

Hooke's law, springs and elastic energy

AQA GCSE Physics 8463 and Combined Science Trilogy 8464 | Papers 1 and 2 | Foundation and Higher

Worked solutions and teaching prompts | 32 parts | 58 marks

Specification points covered

Forces, extension, elastic/inelastic deformation and linear/non-linear behaviour: 8463 4.5.3; 8464 6.5.3

Elastic energy calculations: 8463 4.1.1.2 and 4.5.3; 8464 6.1.1.2 and 6.5.3

Force–extension investigation: 8463 required practical 6; 8464 required practical 18

Related skill — weight of a load: 8463 4.5.1.3; 8464 6.5.1.3

A workshop tests springs for a cradle that carries a delicate field instrument. Use bench-test data to check extension, stored energy and spring choice. The acceptance limits supplied are for this exercise; these tests alone do not establish that a real instrument will survive transport.

All parts are shared content for both routes and tiers. Accept equivalent wording and consistent follow-through. Timing is suggested, not classroom-tested. This original PhysicsUK resource is not an official AQA paper or mark scheme.

1 Checking the basic calculations

Each part refers to a separate spring test.

1(a) A spring is held fixed at the top and pulled down at the bottom. It stretches but remains stationary. Explain why more than one force is needed to stretch it in this test. **[2 marks]**

Answer / mark points: The lower end is pulled down while the support pulls up on the upper end.

[1] These opposing pulls act at different ends and stretch the spring; they balance when the spring is stationary. [1]

Teacher prompt: Do not describe a single unbalanced force as producing a stationary stretch. Ignore spring weight here.

1(b) A spring's unloaded length is 12.0 cm and its loaded length is 14.4 cm. Calculate its extension in cm. **[1 mark]**

Answer / mark points: $e = 14.4 - 12.0 = 2.4$ cm. [1]

1(c) Convert the 2.4 cm extension to metres. **[1 mark]**

Answer / mark points: $e = 2.4 \times 0.01 = 0.024$ m. [1]



1 Checking the basic calculations continued

1(d) A spring in a compression pad has spring constant 250 N m^{-1} . It is compressed by 2.4 cm within its proportional range. Calculate the force on it. **[1 mark]**

Answer / mark points: $e = 0.024 \text{ m}$; $F = ke = 250 \times 0.024 = 6.0 \text{ N}$. [1]

1(e) A spring has spring constant 200 N m^{-1} and unloaded length 0.120 m . A force of 8.0 N stretches it within its proportional range. Calculate its extension and its total loaded length. **[2 marks]**

Answer / mark points: $e = F / k = 8.0 / 200 = 0.040 \text{ m}$. [1]

Loaded length = $0.120 + 0.040 = 0.160 \text{ m}$. [1]

1(f) A spring extends by 0.030 m under a force of 6.0 N , within its proportional range. Calculate its spring constant. **[1 mark]**

Answer / mark points: $k = F / e = 6.0 / 0.030 = 200 \text{ N m}^{-1}$. [1]

2 Measuring extension from a ruler

For spring T, a pointer at the bottom of the unloaded spring reads 80 mm . Table 1 gives readings for total applied forces, not successive force increases.

Table 1

Total force / N	Pointer reading / mm
0	80
2.0	90
4.0	100
6.0	110

2(a) Use Table 1 to calculate the extension at 6.0 N , first in mm and then in m. **[2 marks]**

Answer / mark points: $e = 110 - 80 = 30 \text{ mm}$. [1] $e = 30 \times 0.001 = 0.030 \text{ m}$. [1]

2(b) Calculate the spring constant of spring T using the 6.0 N reading. **[1 mark]**

Answer / mark points: $k = F / e = 6.0 / 0.030 = 200 \text{ N m}^{-1}$. [1]



2 Measuring extension from a ruler continued

2(c) The spring remains in its proportional range at 8.0 N. Predict the pointer's ruler reading in mm at this force. **[2 marks]**

Answer / mark points: $e = 8.0 / 200 = 0.040 \text{ m} = 40 \text{ mm}$. [1] Pointer reading = $80 + 40 = 120 \text{ mm}$. [1]

2(d) A trainee uses 110 mm as the extension when calculating k at 6.0 N. Explain why this gives a spring constant that is too low. **[2 marks]**

Answer / mark points: 110 mm is the pointer position, not the change from the unloaded 80 mm reading; the extension used is too large. [1] With the same force, $k = F / e$ is therefore too small. [1]

Teacher prompt: The correct extension is 30 mm. The ruler's zero need not coincide with either end of the spring.

