

5.3 Forces and elasticity

Name: _____ Class: _____ Date: _____

Total: 30 marks

KEY WORDS Elastic

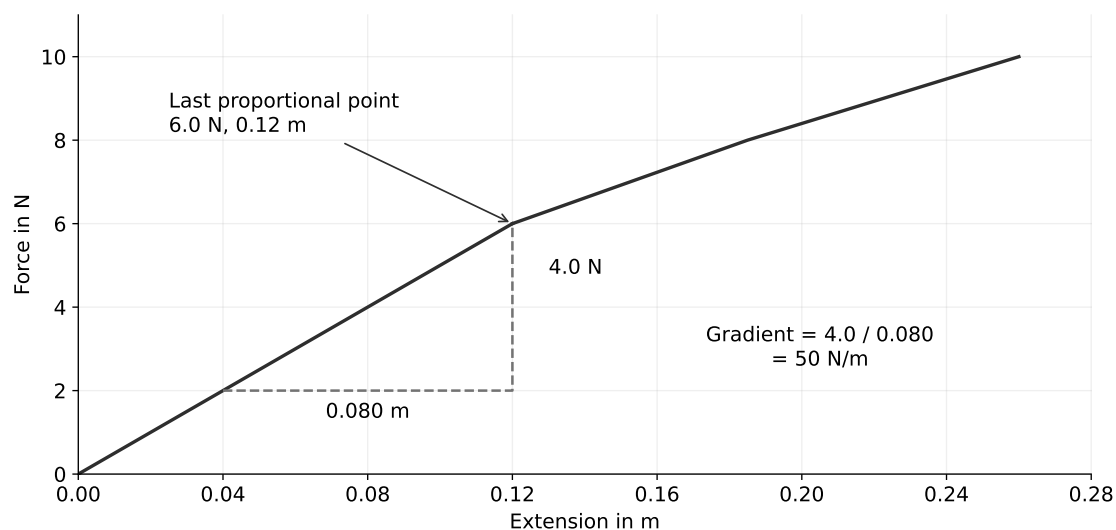
Objective

Use $F = ke$ and $E_e = \frac{1}{2}ke^2$, interpret force–extension graphs, and describe RP6 with the limit of proportionality. Original questions for spec statement 4.5.3 and required practical 6.

1 Key knowledge and worked examples

More than one force is needed to stretch, bend or compress a stationary object (one force alone would accelerate it).

- **Elastic deformation** : the object returns to its original shape when the forces are removed.
- **Inelastic deformation** : it does not fully recover.



Gradient of the straight section = k .

$$F = ke \quad E_e = \frac{1}{2}ke^2$$

- e is the **extension** = stretched length – original length (or compression).
- The equations hold **below the limit of proportionality**.

RP6 method: hang a mass holder on a suspended spring; add equal masses; measure the total length each time with a ruler at eye level (pointer on the spring helps); compute extension; plot force against extension.

Credited analysis points:

- linear section through the origin: $F \propto e$, gradient = k ;
- the line curves beyond the limit of proportionality;
- check for zero error (measure the unloaded length first);
- repeats and a mean reduce random error;
- same k = same stiffness; a stiffer spring has a larger k .

Worked example. A spring of original length 0.84 m stretches to 1.10 m under a child's weight of 340 N.

- Extension: $e = 1.10 - 0.84 = 0.26$ m.

$$k = \frac{F}{e} = \frac{340}{0.26} = 1310 \text{ N/m} \approx 1300 \text{ N/m (2 s.f.)}$$

Worked example. A spring with $k = 250$ N/m is stretched 4.0 cm.

- Convert: $e = 0.040$ m (its own mark).

