**Data**

| | |
|---|---|
| acceleration of free fall | $g = 9.81\,\mathrm{m\,s^{-2}}$ |
| speed of light in free space | $c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$ |
| elementary charge | $e = 1.60 \times 10^{-19}\,\mathrm{C}$ |
| unified atomic mass unit | $1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$ |
| rest mass of proton | $m_\mathrm{p} = 1.67 \times 10^{-27}\,\mathrm{kg}$ |
| rest mass of electron | $m_\mathrm{e} = 9.11 \times 10^{-31}\,\mathrm{kg}$ |
| Avogadro constant | $N_\mathrm{A} = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$ |
| molar gas constant | $R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$ |
| Boltzmann constant | $k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$ |
| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$ |
| | $(\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$ |
| Planck constant | $h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$ |
| Stefan–Boltzmann constant | $\sigma = 5.67 \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$ |

**Formulae**

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| hydrostatic pressure | $\Delta p = \rho g \Delta h$ |
| upthrust | $F = \rho g V$ |
| Doppler effect for sound waves | $f_\mathrm{o} = \dfrac{f_\mathrm{s}v}{v \pm v_\mathrm{s}}$ |
| electric current | $I = Anvq$ |
| resistors in series | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \ldots$ |

1 What is needed to accurately represent all physical quantities?

**A** a base unit and a number

**B** a unit and a number expressed in standard form (scientific notation)

**C** a unit and a numerical magnitude

**D** an SI unit and a numerical magnitude

2 A voltmeter connected across a resistor in a circuit reads 3.6 V.

What could be the current in the resistor and the resistance of the resistor?

| | current | resistance |
|---|---|---|
| **A** | 150 mA | 0.24 kΩ |
| **B** | 15 mA | 2.4 kΩ |
| **C** | 1.5 mA | 0.24 MΩ |
| **D** | 15 μA | 240 kΩ |

3 In an experiment to determine the acceleration of free fall $g$, the time $t$ taken for a ball to fall through distance $s$ is measured. The percentage uncertainty in the measurement of $s$ is 2%. The percentage uncertainty in the measurement of $t$ is 3%.

The value of $g$ is determined using the equation shown.

$$g = \frac{2s}{t^2}$$

What is the percentage uncertainty in the calculated value of $g$?

