Newton’s Law of Motion and Momentum

1. An object **P** is travelling to the right with a momentum of 40 kg m s^{-1}. It collides with another object **Q** travelling to the left along the same path.

The final momentum of **P** is 10 kg m s^{-1} to the right.

What is the change in the momentum of **Q**?

A 0 $kgms^{-1}$
B 10 $kgms^{-1}$
C 30 $kgms^{-1}$
D 50 $kgms^{-1}$

Your answer [1]

2. A ball, initially at rest, is struck by a hockey stick. It leaves the hockey stick at speed *v*.

Which quantity, together with the mass of the ball, can be used to determine *v*?

A The time of the impact.
B The weight of the hockey stick.
C The impulse of the force.
D The final momentum of the hockey stick.

Your answer [1]

3.

State *Newton’s second law of motion*

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[1]

4. State *Newton's second law.*

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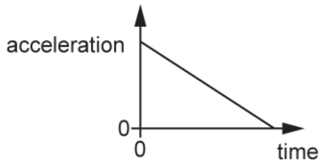
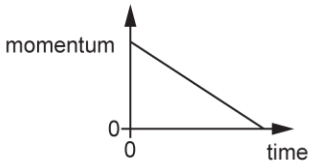
[1]

5. Which one of the graphs below can be used to determine the impulse of a force from the area under the graph?

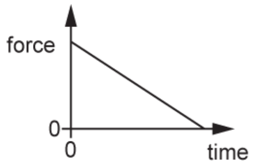
A



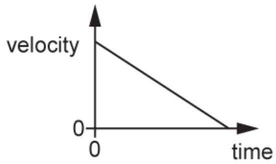
B



C



D



Your answer [ ] **[1]**

6. The de Broglie wavelength of a proton is 160 pm.

The kinetic energy of this proton is doubled.

What is the de Broglie wavelength of the proton now?

A 80 pm
B 110 pm
C 230 pm
D 320 pm

Your answer [ ] **[1]**

7. A trolley **M** collides head-on with a trolley **L**. The mass of trolley **M** is greater than the mass of trolley **L**. The trolleys join together after the collision.

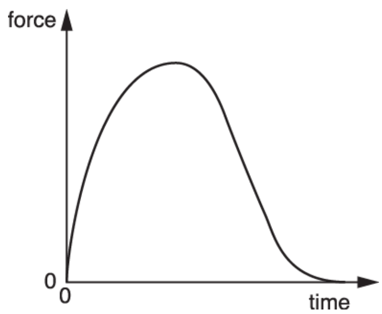
Which statement is correct?

A The momentum of each trolley is conserved.
B Trolley **M** experiences a greater force than trolley **L** during the collision.
C The total force acting on the two-trolley system during the collision is zero.
D Kinetic energy is conserved.

Your answer ☐

[1]

8. The graph shows the resultant force on a football as it is kicked.



Which of the following graphs relating to this kick would have the same shape as the graph above?

A acceleration of the ball against time
B kinetic energy of the ball against time
C momentum of the ball against time
D velocity of the ball against time

Your answer ☐

[1]

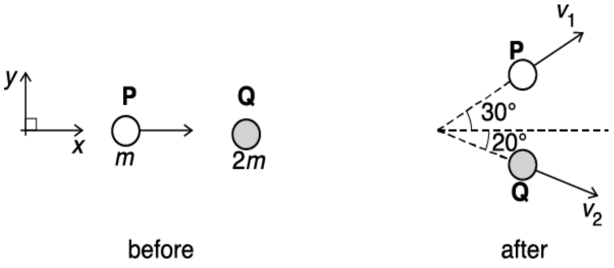
9. What is a reasonable estimate for the momentum of a car travelling at 10 m s^{-1}?

A 10^2 kg m s^{-1}
B 10^4 kg m s^{-1}
C 10^6 kg m s^{-1}
D 10^8 kg m s^{-1}

Your answer ☐

[1]

10. A ball **P** of mass *m* has a velocity in the positive *x*-direction. It makes a collision with a stationary ball **Q** of mass 2*m.* After the collision, the ball **P** has velocity v_1, ball **Q** has velocity v_2 and the balls travel in the directions shown in the diagram below.



After the collision, the total momentum of the balls in the *x*-direction is p_x and the total momentum in the *y*-direction is p_y.

Which row is correct for p_x and p_y?

	p_x	p_y
A	$2mv_2 \cos 20° + mv_1 \cos 30°$	0
B	$2mv_2 \sin 20° + mv_1 \sin 30°$	0
C	$2mv_2 \cos 20° + mv_1 \cos 30°$	$2mv_2 \sin 30° + mv_1 \sin 20°$
D	$2mv_2 \sin 20° + mv_1 \sin 30°$	$2mv_2 \cos 30° + mv_1 \cos 20°$

Your answer

[1]

11. The de Broglie wavelength of an electron after being accelerated through a potential difference (p.d.) *V* is λ_0. The accelerating p.d. is now doubled.

What is the new de Broglie wavelength of the electron in terms of λ_0?

A $\frac{\lambda_0}{2}$

B $\frac{\lambda_0}{\sqrt{2}}$

C $\sqrt{2}\lambda_0$

D $2\lambda_0$

Your answer

[1]

12. Which physical quantity has the same base units as energy?

A. moment
B. momentum
C. force
D. pressure

Your answer

[1]

13. A puck of mass 0.16 kg is sliding on ice with a constant velocity of 11.0 m s^{-1}. A hockey stick exerts a force on the puck, for a short period of time, in the **opposite** direction to the velocity of the puck. The momentum of the puck changes by 2.0 kg m s^{-1}.

Ignore friction.

What is the speed of the puck when it leaves the hockey stick?

A 1.5 m s^{-1}

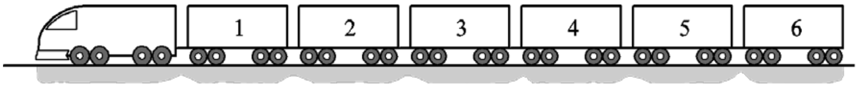
B 3.8 m s^{-1}

C 12.5 m s^{-1}

D 23.5 m s^{-1}

Your answer ☐ **[1]**

14. A train consisting of six trucks each of mass 6.0×10^4 kg is pulled at a constant speed by a locomotive of mass 24×10^4 kg along a straight horizontal track. The horizontal force resisting the motion of each truck is 4000 N.



The coupling between trucks 2 and 3 snaps.

What is the initial acceleration of the locomotive?

