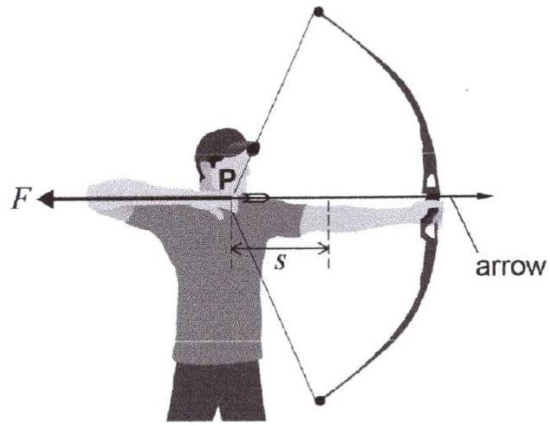
Force, energy and momentum – AS Physics

1. No.4

0 4 **Figure 4** shows an archer using a bow in a competition.

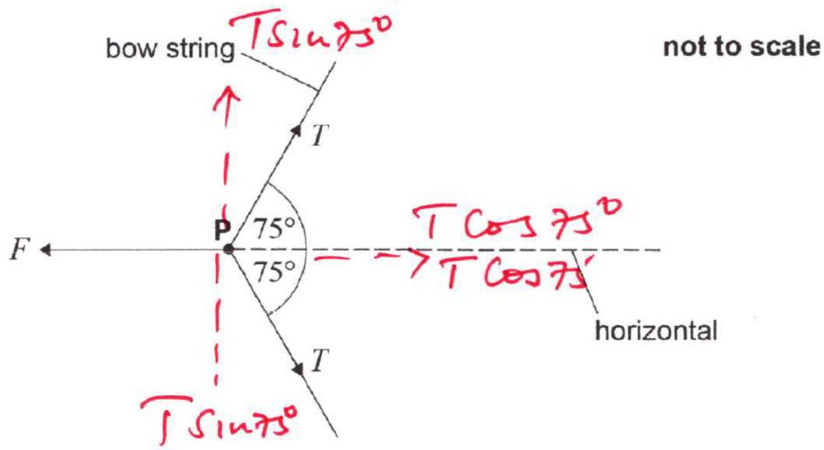
Figure 4



The archer exerts a force F to pull point **P** on the string back through a distance s.

0 4 . 1 **Figure 5** is a simplified diagram of the bow string showing the forces acting on **P**. The tension in the string is T and the string makes an angle of 75° to the horizontal.

Figure 5



In **Figure 5**, F is 160 N and **P** is in equilibrium.

Calculate T. $F = 2T\cos 75^\circ$

[2 marks]