**A** 1% **B** 5% **C** 8% **D** 11%

4 Which quantity is a vector?

**A** momentum

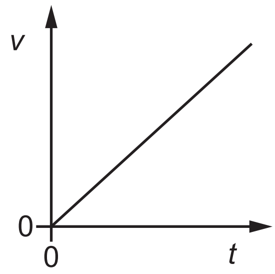
**B** speed

**C** temperature

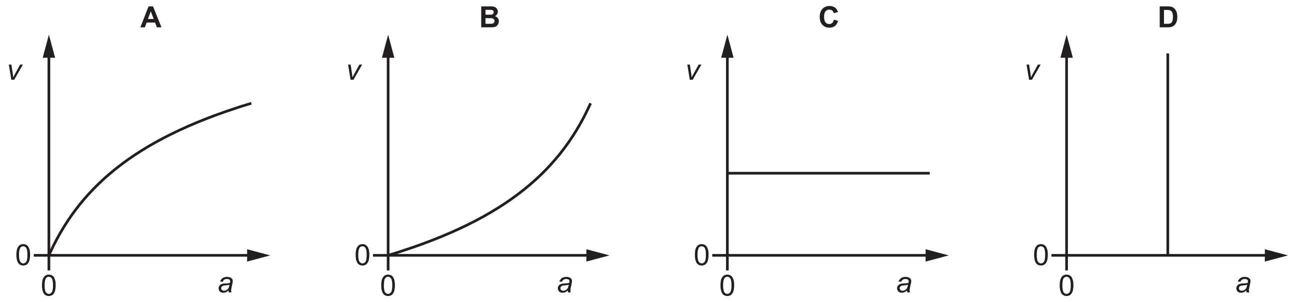
**D** Young modulus

**5** A particle accelerates from rest.

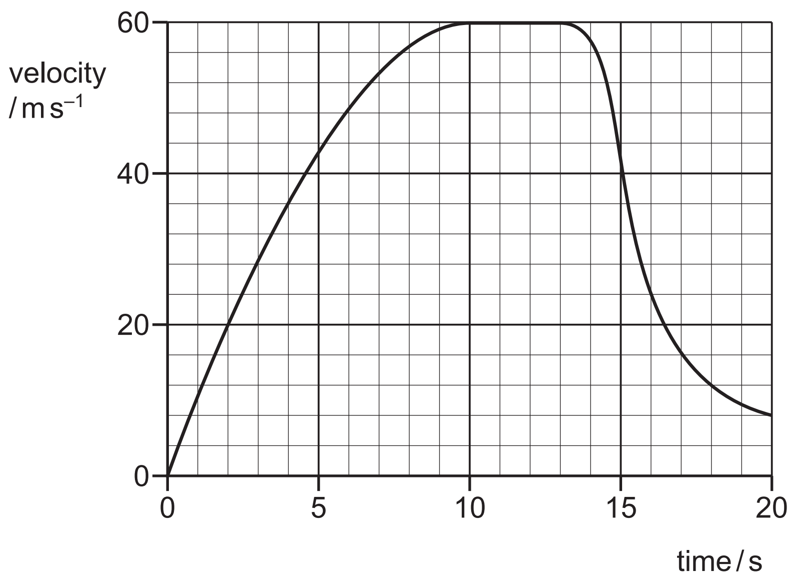
The graph shows the variation of the velocity $v$ of the particle with time $t$.




Which graph shows the variation of the velocity $v$ with the acceleration $a$ of the particle?




**6** The graph shows the vertical velocity of a parachutist during the first 20 s of her jump.




Approximately how far does she fall **before** opening the parachute?

**A** 390 m **B** 570 m **C** 710 m **D** 770 m

**7** What is the definition of linear momentum?

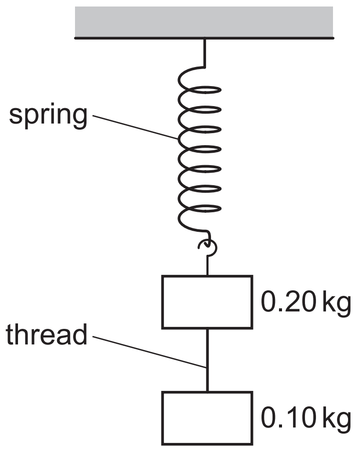
**A** force per unit time

**B** product of force and time

**C** product of velocity and mass

**D** velocity per unit mass

**8** A mass of 0.20 kg is suspended from the lower end of a light spring. A second mass of 0.10 kg is suspended from the first mass by a thread. The arrangement is allowed to come into static equilibrium and then the thread is cut.




Immediately after the thread is cut, what is the upward acceleration of the 0.20 kg mass?

**A** $4.9\,\mathrm{m\,s^{-2}}$ **B** $6.5\,\mathrm{m\,s^{-2}}$ **C** $9.8\,\mathrm{m\,s^{-2}}$ **D** $15\,\mathrm{m\,s^{-2}}$

**9** A snowflake and a raindrop are in still air. They both fall from rest at the same time and from the same height, far above the ground.

The snowflake and raindrop contain the same mass of water. Assume that there is no evaporation or melting. Also assume that, for a given speed, the drag force acting on the snowflake is greater than the drag force acting on the raindrop.

Which statement about the snowflake and raindrop is correct?

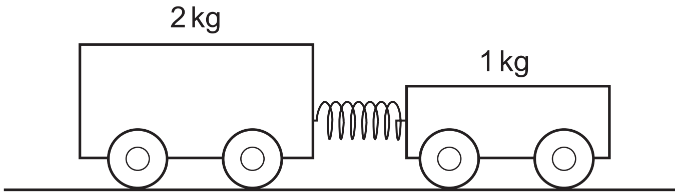
**A** The raindrop takes more time than the snowflake to reach terminal velocity.

**B** The raindrop takes more time than the snowflake to reach the ground.

**C** They reach the same terminal velocity.

**D** They take the same amount of time to reach the ground.

**10** Two trolleys are held together on a horizontal surface with a compressed spring between them.



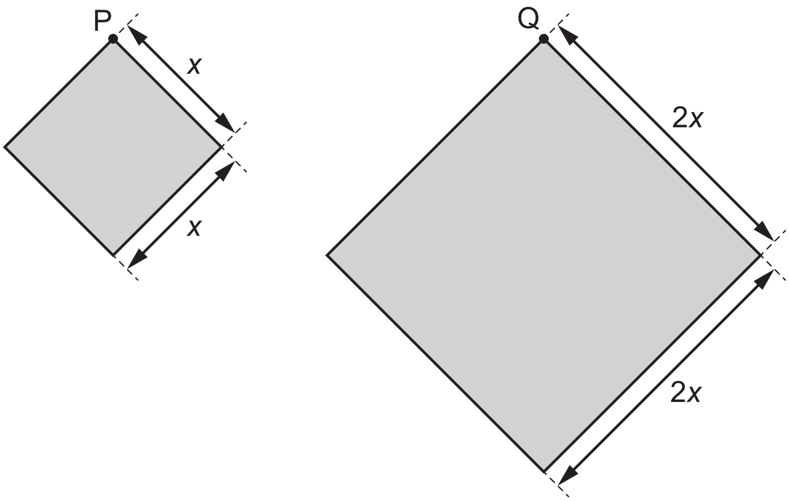

When they are released, the trolleys lose contact with the spring. The trolley of mass 2 kg moves to the left at a final speed of $2\,\text{m s}^{-1}$.