2(e) After the 6.0 N load is removed, the pointer returns to 80 mm. Explain why this is elastic deformation. **[1 mark]**

Answer / mark points: The spring returns to its original unloaded length when the force is removed. [1]

2(f) A separate 12 N test leaves the pointer at 84 mm after the load is removed. State the permanent extension in mm and identify this type of deformation. **[2 marks]**

Answer / mark points: Permanent extension = $84 - 80 = 4 \text{ mm}$. [1] Inelastic deformation: it has not returned to its original length. [1]



3 Interpreting the force–extension graph

Figure 1 shows a loading test on an initially undeformed spring of type T. Use the marked axes; extension is in cm.

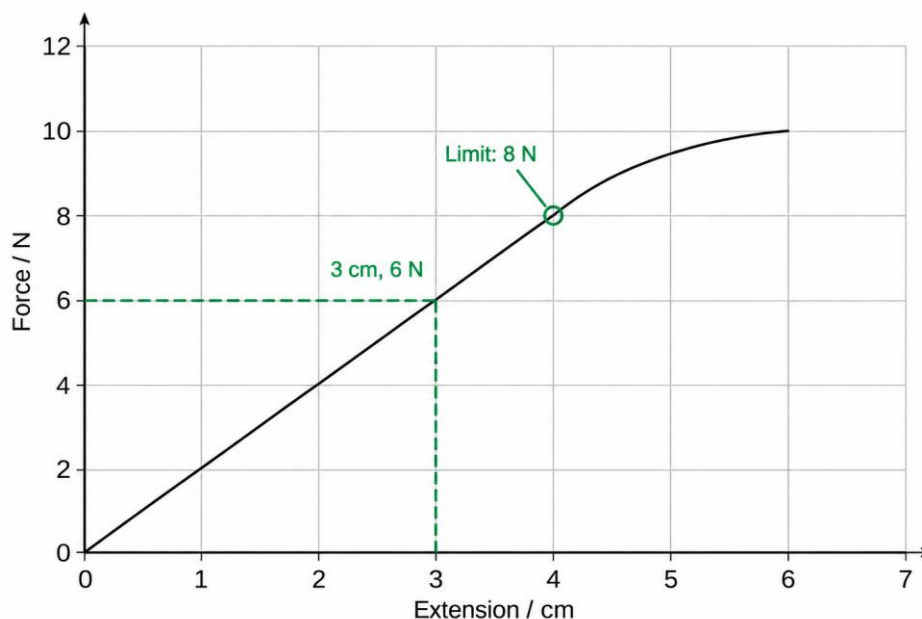


Figure 1

3(a) Use Figure 1 to find the force at an extension of 3.0 cm. **[1 mark]**

Answer / mark points: Force = 6.0 N. [1]

3(b) Use Figure 1 to find the extension at a force of 4.0 N. **[1 mark]**

Answer / mark points: Extension = 2.0 cm. [1]

3(c) Use values from the straight region of Figure 1 to calculate the spring constant in N m^{-1} . Show the conversion to metres. **[2 marks]**

Answer / mark points: For example, $e = 3.0 \text{ cm} = 0.030 \text{ m}$ at $F = 6.0 \text{ N}$. [1] $k = 6.0 / 0.030 = 200 \text{ N m}^{-1}$. [1] Accept another consistent non-zero straight-region pair. A gradient in N cm^{-1} must be multiplied by 100.

3(d) Determine the force at the limit of proportionality in Figure 1. **[1 mark]**

Answer / mark points: About 8.0 N, where the graph first leaves the straight-line proportional region. [1]

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3 Interpreting the force–extension graph continued

3(e) A trainee uses $k = 200 \text{ N m}^{-1}$ in $F = ke$ at an extension of 6.0 cm. Calculate their predicted force, read the actual force from Figure 1, and explain why the values differ. **[3 marks]**

Answer / mark points: Predicted $F = 200 \times 0.060 = 12 \text{ N}$. [1] The graph gives 10 N. [1] 6.0 cm is beyond the limit of proportionality, so force is no longer proportional to extension and the original constant k cannot be used. [1]

Teacher prompt: The graph, not a continued straight line, gives the force beyond the proportional range.

3(f) Does the curved region of Figure 1 alone prove that the spring has been permanently deformed? Explain how to check. **[2 marks]**

Answer / mark points: No: non-linear loading alone does not establish permanent deformation. [1] Remove the load and compare the unloaded length/pointer reading with its original value; residual extension indicates inelastic deformation. [1]

4 Energy stored by springs

Each spring below is loaded slowly from its unloaded length, within its proportional range. Ignore energy losses.