$160 = 2T\cos 75$

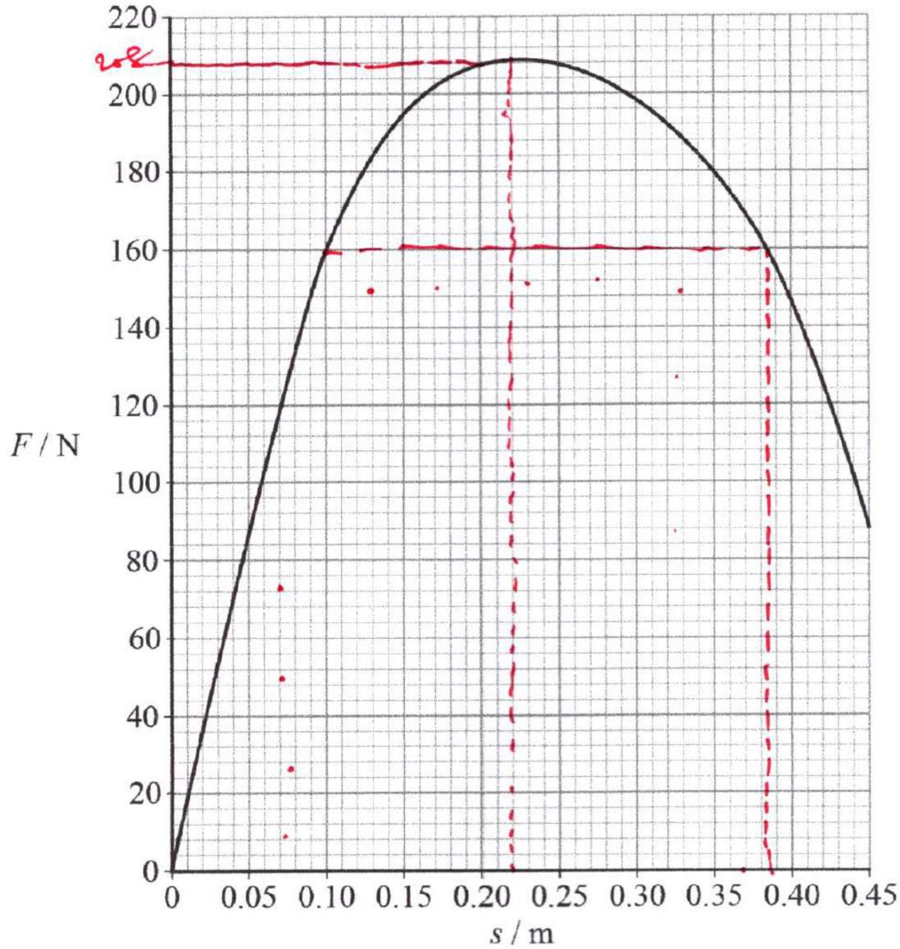
$T = \dfrac{160}{2\cos 75}$

$T = 309\,\text{N}$

$T =$ 309 N

The bow is designed so that F varies with s as shown in **Figure 6**.

Figure 6



0 4 . 2 An arrow of mass $21\ \mathrm{g}$ is placed in the bow.

The archer pulls **P** back by a distance s of $0.22\ \mathrm{m}$ and then releases the arrow in a horizontal direction.

Assume that there are no resistive forces acting on the arrow as it is released.

Determine the initial horizontal acceleration of the arrow.

[2 marks]

When $s = 0.22$, $F = 208$

then

$F = ma$

$a = \frac{F}{m} = \frac{208}{21 \times 10^{-3}} = 9905$

initial horizontal acceleration = 9905 $\mathrm{m\ s^{-2}}$

The arrow is replaced with a different arrow of mass m.
The archer pulls **P** back by a distance s_r so that the energy stored in the bow is 64 J and F is 160 N.

0 4 . 3 Deduce s_r.

[2 marks]

We are given that $F = 160$ N.

Looking at **Figure 6** from the previous graph:

At $F = 160$ N, there are two possible values for s: 0.10 m and 0.385 m.

Energy stored in the bow equals the **area under the** F–s **graph** from 0 to s_r.

Counting/estimating the area up to $s = 0.385$ m gives approximately 64 J.

0 4 . 4 The bow has an efficiency of 0.82

The arrow leaves the bow in a horizontal direction with a velocity of 190 km h^{-1}.

Calculate m.

$190 \times \frac{5}{18} = 52.8$ m/s

[3 marks]

Energy transfere $= 0.82 \times 64$

$= 52.48$ J

$E = \frac{1}{2}mv^2$

$m = \frac{2E}{v^2}$

$m = \frac{2 \times 52.48}{52.8^2}$

$m = 0.038$ kg

$m =$ 0.038 kg

2. No.5

0 5 **Figure 7** shows a robotic helicopter that is used on Mars. The helicopter is powered by a battery. Before each flight, the battery is charged by a solar panel.