How much elastic potential energy was stored in the spring?

**A** 4 J  **B** 6 J  **C** 8 J  **D** 12 J

**11** A square board, of side length $x$, hangs freely from a nail P, as shown.

The board has uniform thickness and is made from material of uniform density.



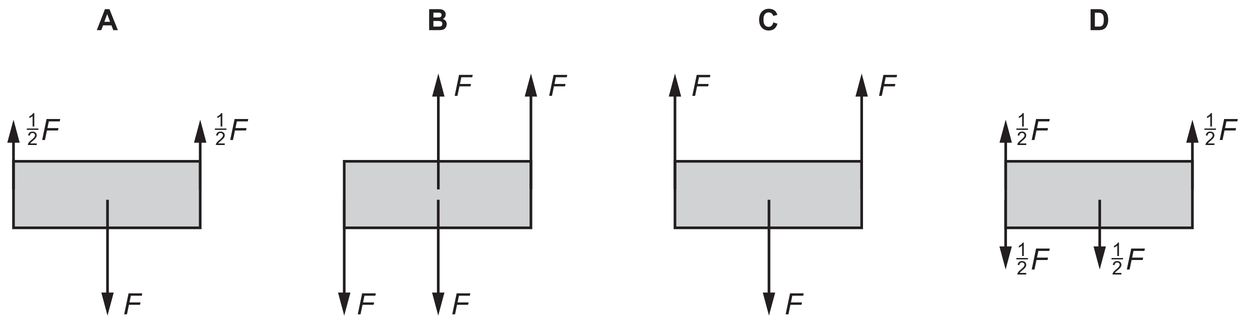

A second square board, of side length $2x$, is made of the same material and has the same thickness as the original board. This second board is then hung from a nail Q. Nails P and Q are at the same height.

What is the vertical distance between the positions of the centres of gravity of the two boards?

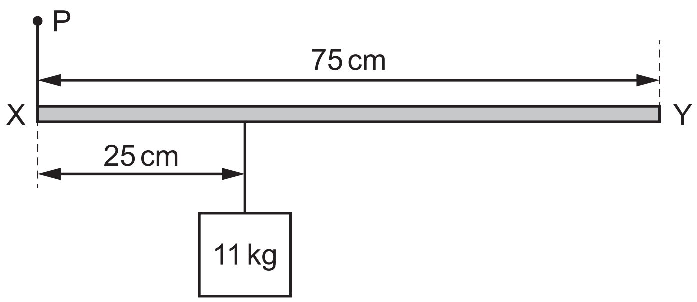
**A** 0  **B** $\dfrac{x}{\sqrt{2}}$  **C** $x$  **D** $x\sqrt{2}$

**12** Forces are applied to a rigid object. The forces all act in the same plane.

In which diagram is the object in equilibrium?




**13** A rigid rod XY has negligible mass and length 75 cm. The rod is suspended from a fixed point P by a string attached to end X. An object of mass 11 kg is suspended by a string that is attached to the rod at a distance of 25 cm from end X, as shown.




Which vertically upward force acting on end Y of the rod would hold the rod horizontally in equilibrium?

**A** 3.7 N **B** 33 N **C** 36 N **D** 320 N

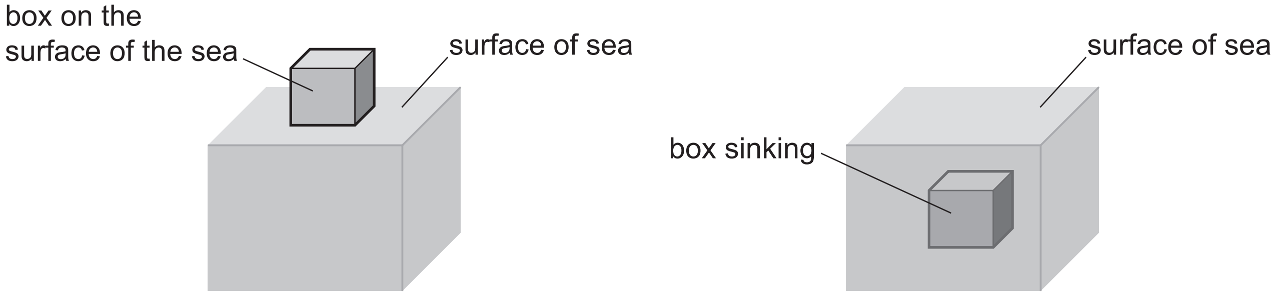
**14** The density of water is $1.0\,g\,cm^{-3}$ and the density of glycerine is $1.3\,g\,cm^{-3}$.

