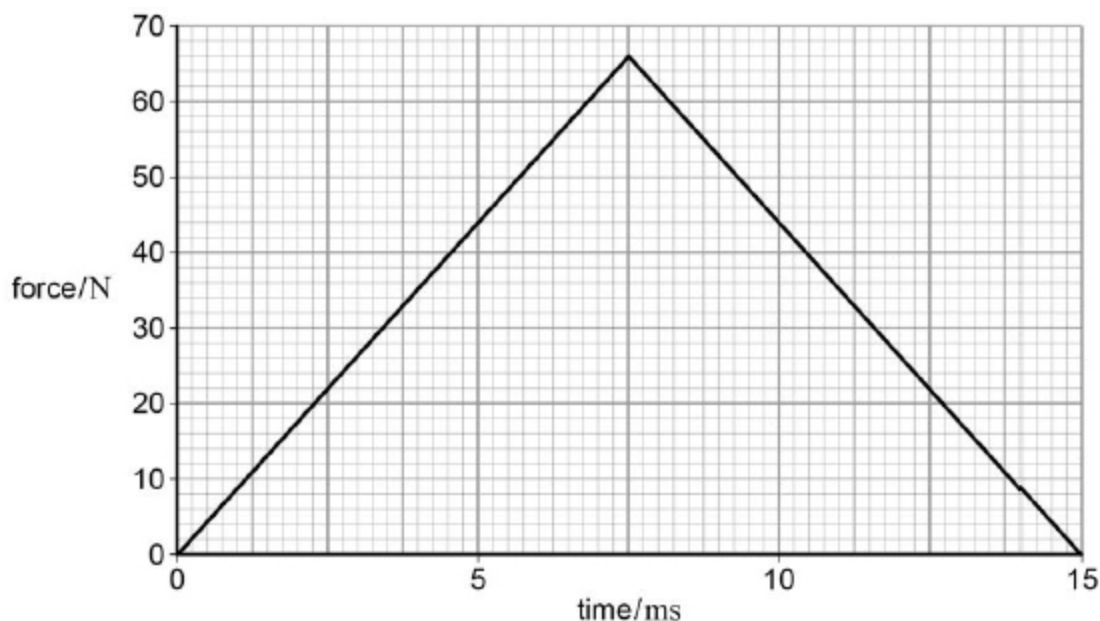


1

A golf ball is raised from the ground and dropped onto a hard plate to test the properties of the ball. A sensor measures the force exerted by the plate on the ball during its collision with the plate. The graph below shows the variation of force exerted on the golf ball with time.



- (a) Show that the change in momentum of the golf ball during the collision is about 0.5 N s.

(2)

- (b) The ball strikes the plate with a speed of 7.1 m s^{-1} and has a mass of 45 g. It leaves the plate with a speed of 3.9 m s^{-1} .

Show that this is consistent with a change in momentum of about 0.5 N s.

(3)

- (c) The ball continues to bounce, each time losing the same fraction of its energy when it strikes the plate. Air resistance is negligible.

Determine the percentage of the original gravitational potential energy of the ball that remains when it reaches its maximum height after bouncing three times.

gravitational potential energy remaining = _____ %

(4)

- (d) Explain, with reference to the conservation of momentum, the effect that the motion of the golf ball has on the motion of the Earth from the instant it is released until it bounces at the plate.

(3)

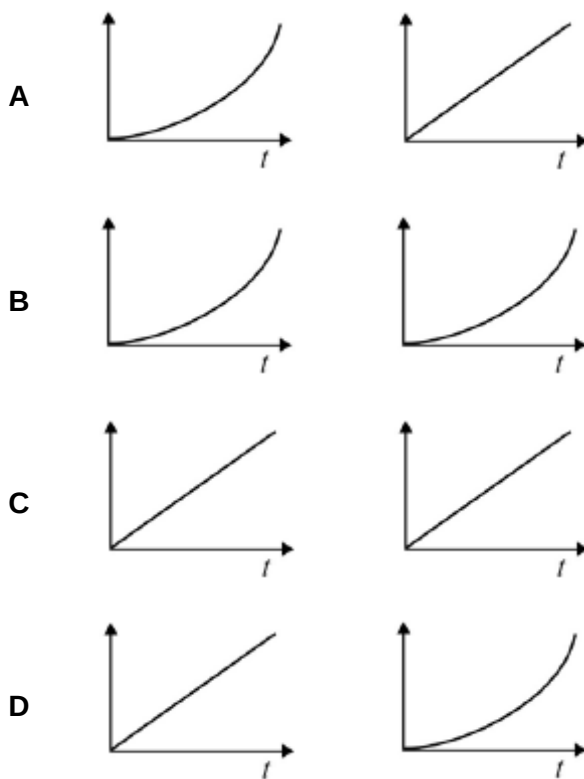
(Total 12 marks)

2

An object is accelerated from rest by a constant force F for a time t . Which graphs represent the variation of time with the change in the kinetic energy and the change in momentum of the object?