Figure 7

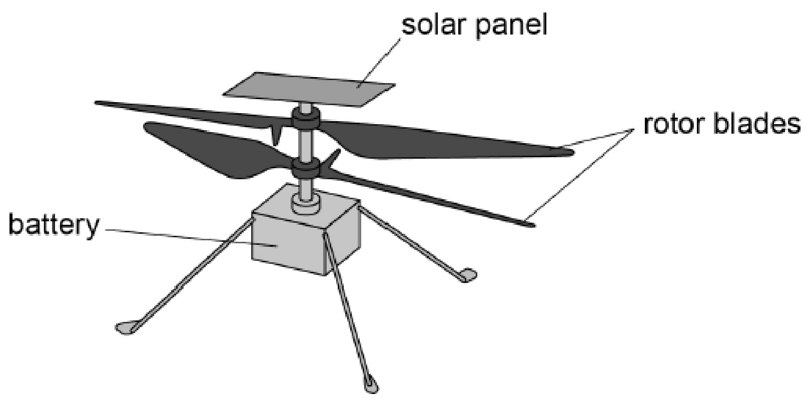
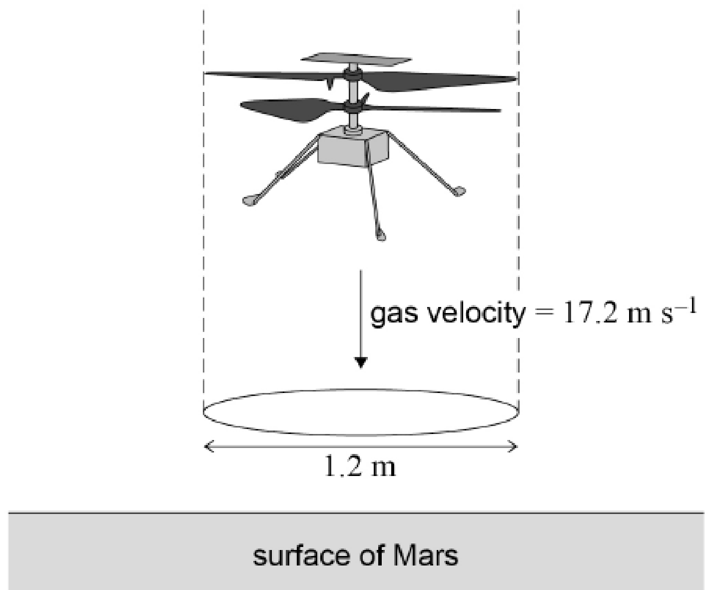


Figure 8 shows the helicopter hovering at a constant height above the surface of Mars. The rotor blades move a column of atmospheric gas vertically downwards at a velocity of $17.2\ \mathrm{m\ s^{-1}}$. The diameter of this column is $1.2\ \mathrm{m}$.

Figure 8



0 5 . 1 The gas moved by the rotor blades has a density of $0.020\ \mathrm{kg\ m^{-3}}$.

Show that the helicopter moves approximately $0.4\ \mathrm{kg}$ of gas every second.

[3 marks]

$$V = \frac{\pi d^2}{4} \times h$$

$$= \frac{\pi \times 1.2^2}{4} \times 17.2$$

$$= 19.453\ m^3$$

But

$$\rho = \frac{m}{V}$$

So

$$m = \rho \times V$$

$$= 0.02 \times 19.43 = 0.389\ kg$$

The movement of the gas creates an upward force on the helicopter. This upward force enables the helicopter to hover at a constant height.

The gravitational field strength on Mars is $3.72\ \mathrm{N\ kg^{-1}}$.

0 5 . 2 Calculate the mass of the helicopter.

[3 marks]

$$F = ma \text{ or } \frac{m \times v}{t} = \frac{0.389 \times 17.2}{1} = 6.69\ N$$

Also

Upthrust = Weight if not moving up (No acceleration

$$W = mg$$

$$\frac{6.69}{3.72} = \frac{m \times 3.72}{3.72}$$

$$m = 1.8$$

mass = 1.8 kg

0 5 . 3 The battery stores $0.035\ \text{kW h}$ of energy before a flight.
The flight lasts for $39\ \text{s}$.
The battery has a power output of $340\ \text{W}$ during the flight.

Determine the percentage of the initial energy stored in the battery that is transferred during the flight.

[2 marks]

$E = Pt$
$= 340 \times 39$
$= 13260\ \text{J}$

$E = 0.035 \times 10^3 \times 3600$
$= 126{,}000$ stored

% Energy transfer $= \dfrac{13260}{126\,000}$
$= 10.5\%$

percentage = 11 %

0 5 . 4 The helicopter has a maximum flight time of a few minutes due to the limited amount of energy stored in the battery. The battery accounts for about 15% of the helicopter's mass.

A student suggests that adding another identical battery that doubles the energy available to the helicopter would double its flight time.

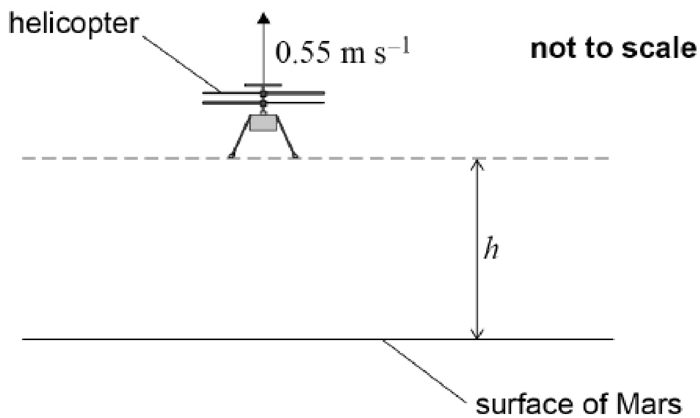
Deduce without calculation whether the student's suggestion is correct.