Water is added to a measuring cylinder containing $40\,cm^3$ of glycerine so that the density of the mixture is $1.1\,g\,cm^{-3}$. Assume that the mixing process does not change the total volume of the liquid.

What is the volume of water added?

**A** $40\,cm^3$ **B** $44\,cm^3$ **C** $52\,cm^3$ **D** $80\,cm^3$

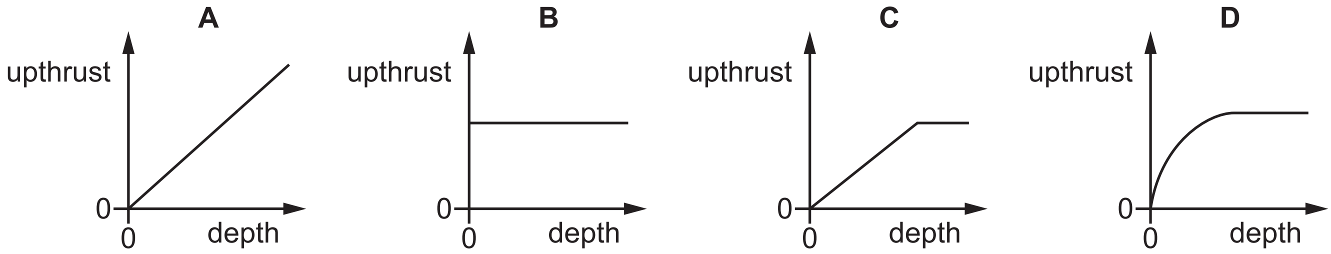
**15** A box, in the shape of a cube, falls from a ship into the sea. The box lands with its lower face level with the surface of the sea.



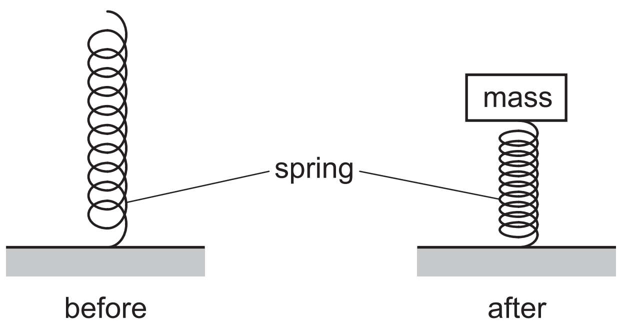

The box begins to sink, becomes totally submerged and then sinks deeper into the sea.

As the box sinks, its lower face is always parallel to the surface of the sea.

Which graph best represents the variation of the upthrust acting on the box with the depth of its lower face below the surface of the sea?




**16** A spring is compressed by a mass, as shown.




Which statement describes the changes to the energy of the spring when it is compressed by the mass?

**A** The spring gains both gravitational potential energy and elastic potential energy.

**B** The spring gains gravitational potential energy and loses elastic potential energy.

**C** The spring loses both gravitational potential energy and elastic potential energy.

**D** The spring loses gravitational potential energy and gains elastic potential energy.

**17** A man of mass 75 kg runs up a staircase consisting of 30 steps. Each step is 20 cm high.

The man takes a time of 7.0 s to run from the bottom of the staircase to the top.

What is the average rate of increase of gravitational potential energy of the man?

**A** 64 W **B** 450 W **C** 630 W **D** 4400 W

**18** An alpha-particle has $2.2 \times 10^{-13}$ J of kinetic energy.

What is the speed of the alpha-particle?