Kinetic energy

Momentum

A ☐B ☐C ☐D ☐

(Total 1 mark)

3

A body falls freely, with negligible air resistance. What quantity of the body is its rate of change of momentum?

A mass ☐B power ☐C kinetic energy ☐D weight ☐

4

A firework rocket is fired vertically into the air and explodes at its highest point. What are the changes to the total kinetic energy of the rocket and the total momentum of the rocket as a result of the explosion?

	total kinetic energy of rocket	total momentum of rocket	
A	unchanged	unchanged	☐
B	unchanged	increased	☐
C	increased	unchanged	☐
D	increased	increased	☐

(Total 1 mark)

5

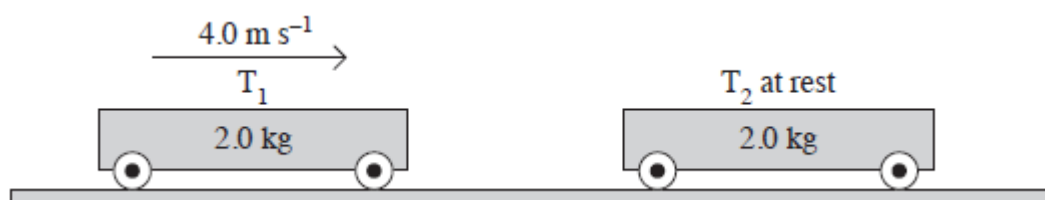
Which one of the following has the same unit as the rate of change of momentum?

- A work
- B energy
- C acceleration
- D weight

(Total 1 mark)

6

Trolley T_1 , of mass 2.0 kg, collides on a horizontal surface with trolley T_2 , which is also of mass 2.0 kg. The collision is elastic. Before the collision T_1 was moving at 4.0 m s^{-1} and T_2 was at rest.



Which one of the following statements is correct?

Immediately after the collision

- A T_1 is at rest and T_2 moves at 4.0 m s^{-1} .
- B T_1 will rebound from T_2 at 4.0 m s^{-1} .
- C T_1 and T_2 will both move at 2.8 m s^{-1} .
- D T_1 and T_2 will both move at 1.4 m s^{-1} .

(Total 1 mark)

7

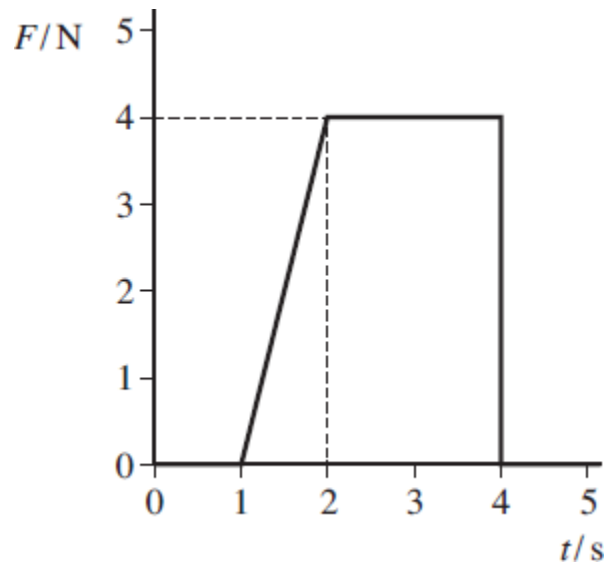
Water of density 1000 kg m^{-3} flows out of a garden hose of cross-sectional area $7.2 \times 10^{-4} \text{ m}^2$ at a rate of $2.0 \times 10^{-4} \text{ m}^3$ per second. How much momentum is carried by the water leaving the hose per second?