[3 marks]

Incorrect.
This increases the weight.
The atmosphere is too thin and can't displace sufficient mass of gass per second and so can't creat sufficient lift force to take off.

Figure 9 shows a simplified side view of the helicopter moving vertically upwards with a speed of 0.55 m s^{-1}.
At the instant shown, the helicopter is at a height h and the blades stop rotating.

Figure 9



The gravitational field strength on Mars is 3.72 N kg^{-1}.

The weight of the helicopter is the only force acting on it when the blades stop rotating. Drag forces on the helicopter are negligible as it rises to a maximum height and then falls back to the surface.

0 5 . 5 Calculate the time taken for the helicopter to reach its maximum height from the instant the blades stop rotating.

[2 marks]

$v = u + at$

$t = \frac{v-u}{a} = \frac{0 - 0.55}{3.72}$

$t = 0.1478$ sec

$t = 0.15$ sec

time = 0.15 s

0 5 . 6 When the helicopter makes contact with the surface it has a velocity of 2.2 m s^{-1}.

Calculate h.

[2 marks]

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

$2.2^2 = 0^2 + 2 \times 3.72 \times s$

$\frac{2.2^2}{7.4} = \frac{7.4 s}{7.4}$

$s = 0.65$ m

Above h;

$s = ut - \frac{1}{2}gt^2$

$= (0.55 \times 0.15) - (0.15^2 \times 0.5 \times 3.72)$

$= 0.041$

$h = 0.65 - 0.041$

$h = 0.61$

h = 0.61 m

0 5 . 7 A student suggests that the acceleration of the helicopter is constant from the instant the blades stop rotating until the helicopter makes contact with the surface.

Discuss this suggestion with reference to an appropriate Newton's law of motion.

[2 marks]

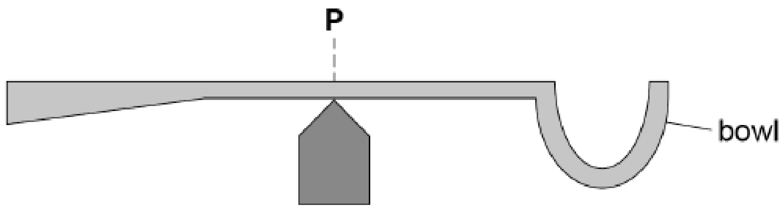
Weight is the only force acting on the helicopter. Due to 2nd Law, the acceleration acts in the same direction as the weight (downwards) so the student is correct.

3. June/2023/Paper_7407/2/No.3

0 3 **Figure 9** shows a spoon used to measure the mass of food.

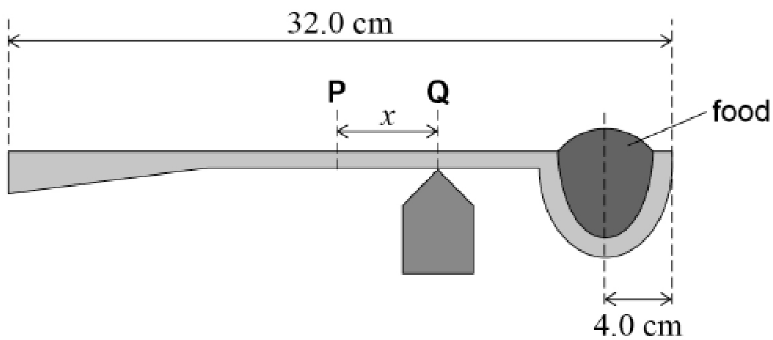
The empty spoon balances when a pivot is placed under a point **P** halfway along the spoon.

Figure 9



The spoon tilts when food of mass M is placed in the bowl. The spoon is rebalanced by moving the pivot a distance x to the right of **P**. The new position of the pivot is under point **Q** in **Figure 10**.