**A** $4.1 \times 10^{6}\,\text{m s}^{-1}$

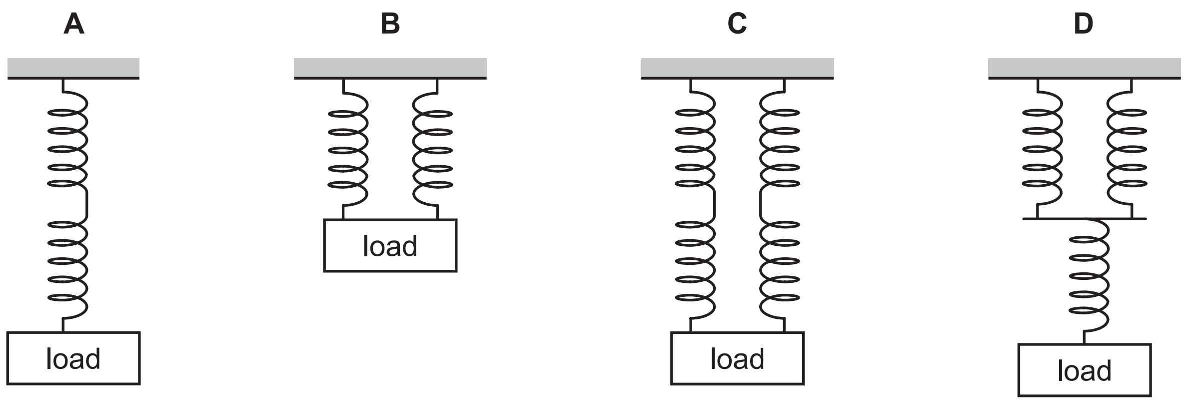
**B** $5.8 \times 10^{6}\,\text{m s}^{-1}$

**C** $8.1 \times 10^{6}\,\text{m s}^{-1}$

**D** $1.2 \times 10^{7}\,\text{m s}^{-1}$

**19** Identical springs are joined in four arrangements.

Which arrangement has the same spring constant as a single spring?




**20** An unstretched spring has a length of 2.0 cm.

The spring is then stretched within its limit of proportionality by a tensile force of 1.5 N so that the elastic potential energy stored in the spring is 0.045 J.

What is the stretched length of the spring?

**A** 3.0 cm **B** 5.0 cm **C** 6.0 cm **D** 8.0 cm

1 **(a)** The boxes in Fig. 1.1 contain terms on the left-hand side and examples of these terms on the right-hand side.

Draw a line between each term on the left and the correct example on the right.

| | |
|---|---|
| base quantity | coulomb |
| base unit | electric current |
| derived quantity | force |
| derived unit | kilogram |

**Fig. 1.1**

[2]

**(b)** A set of experimental measurements is described as precise and not accurate.

State what is meant by:

**(i)** precise

..........................................................................................................................................

.................................................................................................................................. [1]

**(ii)** not accurate.

..........................................................................................................................................

.................................................................................................................................. [1]

**(c)** An object of mass $m$ travels with speed $v$ in a circle of radius $r$. The force $F$ acting on the object is given by

$$F = \frac{mv^2}{r}.$$

The percentage uncertainties of three of the quantities are given in Table 1.1.

**Table 1.1**

| quantity | percentage uncertainty |
|---|---|
| $F$ | ±3% |
| $m$ | ±4% |
| $r$ | ±5% |

The value of $v$ is determined from $F$, $m$ and $r$.

**(i)** Calculate the percentage uncertainty in $v$.

percentage uncertainty = ..................................................... % [2]

**(ii)** The value of $v$ is 15.0 m s$^{-1}$.

Calculate the absolute uncertainty in $v$.

absolute uncertainty = ................................................ m s$^{-1}$ [1]

[Total: 7]

**2** A steel ball is projected horizontally from the top of a table, as shown in Fig. 2.1.

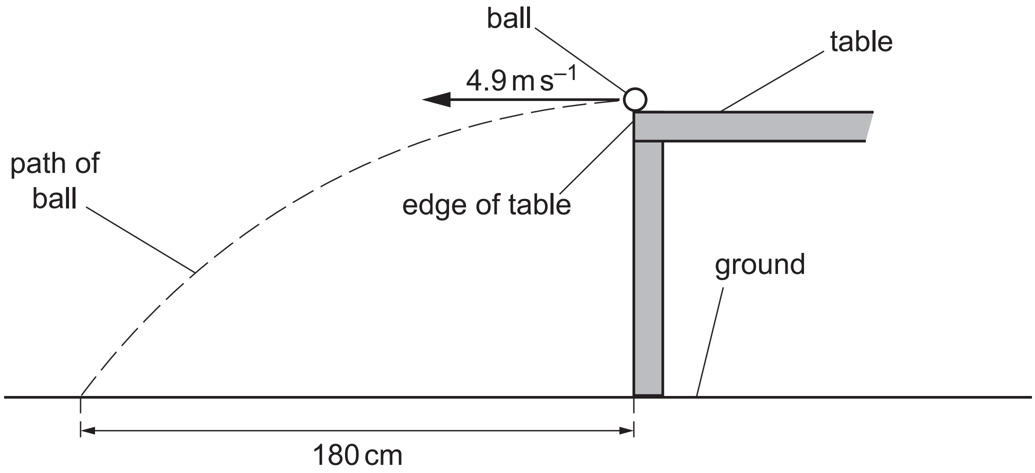



**Fig. 2.1** (not to scale)

The ball is projected horizontally at a speed of $4.9\,\mathrm{m\,s^{-1}}$. The ball lands on the ground a horizontal distance of 180 cm from the edge of the table.

