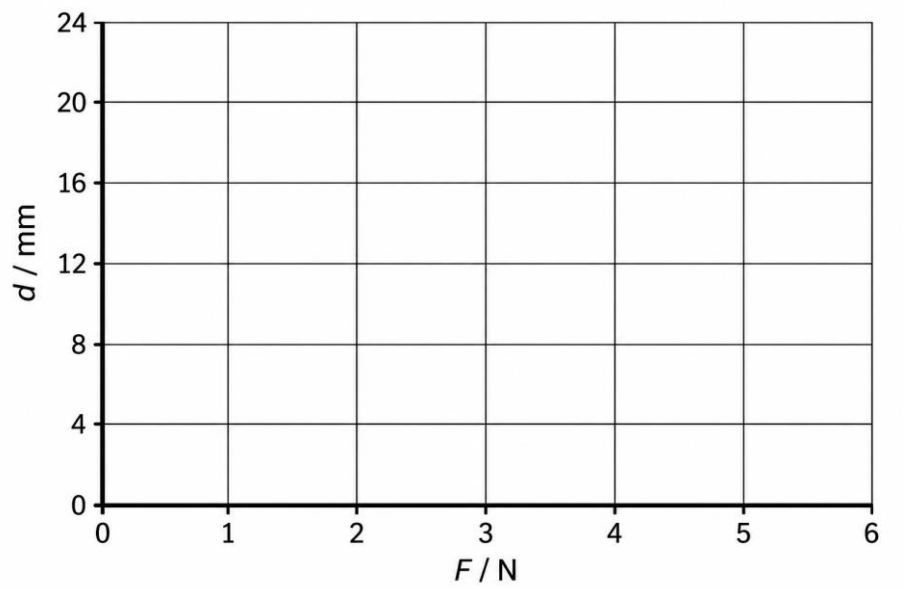



Figure 1 Pointer reading against applied force. Estimate between the coarse grid lines.

(a) Plot all six points from Table 1 on Figure 1 and draw a straight line of best fit. [2 marks]

(b) Use a large gradient triangle on your line to determine the gradient, including its unit. [2 marks]

(c) Use the model and your gradient to determine k in N $m^{-1}$. [2 marks]

(d) Estimate $d_0$ from the graph. Does the spring have this extension when F = 0? Explain. [2 marks]

(e) Predict the pointer reading for an applied force of 3.5 N. [1 mark]

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## 3 Interpret the battery calibration [7 marks]

A portable battery powers the gantry's calibration instruments. Figure 2 is its fitted terminal-voltage graph. Treat emf E and internal resistance r as constant over the tested range. Use V = E − rI.

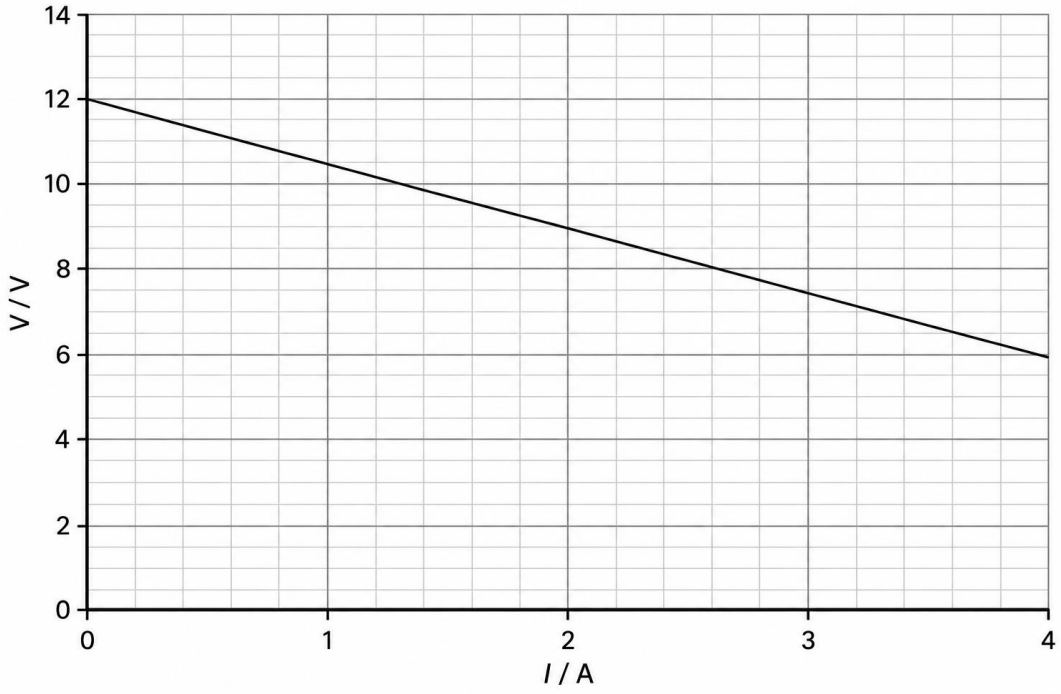



Figure 2 Terminal voltage V against current I.