A. 0.022 ms^{-2}
B. 0.044 ms^{-2}
C. 0.067 ms^{-2}
D. 0.133 ms^{-2}

Your answer ☐

[1]

15. A javelin thrower exerts a force of 100 N on a javelin for a time of 0.30 s.
The javelin has a mass of 0.80 kg.

What is the rate of change of the momentum of the javelin?

A 24 kg ms^{-2}

B 30 kg ms^{-2}

C 100 kg ms^{-2}

D 125 kg ms^{-2}

Your answer ☐ **[1]**

16. The momentum of an object moving to the left is 28 kg m s^{-1}.
A force of magnitude 3.5 N acts on the object to the right for a time of 2.0 s.

What is the **change** in the momentum of the object?

A 7.0 kg m s^{-1}
B 21 kg m s^{-1}
C 28 kg m s^{-1}
D 35 kg m s^{-1}

Your answer ☐ **[1]**

17. A proton has kinetic energy 8.00×10^{-17} J.

Which is the correct expression for the de Broglie wavelength λ of the proton?

A $\lambda = \frac{6.63 \times 10^{-34}}{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}$

B $\lambda = \frac{6.63 \times 10^{-34}}{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}$

C $\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}}$

D $\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}}$

Your answer ☐ **[1]**

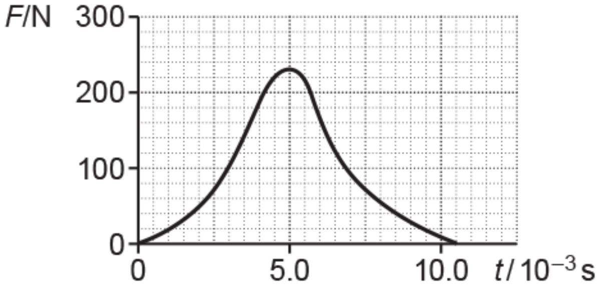
18. A girl standing on a bridge throws a coin upwards with a vertical velocity of 5.0 m s^{-1}. It hits the water below the bridge after 1.5 seconds. Assuming that the effects of air resistance are negligible, what was the initial height of the coin above the water?

A. 1.3 m
B. 3.5 m
C. 7.5 m
D. 18.5 m

Your answer ☐

[1]

19. The variation with time t of the force *F* acting on a ball is shown below.



Which statement is **not** correct?

A The area under the graph is equal to the work done by the force *F*.
B The ball has maximum acceleration at $t = 5.0 \times 10^{-3}$ s.
C The area under the graph is equal to impulse.
D The area under the graph has units kg m s^{-1}.

Your answer [1]

20. A flat, circular disc moves across a horizontal table with negligible friction.
Fig. 19.1 shows the disc **X** of mass 50 g subject to a force *F*. **Fig. 19.2** shows the variation of the force *F* with time *t*.

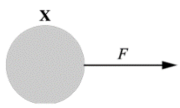


Fig. 19.1

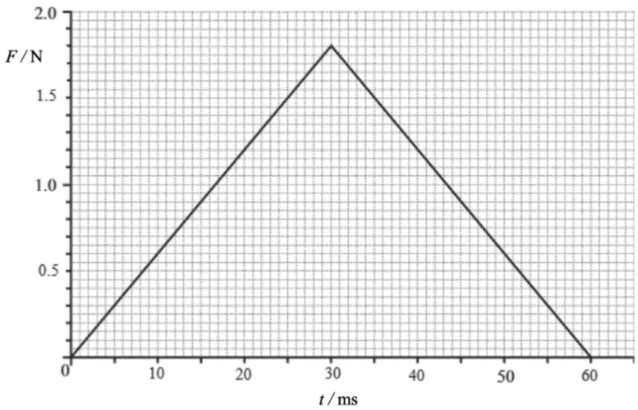


Fig. 19.2

The disc is initially at rest. Calculate the change in velocity of the disc caused by *F*.

change in velocity = ... ms^{-1} **[2]**

21. Two objects collide. The collision is perfectly elastic.

State **two** quantities that are conserved in this type of collision.

1

2

[2]

22.

Use the equations for momentum and kinetic energy to derive an expression for the kinetic energy E_k of a particle in terms of its momentum *p* and mass *m*.

[2]

23.

A massive ball is released from rest above the ground.
According to a student, the principle of conservation of momentum is violated because the ball gains momentum as it falls.
Explain why the student's observation is incomplete and discuss how momentum is conserved in this situation.

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[2]

24. Fig. 21 shows the drum of a washing machine.

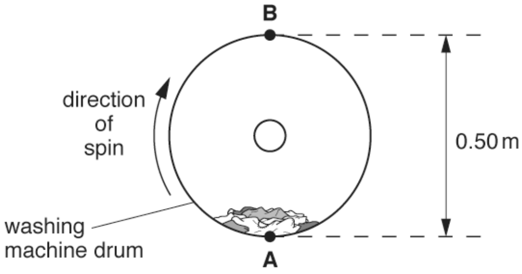

Fig. 21

The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

When the drum is at rest, the weight of the clothes is equal to the normal contact force on the clothes at point **A**.

Explain why these two forces are not an example of Newton's Third Law of motion.

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[2]

25 (a). A ball of mass 160 g is at rest. The ball is hit with a stick.
Fig. 19.1 shows the variation of the force *F* exerted by the stick on the ball with time *t*.

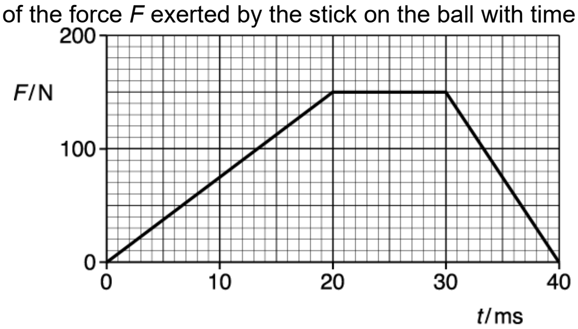

Fig. 19.1

Use Fig. 19.1 to determine the **final** velocity *v* of the ball as it leaves the stick.

v = ... $m\ s^{-1}$ **[3]**

(b). Sketch a graph on Fig. 19.2 to show the variation of the velocity of the ball between t = 30 ms and t = 40 ms. You do not need to show any values on the vertical axis.

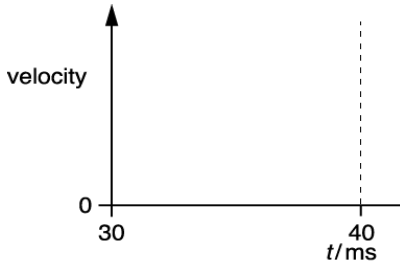

Fig. 19.2

[2]

(c). After time t = 40 ms, the ball travels along the horizontal ground.
The ball experiences a constant friction of 0.80 N.