Figure 10



The total length of the spoon is 32.0 cm. The weight of the food acts through a line at a distance of 4.0 cm from the right-hand edge of the spoon.

0 3 . 1 Explain why the spoon in **Figure 10** is balanced when the pivot is at **Q**.

[2 marks]

- Moments due to weight of spoon from Centre of mass and food are equal
- Centre of mass of system is at Q.

0 3 . 2 The empty spoon has mass m.

Show that, for the arrangement in **Figure 10**,

spoon

$$\text{food} \quad \frac{m}{M} = \frac{(12.0 - x)}{x}$$

[2 marks]

Moment of spoon = Moment of food

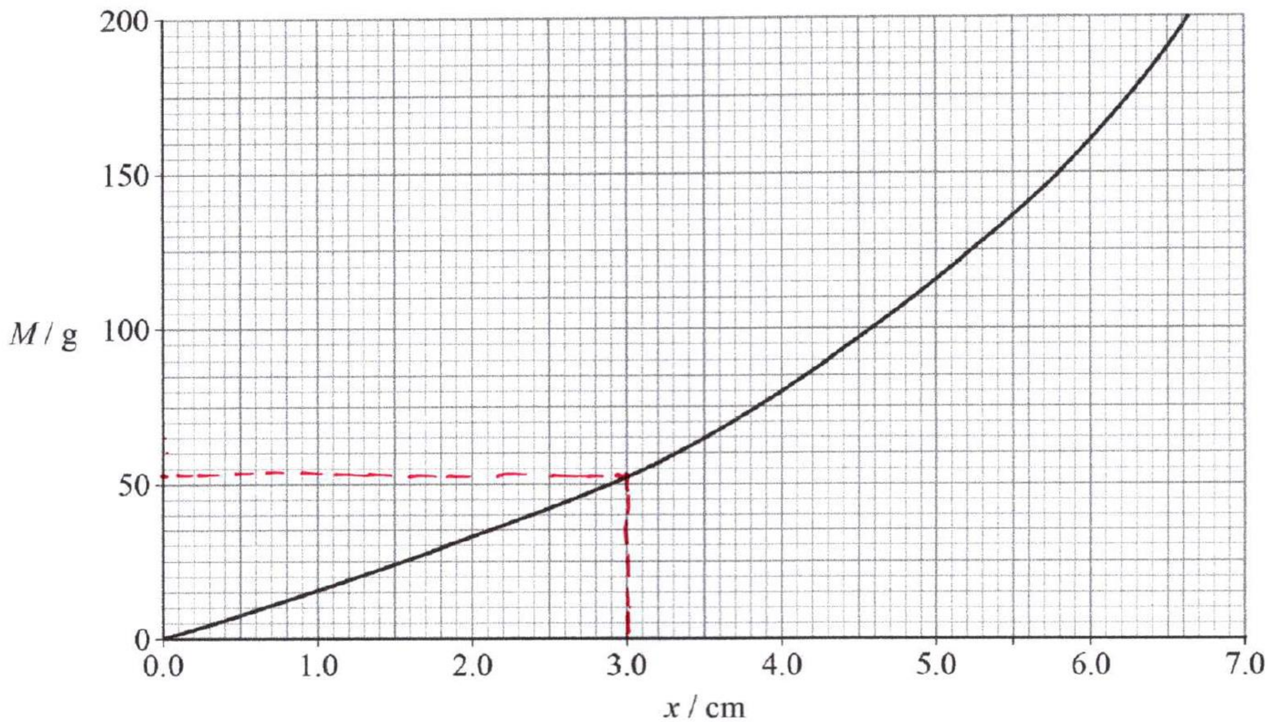
$mgx = Mg(16 - 4 - x)$

$m\cancel{g}x = M\cancel{g}(12 - x)$

So $\frac{m}{M} = \frac{12 - x}{x}$

0 3 . 3 **Figure 11** shows how x varies with M.

Figure 11



Determine, using **Figure 11**, the weight of the empty spoon.

[3 marks]

$m = \frac{(12 - x)M}{x}$

When $x = 3$ cm, $M = 53$

$m = \frac{(12 - 3)}{3} \times 53$

$= 3 \times 53 = 159$ g

$W = mg$

$= \frac{159}{1000} \times 9.81$

$= 1.55979$

$= 1.56$ N

weight = 1.6 N

0 3 . 4 A scale, in grams, is marked on the spoon between **P** and the bowl. **Figure 11** is used to calibrate this scale in intervals of 25 g.