(a) Determine the emf E from Figure 2. [1 mark]

(b) Use a large gradient triangle to calculate the signed gradient, including its unit. [2 marks]

(c) Hence determine the internal resistance r. [1 mark]

(d) Calculate the terminal voltage when the current is 2.40 A. [1 mark]

(e) At I = 2.0 A, a pupil calculates V/I = 4.5 Ω and calls this the internal resistance. Identify what this ratio represents and explain the error. [2 marks]

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## 4 Choose a useful graph for oscillations [6 marks]

The gantry camera sits on a mass–spring mount. An added mass m moves with a fixture of fixed mass $m_0$. For small oscillations, assume negligible damping and a spring of negligible mass. The supplied model is $T = 2\pi\sqrt{[(m + m_0)/k]}$, where T is period and k is stiffness.

A curved relationship may become linear after transforming one or both variables. Worked example: if $z = \sqrt{(Ax + B)}$, then $z^2 = Ax + B$. Plot $z^2$ against x to obtain gradient A and intercept B.

**Table 2**

| m / kg | 0.040 | 0.120 | 0.240 | 0.400 |
|---|---|---|---|---|
| T / s | 0.400 | 0.566 | 0.748 | 0.938 |
| $T^2$ / $s^2$ | | | | |

(a) Complete the $T^2$ row in Table 2. Give each value to three significant figures. [2 marks]

(b) Rearrange the supplied mount model into a straight-line equation. State what to plot on each axis and identify its gradient G and vertical intercept c. [2 marks]

(c) Rearrange your expression for G to make k the subject. [1 mark]

(d) Explain why a graph of T against m is not expected to be a straight line for this model. [1 mark]

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## 5 Find the hidden moving mass [9 marks]

A second camera mount follows the same model as Question 4 but has different k and $m_0$. Figure 3 is a best-fit graph for this second mount; do not reuse the numerical values in Table 2. The added mass m is measured in kg.

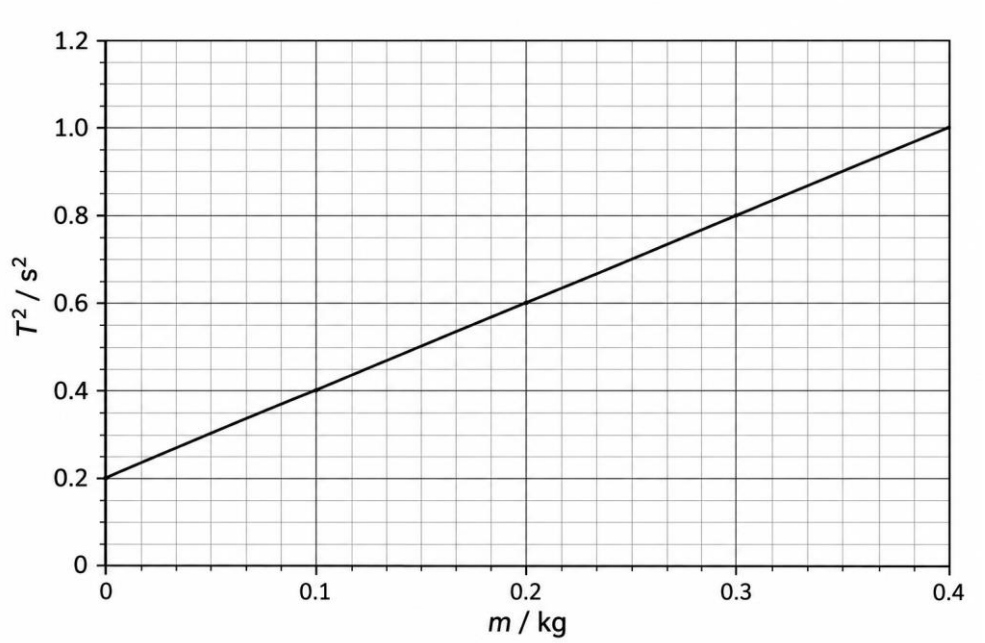



Figure 3 Squared period against added mass for the second mount.

(a) Use a large gradient triangle to determine G, including its unit. [2 marks]

(b) Calculate the stiffness k of this mount. [1 mark]

(c) Use the graph's intercept and gradient to determine $m_0$. [2 marks]

(d) The mount must have a period no greater than 0.800 s with an added camera mass of 0.250 kg. Calculate the period and decide whether it meets this requirement. [2 marks]

(e) A pupil forces the fitted line through the origin, saying that zero added mass means zero oscillating mass. Explain why this is unjustified and how it could affect k. [2 marks]

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## 6 Transfer the method to an unfamiliar model [4 marks]

The laboratory also tests thin connecting wires of equal length and material at constant temperature. A supplied model for the measured resistance is $R = K/D^2 + R_c$. Here D is wire diameter in metres, K is constant and $R_c$ is a constant contact resistance. The model is the only extra physics needed.

Choose an axis quantity that makes the variable part a single multiple of x. Do not assume that plotting the two original measured quantities will give a straight line.

(a) Choose a straight-line plot that would determine both K and $R_c$. State the vertical and horizontal quantities, the gradient and the vertical intercept. [2 marks]

(b) State the SI unit of K. [1 mark]

(c) For non-zero $R_c$, explain why R is not directly proportional to $1/D^2$, even though your chosen graph can be straight. [1 mark]

Final check Name the axes, rearrange, compare coefficients, check units and interpret the intercept.

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