Calculate the time T for it to come to a stop.

T = ... s **[2]**

26 (a). A bicycle manufacturer carries out tests on the braking system of their new model.
A cyclist on this new bicycle travels at a constant initial speed *U*.
The cyclist applies the brakes at time t = 0 and the bicycle comes to a stop at time t = 2.0 s.

Fig. 20.1 shows the variation of the braking force *F* on the bicycle with time *t*.

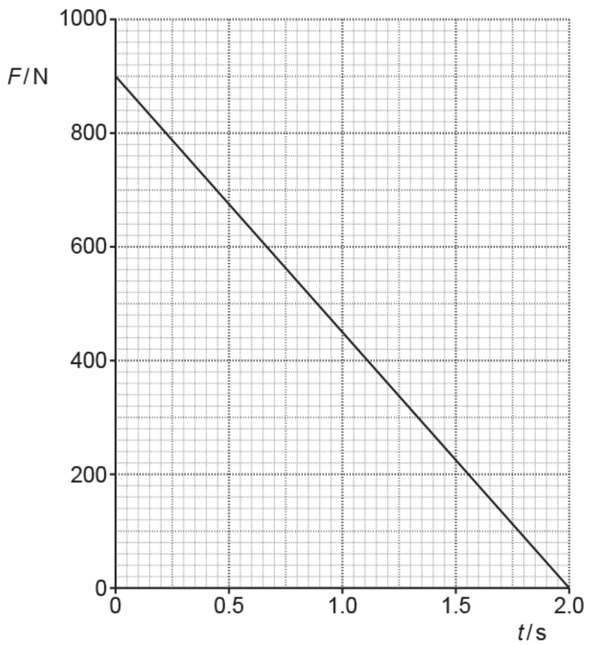

Fig. 20.1

Use Newton's second law of motion to explain the physical quantity represented by the area under the graph shown in Fig. 20.1.

[2]

(b). The total mass of cyclist and bicycle is 71 kg.
Use Fig. 20.1 to calculate the initial speed *U*.

U = ... m s^{-1} **[2]**

(c). Complete Fig. 20.2 to show the variation of the speed of the bicycle from t = 0 to t = 2.0 s.

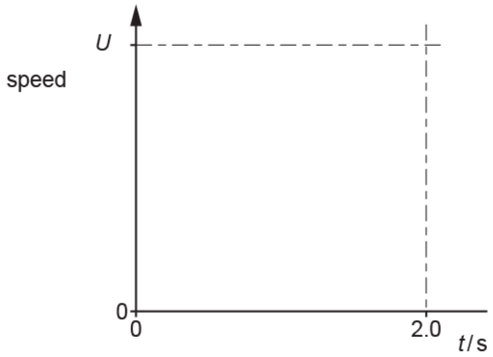

Fig. 20.2

[2]

27(a). A metal ball is released from rest. It falls vertically towards the ground.
Fig. 22 shows the variation with time t of the displacement s of the ball.

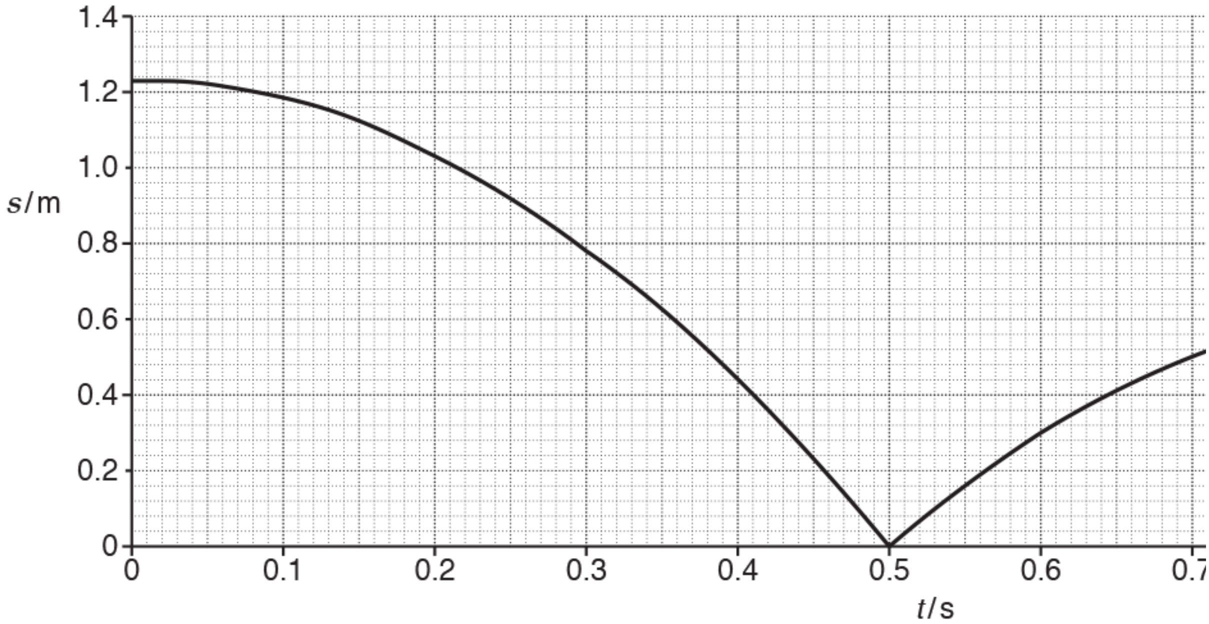

Fig. 22

Air resistance has negligible effect on the motion of the ball.

The ball hits the ground at t = 0.50 s.
During the collision, the ball is in contact with the ground for a time of 1.8 ms.
The mass of the ball is 56 g.

Use an equation of motion to show that the speed of the ball is 4.9 ms^{-1} just before it hits the ground.

[2]

(b). Draw a suitable tangent to the curve in Fig. 22 and show that the **rebound** speed of the ball is about 3.5 ms^{-1}.

[3]

(c). Calculate the average resultant force acting on the ball during the collision.

force = ... N **[2]**

28. Fig. 21.1 shows a ball at **rest** on a horizontal table.

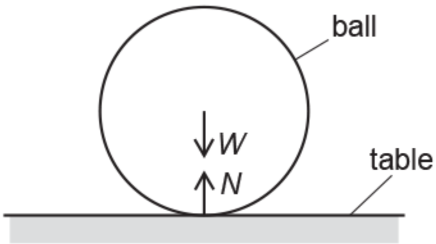

Fig. 21.1

The weight of the ball is *W* and the normal contact force on the ball is *N*.

i. According to Newton's third law of motion, *W* is one of the forces in a pair of equal and opposite forces.

