A Level Mechanics
Practice Test 3: Elasticity and Springs

Instructions:
Answer all questions. Show your working clearly.
Calculators may be used unless stated otherwise.
Draw clear, labelled diagrams where appropriate.
Time allowed: 2 hours

Section A: Hooke's Law and Spring Systems [45 marks]

Question 1 [**12 marks**] A spring obeys Hooke's Law and has a natural length of 25.0 cm.

(a) State Hooke's Law and write its mathematical expression. [**3 marks**]

(b) When a 6.0 N force is applied, the spring extends to 28.5 cm. Calculate the spring constant. [**4 marks**]

(c) A force-extension graph is plotted for this spring. Sketch this graph and explain what the gradient represents. [**3 marks**]

(d) State what happens when the elastic limit is exceeded. [**2 marks**]

Question 2 [**16 marks**] Three identical springs, each with spring constant 120 N/m, are arranged in different configurations.

(a) Two springs are connected in series and a 18 N force is applied.

  (i) Calculate the extension of each spring. [**3 marks**]

  (ii) Find the effective spring constant of the series combination. [**3 marks**]

(b) The same two springs are now connected in parallel and the same 18 N force is applied.

  (i) Calculate the extension of the parallel combination. [**3 marks**]

  (ii) Find the effective spring constant of the parallel combination. [**2 marks**]

(c) A third spring is added in parallel to the arrangement in part (b). Calculate:

  (i) The new effective spring constant. [**2 marks**]

  (ii) The extension when the same 18 N force is applied. [**3 marks**]

Question 3 [**17 marks**] A student investigates the relationship between force and extension for two different springs, A and B. The results are shown in the table below:

Force (N)	Extension of A (cm)	Extension of B (cm)
0.0	0.0	0.0
2.0	1.5	4.0
4.0	3.0	8.0
6.0	4.5	12.0
8.0	6.0	16.0
10.0	7.5	20.0

(a) On the same axes, plot force-extension graphs for both springs A and B. **[5 marks]**

(b) Calculate the spring constant for each spring. **[4 marks]**

(c) Which spring is stiffer? Justify your answer. **[2 marks]**

(d) If both springs were connected in series and a 5.0 N force applied, calculate the total extension. **[4 marks]**

(e) State one source of uncertainty in this experiment. **[2 marks]**

Section B: Elastic Potential Energy [50 marks]

Question 4 [15 marks]

(a) Define elastic potential energy and state the formula for the elastic potential energy stored in a spring. **[4 marks]**

(b) Derive this formula from first principles, starting with the definition of work done. **[6 marks]**

(c) Explain how elastic potential energy can be converted to kinetic energy, giving a practical example. **[3 marks]**

(d) State the principle of conservation of energy as applied to elastic systems. **[2 marks]**

Question 5 [20 marks] A spring gun uses a compressed spring to fire a ball horizontally. The spring has a spring constant of 450 N/m and is compressed by 8.0 cm before firing.

(a) Calculate the elastic potential energy stored in the compressed spring. **[3 marks]**

(b) The ball has a mass of 25 g. Assuming no energy losses, calculate:

(i) The maximum velocity of the ball as it leaves the spring. **[4 marks]**

(ii) The kinetic energy of the ball at this velocity. **[2 marks]**

(c) In practice, only 75% of the elastic potential energy is converted to kinetic energy due to friction and other losses. Calculate:

(i) The actual kinetic energy of the ball. **[2 marks]**

(ii) The actual velocity of the ball as it leaves the spring. **[3 marks]**

(iii) The energy lost to friction and other factors. **[2 marks]**

(d) The ball is fired horizontally from a height of 1.2 m above the ground. Calculate how far horizontally the ball travels before hitting the ground. **[4 marks]**

Question 6 [15 marks] A bungee cord can be modeled as a spring with spring constant 50 N/m and natural length 15 m. A person of mass 60 kg jumps from a platform 40 m above the lowest safe point.

(a) Calculate the gravitational potential energy lost by the person when they reach the lowest safe point. **[2 marks]**

(b) At the lowest safe point, the bungee cord is extended by 25 m from its natural length. Calculate:

(i) The elastic potential energy stored in the cord. **[3 marks]**

(ii) The kinetic energy of the person at this point. **[3 marks]**

(iii) The speed of the person at this point. **[3 marks]**

(c) Calculate the maximum extension of the bungee cord, assuming the person comes to rest momentarily at the lowest point. **[4 marks]**

Section C: Stress, Strain and Young's Modulus [60 marks]

Question 7 [18 marks]

(a) Define the following terms and state their SI units:

(i) Stress **[3 marks]**

(ii) Strain **[3 marks]**

(iii) Young's modulus **[3 marks]**

(b) Write the equation that relates Young's modulus to stress and strain. **[2 marks]**

(c) Explain what Young's modulus tells us about the mechanical properties of a material. **[3 marks]**

(d) A material has a large Young's modulus. What does this tell us about how the material behaves when forces are applied to it? **[4 marks]**

Question 8 [25 marks] A steel cable in a lift system has the following specifications:

- Length: 80.0 m
- Diameter: 12.0 mm
- Young's modulus for steel: 2.0×10^{11} Pa
- Maximum safe stress: 400×10 Pa

(a) Calculate the cross-sectional area of the cable. **[3 marks]**

(b) The cable supports a load of 12,000 N. Calculate:

(i) The tensile stress in the cable. **[3 marks]**

(ii) The tensile strain in the cable. **[3 marks]**

(iii) The extension of the cable. **[4 marks]**

(iv) The elastic potential energy stored in the cable. **[4 marks]**

(c) Determine whether the cable is operating within its safe stress limit. **[2 marks]**

(d) Calculate the maximum load this cable can safely support. **[3 marks]**

(e) If the diameter of the cable were increased to 15.0 mm while keeping all other factors the same, calculate:

(i) The new extension under the original 12,000 N load. **[3 marks]**

Question 9 [17 marks] A student conducts an experiment to determine Young's modulus for a copper wire. The wire has:

- Length: 2.50 m

- Diameter: 0.50 mm

The following data is obtained:

Load (N)	Extension (mm)
0.0	0.0
10.0	0.65
20.0	1.30
30.0	1.95
40.0	2.60
50.0	3.25

(a) Plot a graph of stress (y-axis) against strain (x-axis) for this data. **[8 marks]**

(b) Use your graph to determine Young's modulus for copper. **[5 marks]**

(c) Compare your result with the accepted value of 1.3×10^{11} Pa and calculate the percentage error. **[2 marks]**

(d) State two factors that could contribute to the error in your result. **[2 marks]**

Section D: Simple Harmonic Motion with Springs [35 marks]

Question 10 [20 marks] A mass of 0.75 kg is attached to a horizontal spring with spring constant 300 N/m. The mass is displaced 4.0 cm from its equilibrium position and released.

(a) Show that the motion is simple harmonic and write the equation of motion. **[4 marks]**

(b) Calculate:

(i) The period of oscillation. **[3 marks]**

(ii) The frequency of oscillation. **[2 marks]**

(iii) The angular frequency. **[2 marks]**

(c) Find:

(i) The maximum velocity during the motion. **[3 marks]**

(ii) The maximum acceleration during the motion. **[3 marks]**

(d) Calculate the total mechanical energy of the system. **[3 marks]**

Question 11 [15 marks] A vertical spring with spring constant 180 N/m supports a mass of 1.5 kg.

(a) Calculate the extension of the spring when the mass is in equilibrium. **[3 marks]**

(b) The mass is pulled down an additional 5.0 cm from equilibrium and released. Calculate:

(i) The amplitude of the resulting oscillation. **[1 mark]**

(ii) The period of oscillation. **[3 marks]**

(iii) The maximum speed of the mass during oscillation. **[3 marks]**

(c) At what positions during the oscillation is the speed of the mass equal to half its maximum value? **[5 marks]**

Data and Formulae

Springs and Hooke's Law:

$F = kx$ (Hooke's Law)

Series springs: $\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2} + ...$

Parallel springs: $k_{eff} = k_1 + k_2 + ...$

Energy:

Elastic potential energy: $E_p = \frac{1}{2}kx^2$

Kinetic energy: $E_k = \frac{1}{2}mv^2$

Gravitational potential energy: $E_p = mgh$

Stress and Strain:

Stress: $\sigma = \frac{F}{A}$

Strain: $\epsilon = \frac{\Delta L}{L}$

Young's modulus: $E = \frac{\sigma}{\epsilon} = \frac{FL}{A\Delta L}$

Simple Harmonic Motion:

$F = -kx$ (restoring force)

$T = 2\pi\sqrt{\frac{m}{k}}$ (period)

$f = \frac{1}{T}$ (frequency)

$\omega = 2\pi f = \sqrt{\frac{k}{m}}$ (angular frequency)

$v_{max} = \omega A$ (maximum velocity)

$a_{max} = \omega^2 A$ (maximum acceleration)

Motion equations:

$v^2 = u^2 + 2as$

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

Constants:

$g = 9.81$ m s^{-2}

$\pi = 3.14$

END OF TEST

Total marks: 190

Grade boundaries: A* 171, A 152, B 133, C 114, D 95, E 76

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