- A $5.6 \times 10^{-5} \text{ N s}$
- B $5.6 \times 10^{-2} \text{ N s}$
- C 0.20 N s
- D 0.72 N s

(Total 1 mark)

8

The graph shows how the resultant force, F , acting on a body varies with time, t .



What is the change in momentum of the body over the 5 s period?

- A 2 N s
- B 8 N s
- C 10 N s
- D 12 N s

(Total 1 mark)

9

Two ice skaters, initially at rest and in contact, push apart from each other. Which line, **A** to **D**, in the table states correctly the change in the total momentum and the total kinetic energy of the two skaters?

	total momentum	total kinetic energy
A	unchanged	increases
B	unchanged	unchanged
C	increases	increases
D	increases	unchanged

(Total 1 mark)**10**

Which line, **A** to **D**, in the table shows correctly whether the moment of a force, and momentum, are scalar or vector quantities?

	moment of force	momentum
A	scalar	scalar
B	scalar	vector
C	vector	scalar
D	vector	vector

(Total 1 mark)**11**

Which of the following is a possible unit for rate of change of momentum?

- A** N s
- B** N s⁻¹
- C** kg ms⁻¹
- D** kg ms⁻²

(Total 1 mark)

12

A cricket ball is travelling at a speed of 32.5 ms^{-1} when it is hit by a bat. After impact, the ball has the same speed but is travelling in the opposite direction.

The mass of the ball is 0.156 kg .

- (a) Calculate the change in momentum of the cricket ball. State an appropriate unit for your answer.

change in momentum _____

unit _____

(3)

- (b) The bat is in contact with the ball for 3.80 ms .
Calculate the force exerted by the bat on the ball.

force _____ N

(2)

(Total 5 marks)

13

A gas molecule of mass m in a container moves with velocity v . If it makes an elastic collision at right angles to the walls of the container, what is the change in momentum of the molecule?

- A zero
- B $\frac{1}{2} mv$
- C mv
- D $2 mv$

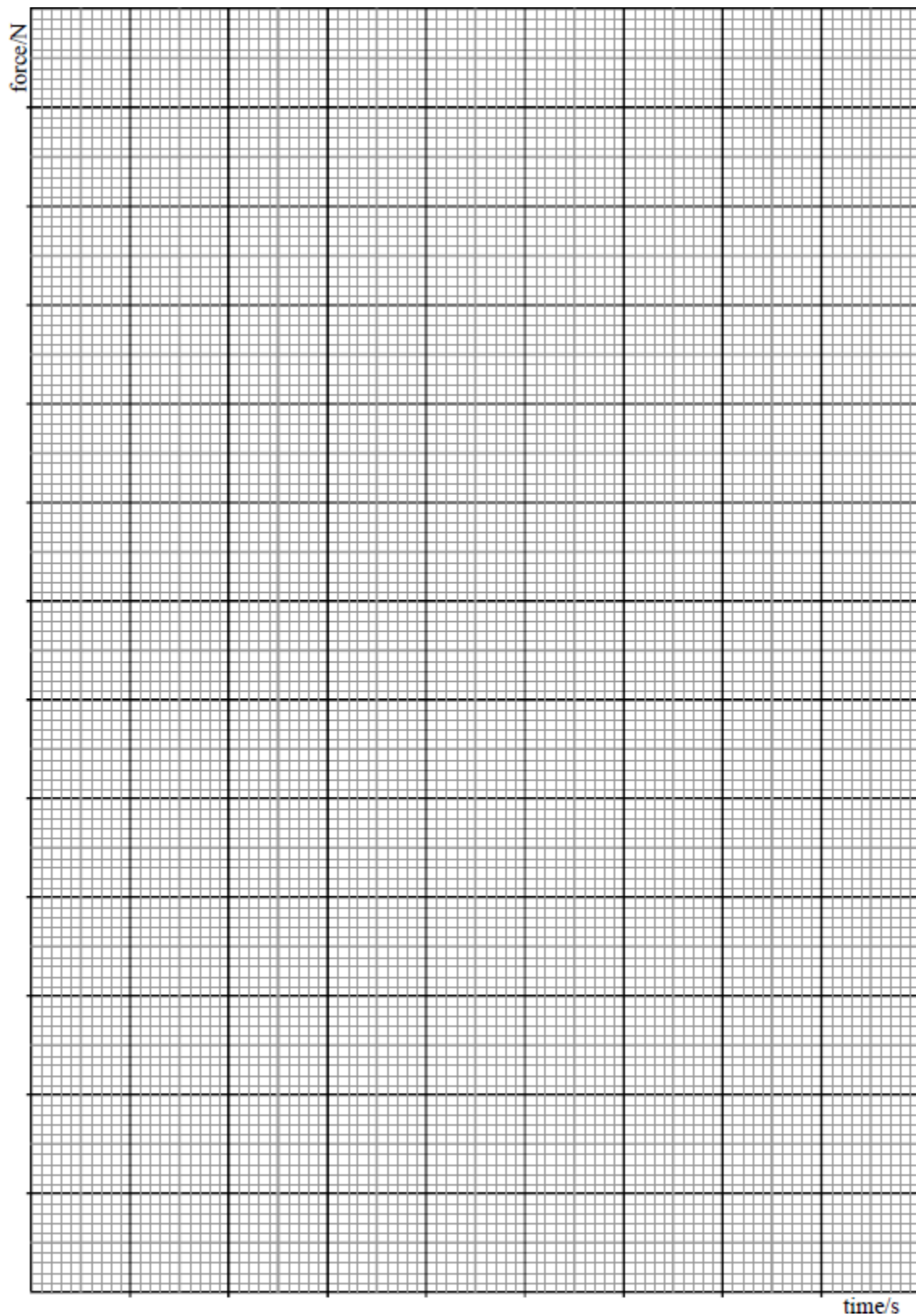
(Total 1 mark)