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 250 \times 0.040^2 = 0.20 \text{ J}$$

2 Practice

2.1 A spring stretches 3.0 cm under a 6.0 N load. Calculate k in N/m. [3]

2.2 A spring of $k = 200$ N/m is compressed 5.0 cm. Calculate the elastic energy stored. [3]

2.3 State the difference between elastic and inelastic deformation. [2]

3 Exam-style questions

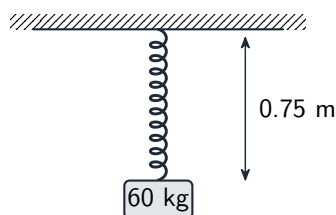
3.1 A student hangs masses on a spring and measures its length.

Load in N	0	2.0	4.0	6.0	8.0	10
Length in cm	20.0	24.0	28.0	32.0	38.5	46.0

- (a) Plot-ready: state the extension at each load. [1]
- (b) Describe the shape of the force–extension graph and identify where the limit of proportionality lies. [2]
- (c) Calculate k using data from the linear section. [2]
- (d) Suggest why the graph curves at large loads. [1]

3.2 A bungee cord behaves like a spring of $k = 800 \text{ N/m}$. A 60 kg person hangs at rest stretching it 0.75 m ($g = 10 \text{ N/kg}$ for this question).

- (a) Show the cord obeys $F = ke$ at this stretch. [3]
- (b) Calculate the elastic energy stored. [2]
- (c) (Link) State where this energy came from, using energy stores. [2]



3.3 Two springs, X ($k = 100 \text{ N/m}$) and Y ($k = 400 \text{ N/m}$), are each stretched by the same 8.0 N force.

- (a) Calculate each extension. [4]
- (b) Calculate the ratio of stored energies $E_X : E_Y$. [3]
- (c) Starting with both springs unstretched, state which needs more work to stretch it by 1.0 cm, with a reason. [2]

Solutions

2.1 Convert: $e = 0.030$ m (C1).

$$k = F/e = 6.0/0.030 = \mathbf{200} \text{ N/m}$$

(C1, A1)

2.2 Convert: $e = 0.050$ m (C1).

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 200 \times 0.050^2 = \mathbf{0.25} \text{ J}$$

(C1, A1)

2.3 Elastic: the object returns to its original length/shape when the load is removed; inelastic: it does not – permanently deformed.

3.1 (a) Extensions: 0, 4.0, 8.0, 12.0, 18.5, 26.0 cm. (b) A straight line through the origin through the data up to 6.0 N load, then departing from proportionality; last measured proportional point is 6.0 N / 12.0 cm; the precise limit lies between 6.0 N and 8.0 N. (c) Using linear data, e.g. 4.0 N over 8.0 cm:

$$k = \frac{F}{e} = \frac{4.0 \text{ N}}{0.080 \text{ m}} = \mathbf{50} \text{ N/m}$$

(C1 for m conversion, A1) (d) The limit of proportionality has been exceeded – the spring deforms beyond Hooke's-law behaviour.

3.2 (a) Weight: $F = mg = 60 \times 10 = 600$ N (C1). Predicted force at 0.75 m: $F = ke = 800 \times 0.75 = 600$ N (C1); the weight equals ke , as required for equilibrium. (b)

$$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 800 \times 0.75^2 = \mathbf{225} \text{ J}$$

(C1, A1) (c) From the person's gravitational potential store (they descended stretching the cord); the cord's elastic potential store filled as they fell.

3.3 (a) $e_X = F/k = 8.0/100 = \mathbf{0.080}$ m (C1, A1); $e_Y = 8.0/400 = \mathbf{0.020}$ m (C1, A1). (b)

$$E_X = \frac{1}{2}k_X e_X^2 = \frac{1}{2} \times 100 \times 0.080^2 = 0.32 \text{ J}$$

$$E_Y = \frac{1}{2}k_Y e_Y^2 = \frac{1}{2} \times 400 \times 0.020^2 = 0.080 \text{ J}$$

(each energy C1; ratio **4 : 1** A1) (c) Spring Y: for the same extension from the natural length, $E_e = \frac{1}{2}ke^2$ is proportional to k , so Y requires four times the work.