M can be measured by balancing the spoon. The value is read from the point of the scale directly above the pivot.

State and explain how the uncertainty in the value read from the scale changes as M increases.

[3 marks]

- As M increases, Δx increases less.
- The gap decreases and therefore the percentage uncertainty increases.

4. June/2023/Paper_7407/2/No.8

An object of mass 0.20 kg moves with an initial velocity u. It collides with a stationary object of mass 0.30 kg.

The objects stick together when they collide.
No external forces act on the objects.

What is the final velocity of the two objects after the collision?

[1 mark]

A $0.40u$ ☒

B $0.67u$ ☐

C $1.5u$ ☐

D $2.5u$ ☐

$P_{Before} = P_{After}$

$\frac{0.2u}{0.5} = \frac{0.5v}{0.5}$

$v = \frac{2}{5}u$ or $0.4u$

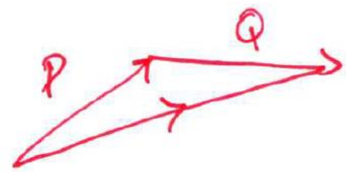
5. June/2023/Paper_7407/2/No.9

P and **Q** represent displacements.

What is the resultant displacement when **P** and **Q** are added?

[1 mark]

A 



B 

C 

D 

6. June/2023/Paper_7407/2/No.10

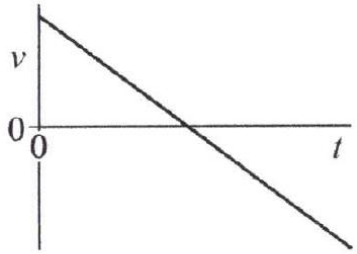
A girl kicks a football vertically upwards at time $t = 0$

Air resistance is negligible.

What is the variation of the vertical component of velocity v of the football with t until it reaches the ground?

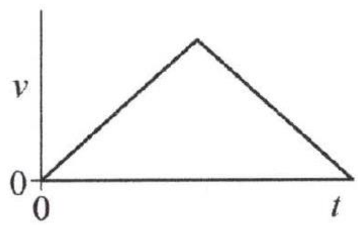
[1 mark]

A



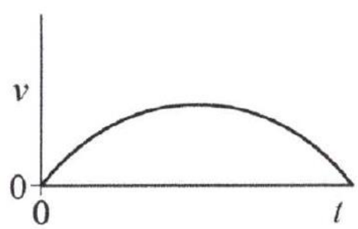
☒

B



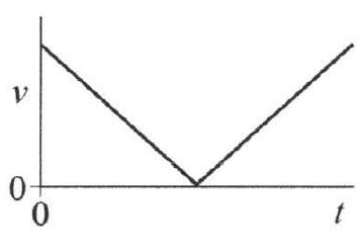
☐

C



☐

D



☐

Acceleration is always constant (gravity) so constant gradient. (Air resistance is negligible)

7. June/2023/Paper_7407/2/No.26

A ball is dropped from a height h. The ball hits the ground with a velocity v.

The ball is now dropped from a height of $2h$.
Air resistance is negligible.

What is the velocity at which the ball hits the ground?

[1 mark]

A v ☐

B $\sqrt{2v}$ ☐

C $v\sqrt{2}$ ☒

D $2v$ ☐

s
u – 0
v –
a – Constant
t

$v^2 = \cancel{u^2}^{\,0} + 2as$

$v^2 = 2as$ (a = constant

$v^2 \propto s$ so $v \propto \sqrt{s}$

So

$v \propto \sqrt{2s}$

$v \propto \sqrt{2}\,v$

Turn over for the next question

8. June/2023/Paper_7407/2/No.33

A pellet of mass 25 g travelling horizontally at 40 m s^{-1} enters a fixed wooden block. The pellet stops after travelling a horizontal distance of 2.5 cm in the block.

What is the average resistive force acting on the pellet?