Assume that air resistance is negligible.

**(a)** **(i)** Calculate the time taken for the ball to reach the ground.

time = ........................................................ s [1]

**(ii)** Calculate the vertical component of the velocity of the ball as it hits the ground.

velocity = ................................................ $\mathrm{m\,s^{-1}}$ [2]

**(iii)** Determine the magnitude and the angle to the horizontal of the velocity of the ball as it hits the ground.

magnitude of velocity = .................................................... $m\,s^{-1}$

angle to the horizontal = .......................................................... °

[3]

**(b)** The ball is projected by means of a compressed spring which is attached to a fixed block as shown in Fig. 2.2.

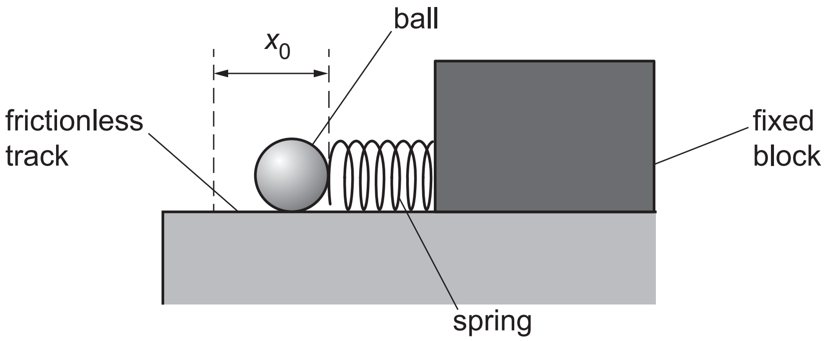



**Fig. 2.2**

The ball is placed on a frictionless track in front of the spring. The ball is then pulled back so that the spring has compression $x_0$.

When the spring is released, the ball is projected horizontally as shown in Fig. 2.3.

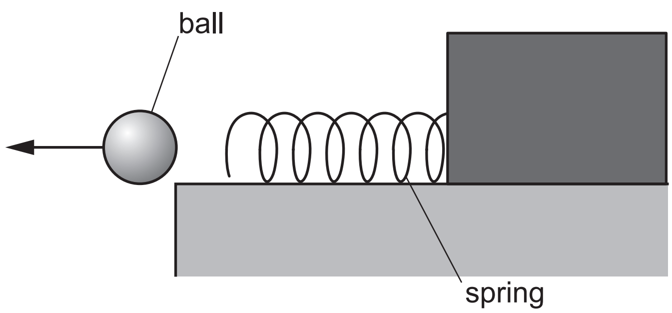



**Fig. 2.3**

The variation with compression $x$ of the applied force $F$ for the spring is shown in Fig. 2.4.