Name the object that experiences a force of magnitude *W* but in the opposite direction to *W*.

---

[1]

ii. According to a student, $W = N$ is a consequence of Newton's third law of motion.

State why this is incorrect.

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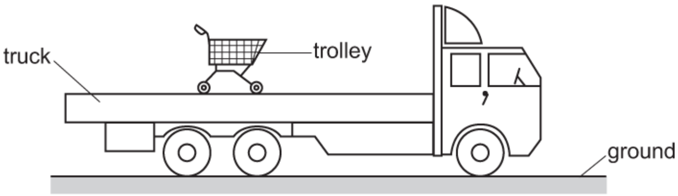
[1]

29. The diagram below shows a trolley loaded onto the back of a truck.



The truck suddenly accelerates. The trolley is observed to remain in the same position relative to the ground.

Explain the lack of motion of the trolley in terms of one of Newton's laws of motion.

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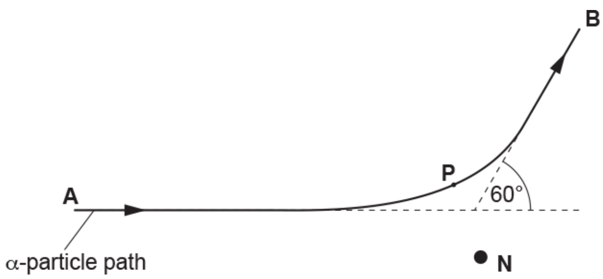
[2]

30. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.

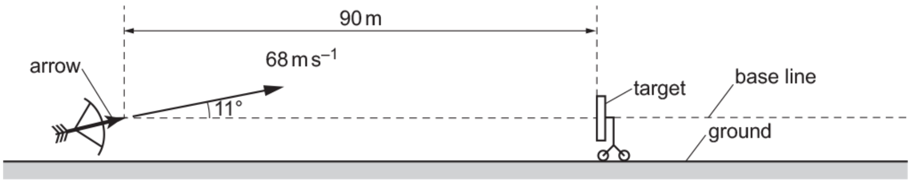


The initial kinetic energy of each α-particle is 5.0 MeV.

Show that the magnitude of the initial momentum of each α-particle is about 10^{-19} kg m s^{-1}. Take the mass of the α-particle to be 6.6×10^{-27} kg.

[3]

31 (a). An archer fires an arrow towards a target as shown below.



The diagram is **not** drawn to scale.

The centre of the target is at the same height as the initial position of the arrow.
The target is a distance of 90 m from the arrow.
The arrow has an initial velocity of 68 m s^{-1} and is fired at an angle of 11° to the horizontal.

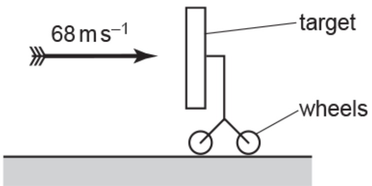
Air resistance has negligible effect on the motion of the arrow.

The arrow misses the target.

Calculate the horizontal distance, measured along the base line, by which the arrow misses the target.

horizontal distance = ... m **[3]**

(b). The arrow is now fired horizontally at 68 m s^{-1} into the target at very close range.



The arrow sticks into the target. The collision between the arrow and the target is inelastic.

i. Explain what is meant by an **inelastic collision** .

[1]

ii. The target is mounted on wheels. The target has a much larger mass than the mass of the arrow. Using ideas of momentum, explain the velocity of the target immediately after the arrow sticks into the target.

[2]

32 (a). The ball hits a wall with a speed of 11 m s^{-1}. It rebounds from the wall along its initial path with a speed of 6.0 m s^{-1}. The impact lasts for 0.18 s.

Calculate the mean force exerted by the ball on the wall.

mean force = ... N **[3]**

(b). A sports manufacturer is testing the quality of one of their footballs.

Fig. 3.1 shows how the force *F* applied to a football varies with time *t* whilst it is being kicked horizontally. The ball is initially at rest.

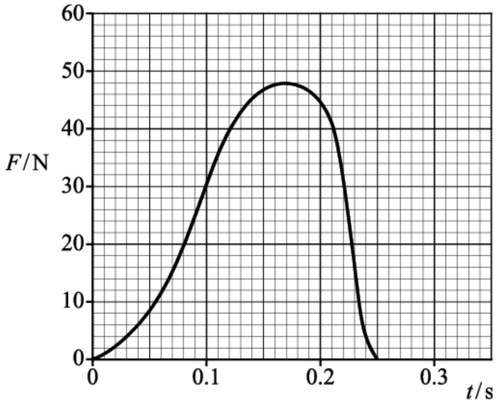


Fig. 3.1

i. Use the graph to find:

1. the maximum force applied to the ball .... N

2. the time the boot is in contact with the ball .... s.

[1]

ii. The mean force multiplied by the time of contact is called the impulse delivered to the ball. The impulse delivered to the ball is about 6.5 N s.

Explain how you would use the graph to show that the impulse has this value.

---

[2]

(c). The mass of the ball is 0.60 kg. Use your answers in **(a)** to calculate

i. the maximum acceleration of the ball

acceleration = ... m s^{-2} **[2]**

ii. the final speed of the ball.

speed = ... m s^{-1} **[2]**

33. The diagram below shows a person on a horizontal skateboard holding a heavy ball.

The person is initially stationary.
The person throws the ball horizontally to the right.

Describe and explain the motion of the person on the skateboard **immediately** after the ball is thrown.

----

[3]

34. A hydrogen atom travelling at 500 m s^{-1} makes a head-on collision with a stationary carbon atom. The collision is perfectly elastic. After the collision the hydrogen atom bounces back with a speed of 420 m s^{-1}. Fig. 24.2 shows the atoms before and after the collision.

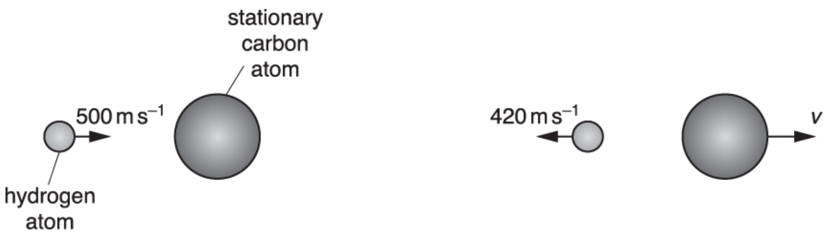


Fig. 24.2

The mass of the hydrogen atom is 1.7×10^{-27} kg and the mass of the carbon atom is 2.0×10^{-26} kg. Calculate the speed *v*of the carbon atom after the collision.

v = ... m s^{-1} **[3]**

35. A golf ball initially at rest is hit by a golf club. A data-logger records the variation of force *F* acting on the ball with time *t*, as shown in **Fig. 3.2**.