[1 mark]

A 20 N ☐

B 800 N ☒

C 1600 N ☐

D 8000 N ☐

m = 0.025 kg
v = 40 m/s
d = 0.025

$W = F \times d = \frac{1}{2}mv^2$

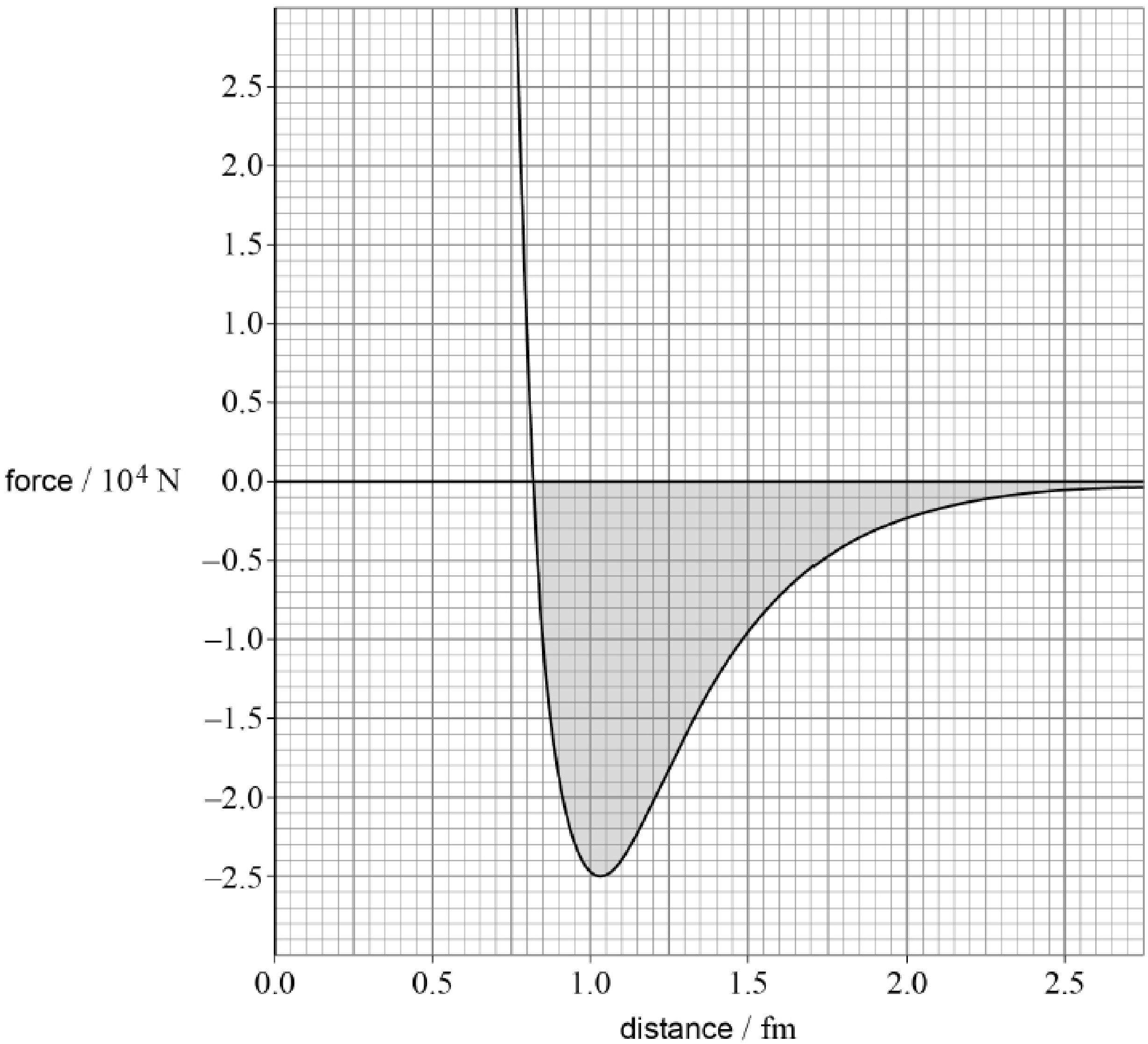
$F = \frac{0.5 \times mv^2}{d}$

$= \frac{0.025 \times 40^2}{2 \times 0.025}$

$= 800\,N$

9. June/2023/Paper_7407/2/No.34

The graph shows the variation of force with distance between a proton and a neutron.



The shaded area represents

[1 mark]

Area = F×d
So
has to be
work done or
Potential energy

A acceleration. ☐

B impulse. ☐

C rate of change of kinetic energy. ☐

D work done. ☒