14

A toy locomotive of mass 0.50 kg is initially at rest on a horizontal track. The locomotive is powered by a twisted rubber band which, as it unwinds, exerts a force which varies with time as shown in the table.

time/s	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
force/N	0.20	0.18	0.15	0.12	0.10	0.08	0.05	0.02	0.00

- (a) (i) On the grid below plot a graph of force against time for the rubber band power source.



- (ii) State what is given by the area between the graph and the time axis.

- (b) The rubber band is wound up and released to power the locomotive. Use your graph to show that the speed of the locomotive 8.0 s after the twisted rubber band is released is 1.6 m s^{-1} . Ignore the effects of air resistance and energy losses due to friction.

(2)

- (c) 8.0 s after release the locomotive collides with and couples to a toy truck, initially at rest, which has a mass of 1.50 kg.

- (i) Calculate the speed of the coupled locomotive and truck after collision.

- (ii) Calculate the combined kinetic energy of the locomotive and truck immediately after collision.

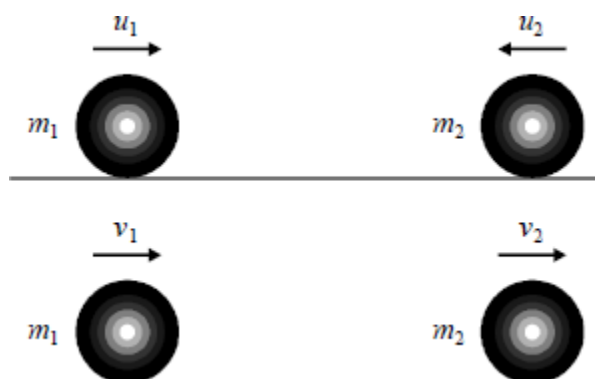
- (iii) Show, with the aid of a calculation, whether or not the collision is elastic.

(5)

(Total 11 marks)

15

- (a) (i) Give an equation showing how the principle of conservation of momentum applies to the colliding snooker balls shown in the diagram.



- (ii) State the condition under which the principle of conservation of momentum applies.

(3)

- (b) A trolley, A, of mass 0.25 kg and a second trolley, B, of mass 0.50 kg are held in contact on a smooth horizontal surface. A compressed spring inside one of the trolleys is released and they then move apart. The speed of A is 2.2 m s^{-1} .

- (i) Calculate the speed of B.

- (ii) Calculate a minimum value for the energy stored in the spring when compressed.

(4)

- (c) The rotor blades of a helicopter sweep out a cross-sectional area, A . The motion of the blades helps the helicopter to hover by giving a downward velocity, v , to a cylinder of air, density ρ . The cylinder of air has the same cross-sectional area as that swept out by the rotor blades.

Explaining your reasoning,

- (i) derive an expression for the mass of air flowing downwards per second, and

- (ii) derive an expression for the momentum given per second to this air.