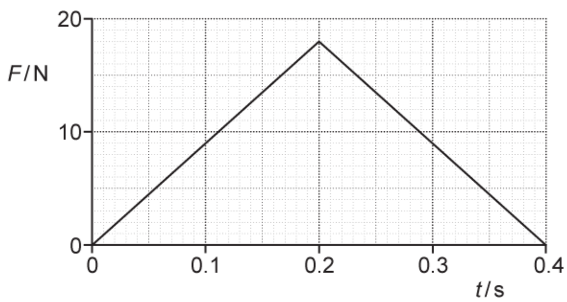


Fig. 3.2

The golf ball has a mass of 0.045 kg.

Calculate the speed *v* at which the ball leaves the club.

v = ... ms^{-1} **[3]**

36. A comet makes an inelastic collision with a small asteroid in space.

i. State **two** physical quantities conserved in this collision.

1

2

[1]

ii. Fig. 24.1 shows how the force F acting on the **comet** varies with time t during the collision.

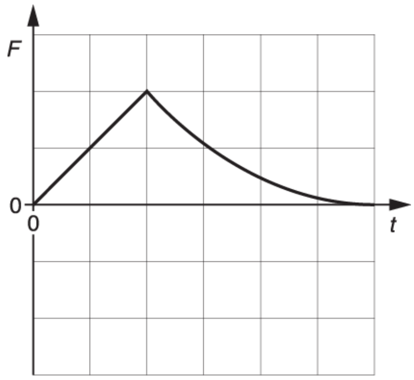


Fig. 24.1

Describe and explain how the force acting on the **asteroid** varies with time during this collision. You may sketch a suitable graph on **Fig. 24.1** to support your answer.

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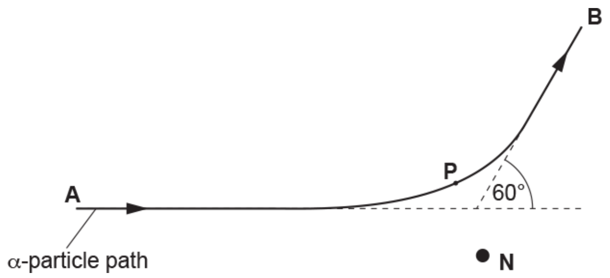
[2]

37. A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil.
A few are deflected by gold nuclei.

The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil.
The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The **magnitude** of the final momentum of the α-particle at **B** is equal to its initial value at **A**.

The gold nucleus **N** is initially at rest. During the passage of the α-particle from **A** to **B**, no other forces act on the two particles.

In the following questions label any relevant angles.

i. Draw two vectors in the spaces below to represent the initial momentum and the final momentum of the α-particle.

initial momentum at **A**

final momentum at **B**

[2]

ii. Draw a vector in the space below to represent the momentum of the nucleus **N** when the α-particle reaches **B**.

Explain how you determined this momentum.

---

[2]

38. A helium atom **X** travelling at 610 m s^{-1} makes an elastic collision with a stationary helium atom **Y**. The magnitude of the velocity of **X** after the collision is 258 m s^{-1}. The directions of the velocities of **X** and **Y** are as shown in Fig. 22.

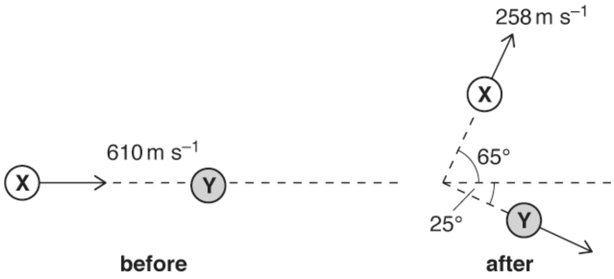


Fig. 22

i. Explain what is meant by an *elastic collision.*

-- **[1]**

ii. The mass of a helium atom is 6.64×10^{-27} kg.
Calculate the magnitude of the momentum *p* of **Y** after the collision.

p = ---------------------------------- kg m s^{-1} **[2]**

39(a). A stationary uranium-238 nucleus $\left({}^{238}_{92}U\right)$ decays into a nucleus of thorium-234 by emitting an alpha-particle.

The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

(b). The mass of the uranium nucleus is 4.0×10^{-25} kg. After the decay the thorium nucleus has a speed of 2.4×10^{5} m s^{-1}.

Calculate the kinetic energy, in MeV, of the alpha-particle.

kinetic energy = ... MeV **[4]**

(c). The uranium-238 $\left({}^{238}_{92}U\right)$ nucleus starts the decay chain which ends with a nucleus of lead-206 $\left({}^{206}_{82}Pb\right)$.
Show that 14 particles are emitted during this decay chain. Explain your reasoning.

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[3]

40. Two balls **X** and **Y** are travelling in the same direction along a horizontal track.
Ball **X** makes a head-on collision with ball **Y**.
Fig. 23 shows the momentum against time *t* graph for ball **X** before, during and after the collision.

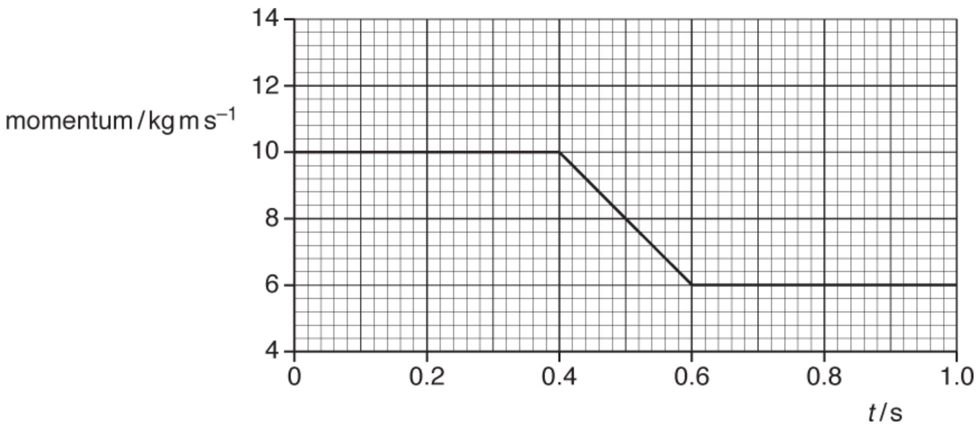


Fig. 23

i. Use Fig. 23 to calculate the force *F* acting on ball **X** during the collision.