4(a) A spring has $k = 200 \text{ N m}^{-1}$ and extension 0.020 m. Calculate the elastic energy stored. **[1 mark]**

Answer / mark points: $E = 0.5ke^2 = 0.5 \times 200 \times 0.020^2 = 0.040 \text{ J}$. [1]

4(b) The same spring is extended by 0.040 m. Calculate its elastic energy. **[1 mark]**

Answer / mark points: $E = 0.5 \times 200 \times 0.040^2 = 0.160 \text{ J}$. [1]

4(c) Compare the energy in parts (a) and (b). Explain why doubling the extension does not just double the energy. **[2 marks]**

Answer / mark points: The energy is four times as large ($0.160 / 0.040 = 4$). [1] For the same k , E is proportional to e^2 , so doubling e multiplies E by $2^2 = 4$. [1]

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4 Energy stored by springs continued

4(d) How much work is done to extend the spring in part (b) from its unloaded length to 0.040 m? Ignore energy losses. **[1 mark]**

Answer / mark points: Work done = increase in elastic energy = 0.160 J. [1]

Teacher prompt: Do not use final force $\times$ extension: the force increases during stretching.

4(e) Two springs, with $k = 300 \text{ N m}^{-1}$ and $k = 150 \text{ N m}^{-1}$, are each extended by 0.030 m. Calculate the energy in each. **[2 marks]**

Answer / mark points: For $k = 300$: $E = 0.5 \times 300 \times 0.030^2 = 0.135 \text{ J}$. [1]

For $k = 150$: $E = 0.5 \times 150 \times 0.030^2 = 0.0675 \text{ J}$. [1]

4(f) A spring with $k = 150 \text{ N m}^{-1}$ must store 0.120 J. Calculate the required extension in m. **[2 marks]**

Answer / mark points: $e^2 = 2E / k = 2 \times 0.120 / 150 = 0.00160 \text{ m}^2$. [1]

$e = \sqrt{0.00160} = 0.040 \text{ m}$. [1]

Teacher prompt: Take the square root after rearranging; extension is a length, not a squared length.

5 Choosing a cradle spring

Table 2 gives two candidate springs. At a steady bench-test force of 6.0 N, the acceptable extension is 2.5–4.5 cm inclusive, and the spring must store at least 0.090 J. Both remain within their proportional ranges at 6.0 N.

Table 2

Spring	Spring constant / N m^{-1}	Force at limit of proportionality / N
A	150	9.0
B	300	15

5(a) Calculate the extension in m of spring A and spring B at the 6.0 N bench-test force. **[2 marks]**

Answer / mark points: A: $e = 6.0 / 150 = 0.040 \text{ m}$. [1] B: $e = 6.0 / 300 = 0.020 \text{ m}$. [1]

5(b) Which spring meets the 2.5–4.5 cm extension requirement? Compare both springs with the permitted range. **[2 marks]**

Answer / mark points: A meets it: $0.040 \text{ m} = 4.0 \text{ cm}$ is within the range. [1] B does not: $0.020 \text{ m} = 2.0 \text{ cm}$ is below the 2.5 cm minimum. [1]



5 Choosing a cradle spring continued

5(c) Calculate the energy stored in each spring at 6.0 N. Use the energy and extension requirements together to choose a spring for this bench test. **[3 marks]**

Answer / mark points: A: $E = 0.5 \times 150 \times 0.040^2 = 0.120 \text{ J}$. [1] B: $E = 0.5 \times 300 \times 0.020^2 = 0.060 \text{ J}$. [1] Choose A: it meets both the extension range and the minimum 0.090 J energy; B meets neither. [1]

Teacher prompt: At the same force, the stiffer spring extends less and stores less energy. Compare both criteria, not k alone.

5(d) After the cradle moves down and stretches its spring, why does an elastic spring alone not guarantee that the instrument will settle without bouncing? **[2 marks]**

Answer / mark points: The spring can return its stored elastic energy as it contracts, doing work on the cradle. [1] This can make the cradle move again rather than bring it permanently to rest; energy must be dissipated to stop continued bouncing. [1]

Teacher prompt: Do not claim elastic energy is destroyed, or that an elastic spring automatically dissipates all transferred energy.

6 Investigating force and extension

Figure 2 shows a force–extension experiment. Its ruler ticks have no numerical scale; no readings are taken from this schematic. Ignore the mass of the spring and pointer.