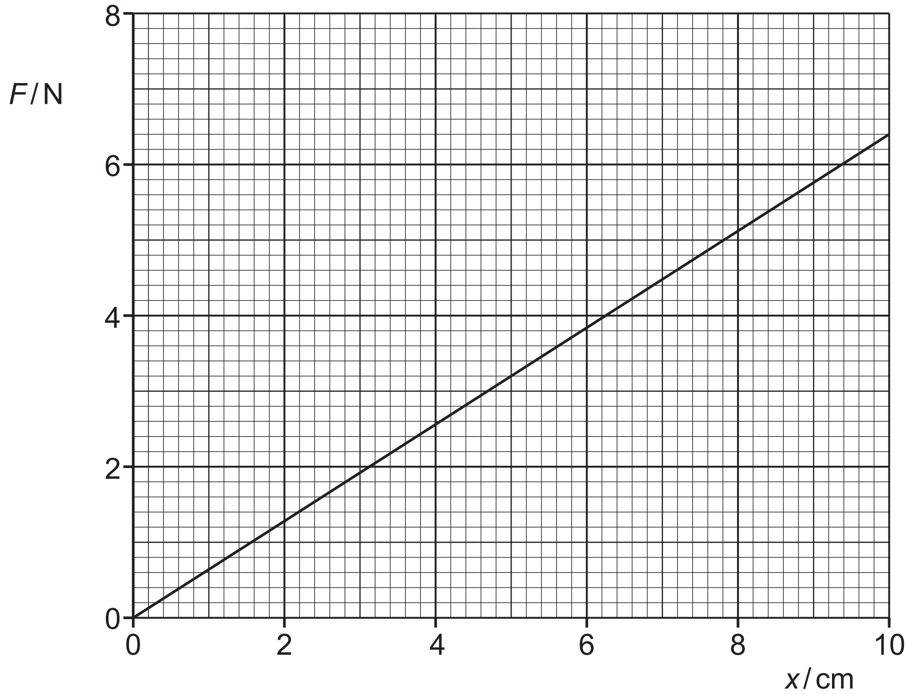



**Fig. 2.4**

The ball is a uniform sphere of steel of diameter 0.016 m and mass 0.017 kg.

**(i)** Calculate the density of the steel.

density = ............................................... $kg\,m^{-3}$ [3]

**(ii)** All of the elastic potential energy in the spring is converted into kinetic energy of the ball. The speed of the ball as it leaves the spring is $4.9\,m\,s^{-1}$.

Show that the maximum elastic potential energy of the spring is 0.20 J.

[2]

**(iii)** Use Fig. 2.4 to determine the spring constant $k$ of the spring.

$k$ = .............................................. $\mathrm{N\,m^{-1}}$ [2]

**(iv)** Use your answer in **(b)(iii)** and the value of energy given in **(b)(ii)** to determine the compression $x_0$ of the spring.

$x_0$ = .................................................... m [2]

**(c)** The steel ball is replaced by a polystyrene ball of the same diameter but of much lower mass. The spring is given compression $x_0$ and is then released.

Air resistance on this ball is **not** negligible after it leaves the spring.

Explain:

**(i)** why this ball leaves the spring with a greater speed than that of the steel ball

...........................................................................................................................

...........................................................................................................................

..................................................................................................................... [1]

**(ii)** why this ball takes a longer time to reach the ground than the steel ball.

...........................................................................................................................

...........................................................................................................................

..................................................................................................................... [1]

[Total: 17]

3 **(a)** **(i)** Define power.

.............................................................................................................................................

............................................................................................................................................. [1]

**(ii)** Mechanical power $P$ can be calculated using the formula $P = Fv$.

Use the concept of work and the definition of power to show how this formula is derived.

[2]

**(b)** The engine of a lorry provides 130 kW of power to the lorry's wheels when it is travelling at a constant speed of 25 m s$^{-1}$ along a straight horizontal road.

Show that the resistive force opposing the forward motion of the lorry is 5200 N.

[1]

**(c)** The lorry in **(b)** travels up a straight section of road that is inclined at an angle $\theta$ to the horizontal, as shown in Fig. 3.1.

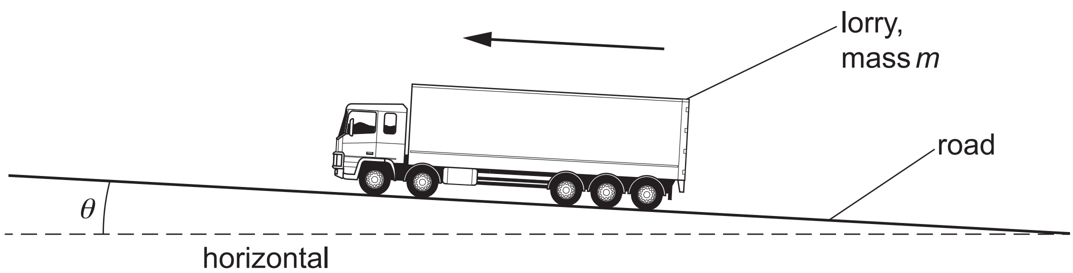



**Fig. 3.1** (not to scale)

The lorry has mass $m$ and the acceleration of free fall is $g$.

**(i)** Determine an expression, in terms of $m$, $g$ and $\theta$, for the component of the weight of the lorry that acts parallel to the surface of the road.

[1]

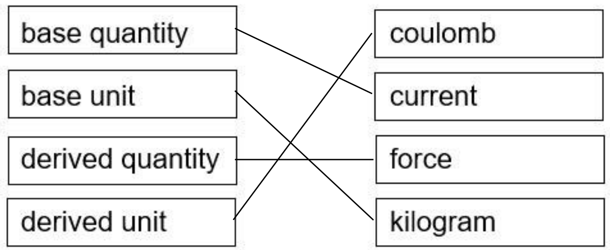
**(ii)** The total resistive force remains unchanged at 5200 N and the engine now provides greater power to maintain the speed of 25 m s$^{-1}$. The total mass $m$ of the lorry is 36 000 kg. The angle $\theta$ is 1.4°.