F = ... N **[2]**

ii. The momentum of ball **Y** before the collision is 8.0 kg m s^{-1}.
On Fig. 23 sketch a graph to show the variation of the momentum of **Y** with time *t*. Label this graph **Y**. **[3]**

41. A cyclist moves along a horizontal road. She pushes on the pedals with a constant power of 250 W. The mass of the cyclist and bicycle is 85 kg. The total drag force is $0.4v^2$, where v is the speed of the cyclist.

i. Calculate the energy provided by the cyclist each minute when the overall efficiency of the cyclist's muscles is 65%.

energy = ... J **[2]**

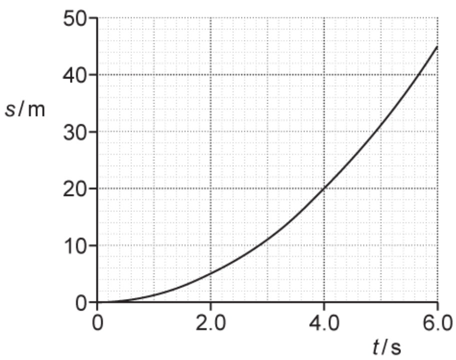
ii. Calculate the drag force and hence the instantaneous acceleration of the cyclist when the speed is 6.0 ms^{-1}.

acceleration = ... ms^{-2} **[3]**

42. A car starts from rest at time $t = 0$.

The car travels in a straight line with a **constant** acceleration.

The displacement s against time t graph for this car is shown below.



i. Use the graph to show that the speed of the car at t = 4.0s is $10ms^{-1}$.

---

[3]

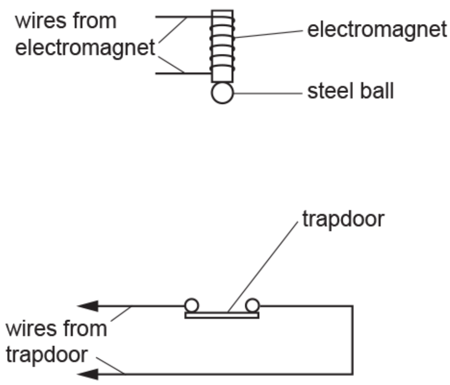
ii. The mass of the car is 1200kg.

Calculate the rate of change of momentum of the car from $t = 0$ to $t = 4.0$ s. Include an appropriate unit for your answer.

rate of change of momentum = ... unit .... **[3]**

43. A student wants to determine the value of the acceleration of freefall g.

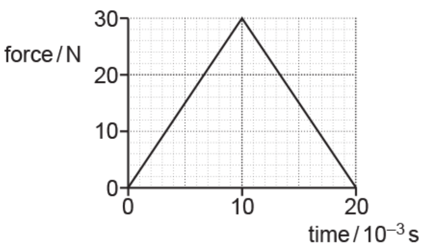
The diagram below shows part of the arrangement which the student used.



A steel ball is dropped from an electromagnet. The ball falls vertically. The ball hits a trapdoor and opens the trapdoor.

The trapdoor falls downwards when the ball hits it.
The ball collides **elastically** with the trapdoor with a speed of 4.4 m s^{-1}.

The graph of force acting on the ball against time is shown below.



The mass of the ball is 0.050 kg.

i. Calculate the initial momentum p_1 of the ball just before it hits the trapdoor.

p_1 = ... kg m s^{-1} **[1]**

ii. Use the graph to calculate the magnitude of the final momentum p_2 of the ball immediately after the collision.

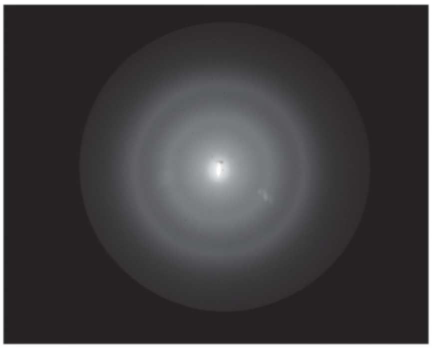
p_2 = ... kg m s^{-1} **[3]**

iii. The mass of the trapdoor is 100 g.

Calculate the final speed v of the trapdoor immediately after the collision.

v = ... m s^{-1} **[2]**

44. * A student is investigating electron diffraction. A beam of electrons is directed towards a thin slice of graphite in an evacuated tube.
The electrons are accelerated by a potential difference of 2000 V. The diagram below shows the pattern formed on the fluorescent screen of the evacuated tube.



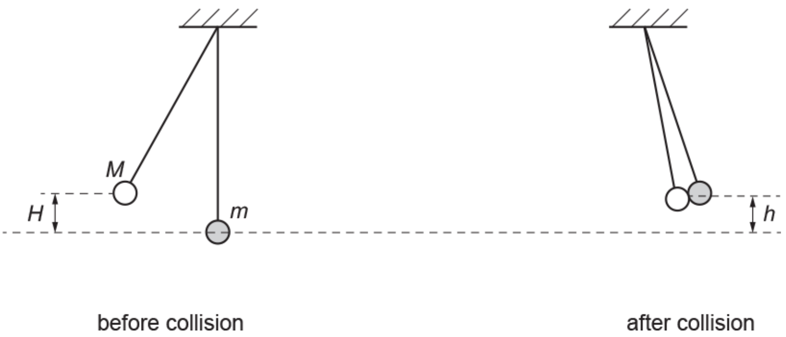
Describe and explain how the pattern changes as the potential difference is increased. Include how the de Broglie wavelength λ of the electron is related to the potential difference V.

----

[6]

45. * A student makes a pendulum using a length of string with a ball of adhesive putty which acts as a bob. The mass of this bob is *M*.
A similar second pendulum is constructed with the same length of string but with a bob of a smaller mass. The mass of this bob is *m*.

The arrangement of the pendulums is shown below.



The bob of mass *M* is pulled back to a vertical height of *H* from its rest position. It is released and collides with the bob of mass *m*. The two bobs then stick together and reach a maximum vertical height *h* from the rest position.

The height *h* is given by the equation $h = \left(\frac{M}{M+m}\right)^2 H$.

Describe how to perform an experiment to test the validity of this equation and how the data can be analysed.