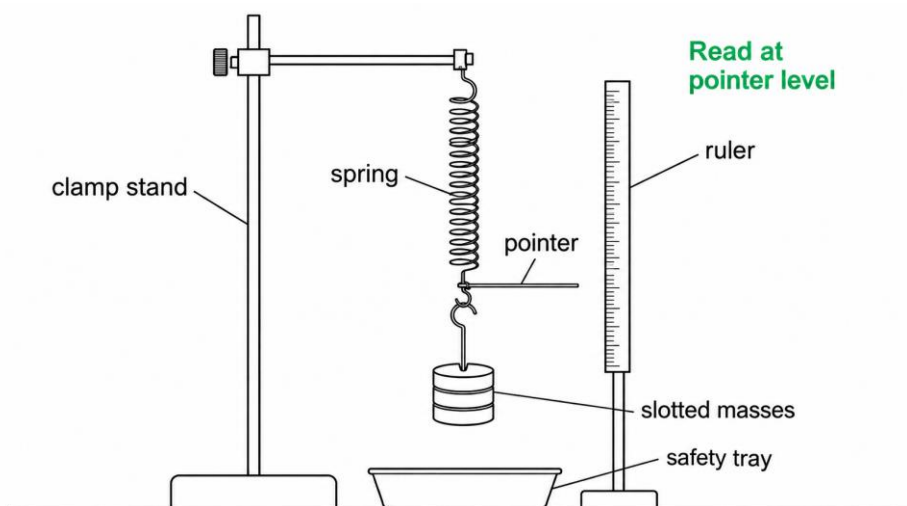


Figure 2

6(a) State how to position the ruler and your eye to reduce parallax when reading the pointer in Figure 2. **[2 marks]**

Answer / mark points: Keep the ruler close to the pointer. [1] Read with your eye at the same level as the pointer, looking straight at the scale. [1]



6 Investigating force and extension continued

6(b) The mass hanger is 50 g and the added slotted masses total 150 g. Calculate the total force stretching the spring. Use $g = 10 \text{ N kg}^{-1}$. **[2 marks]**

Answer / mark points: Total mass = $50 + 150 = 200 \text{ g} = 0.200 \text{ kg}$. [1] Force = weight = $mg = 0.200 \times 10 = 2.0 \text{ N}$. [1]

Teacher prompt: Include the hanger; use the total added load, not just the latest mass increment.

6(c) A technician tests only 1 N and 2 N, although the cradle's bench-test force is 6 N within the spring's proportional range. Suggest two improvements: one to the force range and one to the treatment of repeat readings. **[2 marks]**

Answer / mark points: Use several forces over a meaningful range including 6 N, without exceeding the proportional/elastic working range. [1] Repeat extension measurements at each force and calculate a mean for each force. [1]

Teacher prompt: "Repeat it" alone does not describe how repeated readings improve the result. Include a mean.

6(d) Describe a method using Figure 2 to investigate the relationship between force and extension and determine the spring constant. Include reliable measurements and safe loading. Structure your answer: unloaded reading → known forces and extension → repeats and range → graph and spring constant. **[6 marks]**

Answer / mark points: Model method: Secure the stand and clamp; place the ruler close and parallel to the spring. Record the unloaded pointer reading with no hanger or masses attached. Add the hanger and known masses in small increments; calculate each total force using $F = mg$, including the hanger, with mass in kg. Wait for the load to become stationary, read at pointer level and subtract the original reading to obtain each extension. Use several suitable loads over a meaningful range without overstretching. Repeat each reading and calculate a mean extension for each force. Plot force in N vertically against extension in m horizontally; draw a best-fit line through the proportional region. Its gradient, change in force / change in extension, gives k in N m^{-1} . Check return to the original reading after unloading; secure the base, keep feet clear of masses and use a catch tray and eye protection.

Holistic levels: 5–6 marks — a coherent, usable method linking controlled loads, correct extensions and graph/calculation to k , with reliable/safe practice; 3–4 — a mostly workable measurement method with some analysis or reliability detail but important omissions; 1–2 — isolated relevant measurements or actions without a usable sequence; 0 — no relevant method. Judge overall quality; this is not six automatic checklist marks.

Teacher prompt: Accept an extension-versus-force graph if its gradient is correctly identified as $1/k$ with consistent units. Do not confuse an arbitrary ruler position with extension. If plotting extension in cm, a force–extension gradient in N cm^{-1} must be multiplied by 100 to obtain k in N m^{-1} .

Review and improve

Use change in length, not total length or ruler position. $F = ke$ and $E = 0.5ke^2$ require the proportional range. A curved graph is not proof of permanent deformation: check the unloaded length. A spring stores energy; it does not necessarily dissipate it.

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