Determine the power, in kW, now provided by the engine.

power = .................................................... kW [3]

[Total: 8]

| Question | Answer | Marks |
|---|---|---|
| 1 | C | **1** |
| 2 | D | **1** |
| 3 | C | **1** |
| 4 | A | **1** |
| 5 | D | **1** |
| 6 | B | **1** |
| 7 | C | **1** |
| 8 | A | **1** |
| 9 | A | **1** |
| 10 | D | **1** |
| 11 | B | **1** |
| 12 | A | **1** |
| 13 | C | **1** |
| 14 | D | **1** |
| 15 | C | **1** |
| 16 | D | **1** |
| 17 | C | **1** |
| 18 | C | **1** |
| 19 | C | **1** |
| 20 | D | **1** |

| Question | Answer | Marks |
|---|---|---|
| 1(a) | <br>any two joined correctly | **C1** |
| | all four joined correctly | **A1** |
| 1(b)(i) | the measurements have a small range | **B1** |
| 1(b)(ii) | (average of the) measurements not close to the true value | **B1** |
| 1(c)(i) | percentage uncertainty = (3 + 5 + 4) / 2 | **C1** |
| | = 6% | **A1** |
| 1(c)(ii) | absolute uncertainty = (6 / 100) × 15.0<br>= $0.9\ \mathrm{m\,s^{-1}}$ | **A1** |

| Question | Answer | Marks |
|---|---|---|
| 2(a)(i) | $t = 1.8 / 4.9$<br>$= 0.37$ s | **A1** |
| 2(a)(ii) | $v = u + at$<br>$= 9.81 \times 0.37$ | **C1** |
| | $= 3.6$ m s$^{-1}$ | **A1** |
| 2(a)(iii) | $v^2 = 3.6^2 + 4.9^2$ | **C1** |
| | $v = 6.1$ m s$^{-1}$ | **A1** |
| | $\theta = \tan^{-1}(3.6 / 4.9)$<br>$= 36°$ | **A1** |
| 2(b)(i) | $\rho = m / V$ | **C1** |
| | $V = \frac{4}{3}\pi r^3$ | **C1** |
| | $\rho = 0.017 / [\frac{4}{3}\pi \times (0.016 / 2)^3]$<br>$= 7900$ kg m$^{-3}$ | **A1** |
| 2(b)(ii) | ($E$ =) $\frac{1}{2}mv^2$ | **C1** |
| | ($E$ =) $\frac{1}{2} \times 0.017 \times 4.9^2 = 0.20$ (J) | **A1** |

| Question | Answer | Marks |
|---|---|---|
| 2(b)(iii) | $k = F / x$ **or** $k$ = gradient | **C1** |
| | e.g. $k = 6.4 / 10 \times 10^{-2}$<br><br>$= 64\ \text{N m}^{-1}$ (*allow 63–65 N m*$^{-1}$) | **A1** |
| 2(b)(iv) | $E = \frac{1}{2}kx^2$<br>**or**<br>$E = \frac{1}{2}Fx$ **and** $F = kx$ | **C1** |
| | $x_0 = [(2 \times 0.20) / 64]^{0.5}$<br><br>$= 0.079$ m or 0.080 m | **A1** |
| 2(c)(i) | same elastic potential energy / same (initial) kinetic energy and (polystyrene ball has) smaller mass (so greater speed)<br>**or**<br>same (average) force and (polystyrene ball has) smaller mass, (so greater average acceleration so greater speed) | **B1** |
| 2(c)(ii) | (for the polystyrene ball there is)<br>less (average vertical) acceleration / smaller (average vertical component of) resultant force<br>(so takes longer time to reach ground) | **B1** |

| Question | Answer | Marks |
|---|---|---|
| 3(a)(i) | work done per unit time | **B1** |
| 3(a)(ii) | $W = Fs$ | **B1** |
| | $P = Fs / t$ <u>and</u> (so) $P = Fv$ | **B1** |
| 3(b) | ($F$ =) $130 \times 10^3 / 25 = 5200$ (N) | **A1** |
| 3(c)(i) | (component of weight =) $mg \sin\theta$ | **A1** |
| 3(c)(ii) | $F$ (along slope due to weight) $= 36\,000 \times 9.81 \times \sin 1.4°$<br>( = 8600 N) | **C1** |
| | (total) $F = 5200 + 36\,000 \times 9.81 \times \sin 1.4°$<br>(= 13 800 N) | **C1** |
| | $P = 13\,800 \times 25$<br>$= 350 \times 10^3$ (W)<br>$= 350$ kW | **A1** |