[6]

46. A linear air track is used to investigate the collision of two gliders **A** and **B**, as shown in **Fig. 3.1**.

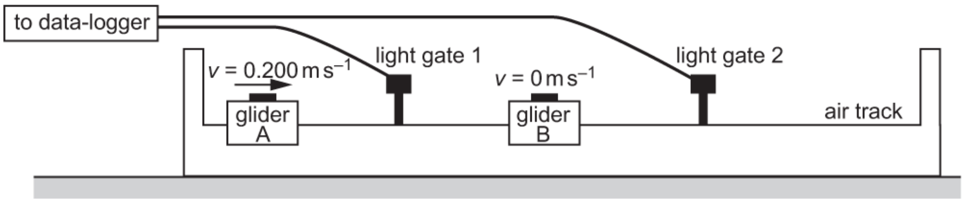


Fig. 3.1

Light gates 1 and 2 are connected to a data-logger to determine the speed of the gliders. Glider **A** has a mass of 0.75kg and glider **B** has a mass of 1.25 kg.

Two experiments are carried out.

Experiment 1

- Glider **B** is initially at rest between light gates 1 and 2.
- Glider **A** passes light gate 1 at a speed of 0.200 m s^{-1}.
- Glider **A** collides with glider **B**.
- Glider **A** rebounds and passes light gate 1 at a speed of 0.050ms^{-1} and glider **B** passes light gate 2 at a speed of 0.150 m s^{-1}.

Experiment 2

- Glider **B** is initially at rest between light gates 1 and 2.
- Glider **A** passes light gate 1 at a speed of 0.200 m s^{-1}.
- Glider **A** collides with glider **B**.
- Glider **A** sticks to glider **B**.
- Both gliders pass light gate 2 at a speed of 0.075 m s^{-1}.

With the help of calculations and the terms below, explain the results of the two experiments.

[6]

elastic **inelastic** **momentum**

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47. This question is about the operation of an electrically powered shower designed by an electrical firm.

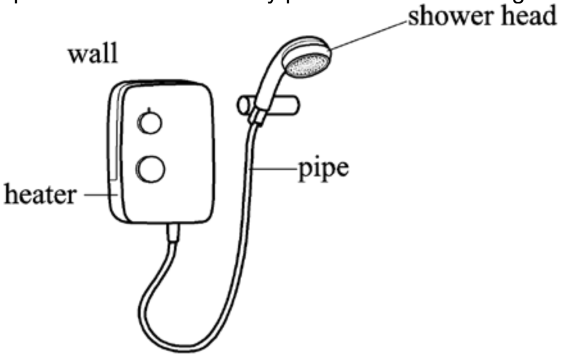


Fig.1.1

Water moves at constant speed through a pipe of cross-sectional area 7.5×10^{-5} m^2 to a shower head shown in **Fig. 1.1.** The maximum mass of water which flows per second is 0.070 kg s^{-1}.

i. Show that the maximum speed of the water in the pipe is about 0.9 m s^{-1}.

density of water = 1000 kg m^{-3}

[2]

ii. The total cross-sectional area of the holes in the shower head is one quarter that of the pipe. Calculate the maximum speed of the water as it leaves the shower head.

maximum speed = ... m s^{-1} **[1]**

iii. Calculate the magnitude of the force caused by the accelerating water on the shower head.

force = ... N **[2]**

iv. Draw on to **Fig. 1.1** the direction of the force in **(iii)**.

[1]

48. In an experiment disc **X** moving at 1.5 ms^{-1} collides elastically with two other discs **Y** and **Z** which are touching and at rest. All the discs are identical. The positions of the discs are shown in **Fig. 19.3**.

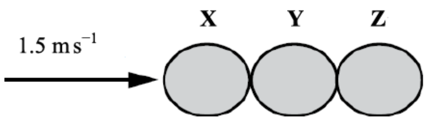


Fig. 19.3

i. Draw arrows on **Fig. 19.3** to show the relative magnitude and direction of the forces which act on disc **Y** during the collision.

[1]

ii. State the resultant force on **Y** during the collision.

---

[1]

iii. Show that after the elastic collision **X** is at rest and **Z** moves with a velocity of 1.5 ms^{-1}.

[4]

49. Fig. 5.1 shows a tennis ball before and after bouncing on the ground.

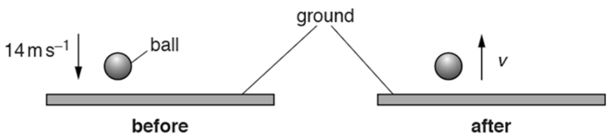


Fig. 5.1

The mass of the tennis ball is 0.062 kg. The tennis ball is slightly warmer after its collision with the ground.

i. The tennis ball hits the ground at a speed of 14 m s^{-1}.
Calculate the momentum *p* of the tennis ball as it hits the ground.

p = ________________ Ns **[1]**

The force acting on the ball during collision with the ground is *F*.
Fig. 5.2 shows a graph of force *F* acting on the tennis ball against time *t*.

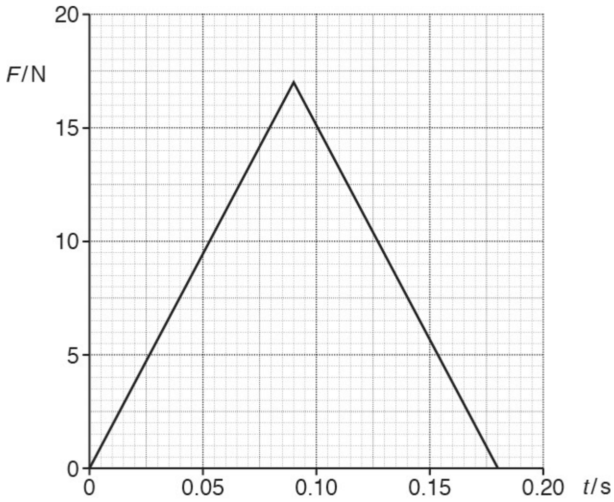


Fig. 5.2

The tennis ball is in contact with the ground for 0.18 s.

ii. Determine the speed *v* of the tennis ball as it leaves the ground.

v = ________________ m s^{-1} **[3]**

iii. State what is meant by an elastic collision and explain how your answer to **(ii)** shows that this collision is **not** elastic.

____

____

____ **[2]**

50. Fig. 3.1 shows a simple representation of a hydrogen iodide molecule. It consists of two ions $^{1}_{1}H^{+}$ and $^{127}_{53}I^{-}$, held together by electric forces.

Fig. 3.1

Fig. 3.2 shows a simple mechanical model of the molecule consisting of two unequal masses connected by a spring of force constant *k* and negligible mass. The ions oscillate in simple harmonic motion when disturbed.

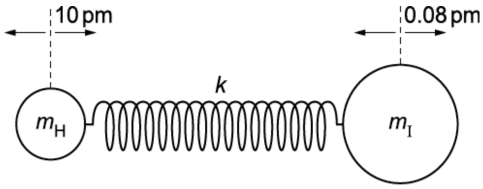


Fig. 3.2

i. The approximate acceleration *a* of the hydrogen ion, mass m_H, is given by the equation

$$a = -\left(\frac{k}{m_H}\right)x$$

where *k* is the force constant of the spring and *x* is the displacement of the ion.
The ions oscillate with a frequency of 6.6×10^{13} Hz. The mass m_H is 1.7×10^{-27} kg.
Show that the value of *k* is about 300 N m^{-1}.

[3]

ii. Use Newton's laws of motion and a requirement for simple harmonic motion to explain why the amplitude of oscillation of the iodine ion, mass m_I, is about 0.08 pm when the amplitude of oscillation of the hydrogen ion is about 10 pm.

[4]

51. A gas is at a temperature of 20°C. The mass of each molecule is 4.7×10^{-26} kg.

i. Show that the root mean square (r.m.s.) speed the gas molecules is about 500 m s^{-1}.

[3]

ii. A gas molecule makes a head-on collision with a **stationary** smoke particle. Fig. 20 shows the gas molecule and the smoke particle before and after the collision. The final speed of the smoke particle is 23 m s^{-1}.

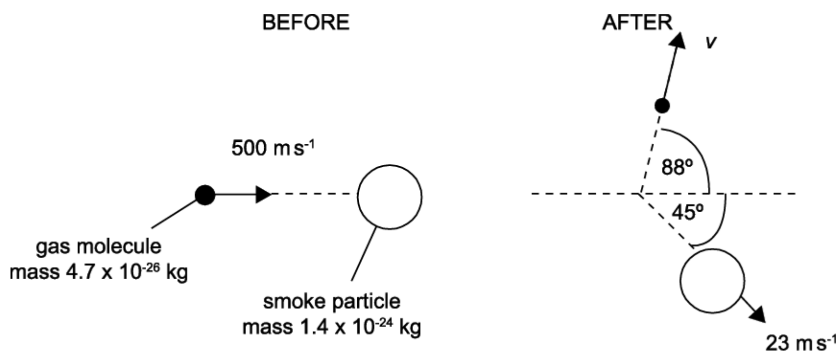


Fig. 20

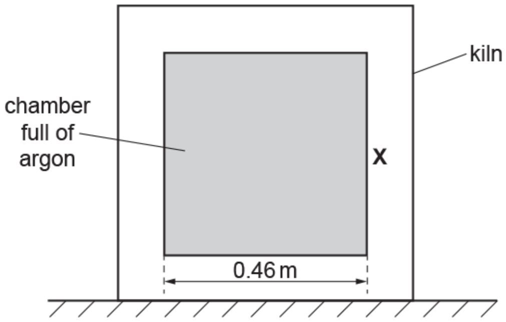
1. State and explain the **total** momentum of the molecule and smoke particle after the collision in a direction perpendicular to initial velocity of the gas molecule.

-- **[2]**

2. Calculate the speed *v* of the gas molecule after the collision.

v = ...m s^{-1} **[2]**

52. A kiln used to harden ceramics is shown below.



The internal chamber is a cube. Each side of this cube has length 0.46 m.
The chamber is sealed and full of argon. Argon behaves as an ideal gas.

The temperature of the kiln is 1300 °C.
A single atom of argon is travelling horizontally towards the vertical side **X** of the chamber.
The initial speed of this atom is 990 m s^{-1}. After collision, it rebounds at the same speed.

i. Calculate the change in momentum Δ*p* of this atom.
   - mass of argon atom = 6.6×10^{-26} kg

Δ*p* = ... kg m s^{-1} **[2]**

ii. Assume that this atom does not collide with any other argon atoms inside the chamber. Instead, it travels horizontally, making repeated collisions with the opposite vertical walls of the chamber.
   - Show that the atom makes about 1000 collisions with side **X** in a time interval of 1.0 s.

---

[1]

   - Calculate the average force *F* on side **X** made by the atom.

F = ... N **[2]**

iii. Without calculation, explain how your answer to **(ii)2** could be used to estimate the total pressure exerted by the atoms of the argon gas in the kiln.

---

[2]

53. Fig. 20.1 shows an electric motor used to lift and lower a load.

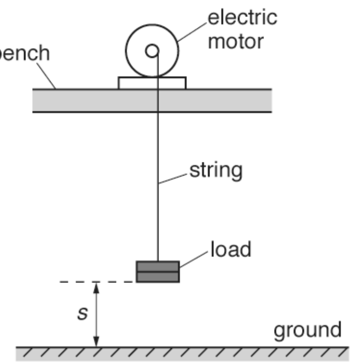


Fig. 20.1

At time t = 0 the load is on the ground with displacement s = 0.
Fig. 20.2 shows the variation of the displacement s of the load with time t.

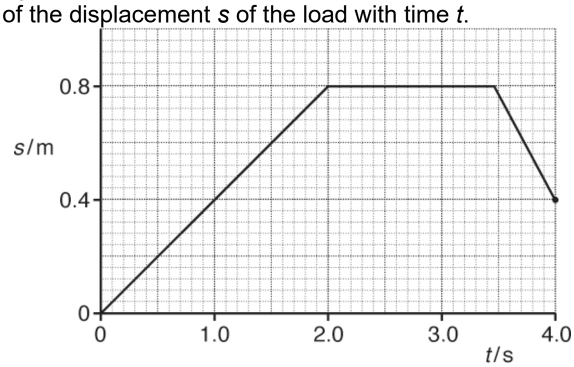


Fig. 20.2

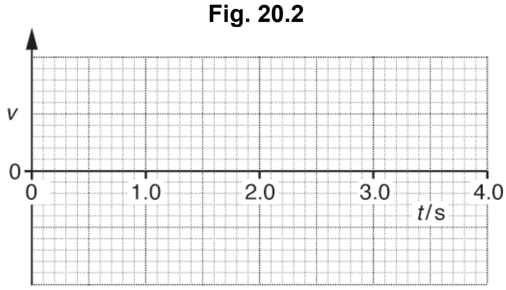


Fig. 20.3

i.

On Fig. 20.3, sketch a graph to show the variation of the velocity v of the load with time t.
You do not need to insert a scale on the v axis.

[3]

ii. Describe how the kinetic energy and the gravitational potential energy of the load varies from t = 0 to t = 2.0 s.

---

[2]

iii. During the **downward** journey of the load, the string breaks at t = 4.0 s. It then falls vertically towards the ground. The mass of the load is 120 g.
Air resistance is negligible.

1 Calculate the velocity V of the load just before it hits the ground.

V = ---------------------------------- ms^{-1} **[2]**

2 The load hits the ground and comes to **rest** in a time interval of 25 ms.

Calculate the average force F exerted by the ground on the load.

F = ---------------------------------- N **[2]**

END OF QUESTION PAPER