- (iii) Hence show that the motion of the air results in an upward force, F , on the helicopter given by

$$F = \rho A v^2.$$

(5)

- (d) A loaded helicopter has a mass of 2500 kg. The area swept out by its rotor blades is 180 m². If the downward flow of air supports 50% of the weight of the helicopter, what speed must be given to the air by the motion of the rotor blades when the helicopter is hovering? Take the density of air to be 1.3 kg m⁻³.

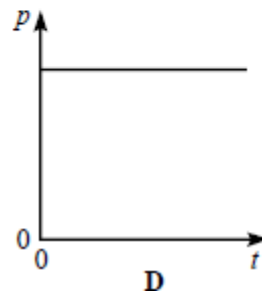
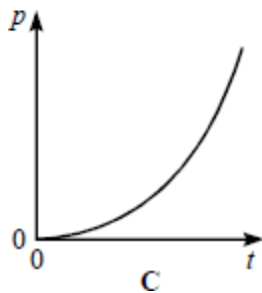
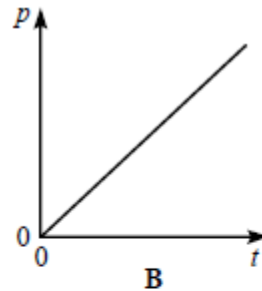
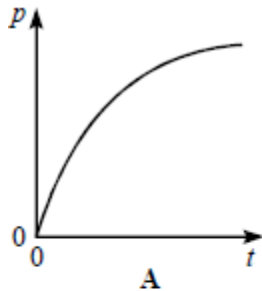
(3)

(Total 15 marks)

16

A body is accelerated from rest by a constant force.

Which one of the following graphs best represents the variation of the body's momentum p with time t ?



(Total 1 mark)

17

- (a) (i) State the principle of conservation of momentum.

(2)

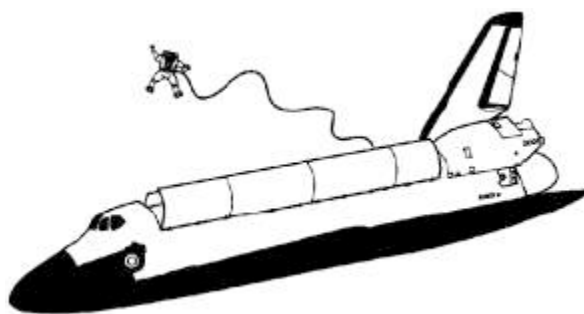
- (ii) Explain briefly how an elastic collision is different from an inelastic collision.

(1)

- (b) Describe and explain what happens when a moving particle collides elastically with a stationary particle of equal mass.

(3)

- (c) The diagram below shows an astronaut undertaking a space-walk. The astronaut is tethered by a rope to a spacecraft of mass 4.0×10^4 kg. The spacecraft is moving at constant velocity.



The astronaut and spacesuit have a total mass of 130 kg. The change in velocity of the astronaut after pushing off is 1.80 m s^{-1} .

- (i) Determine the velocity change of the spacecraft.

(2)

- (ii) The astronaut pushes for 0.60 s in achieving this speed. Calculate the average power developed by the astronaut. Neglect the change in motion of the spacecraft.

(3)

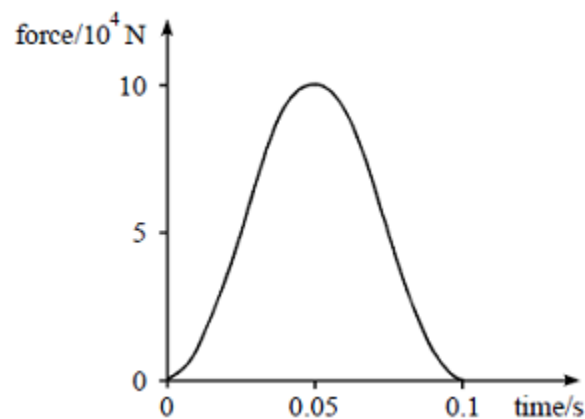
(iii) The rope eventually becomes taut. Suggest what would happen next.

(2)

(Total 13 marks)

18

The diagram shows the graph of force on a car against time when the car of mass 500 kg crashes into a wall without rebounding.



Which one of the following statements is correct?

- A The area under the graph is equal to the initial momentum of the car
- B Momentum is not conserved in the collision
- C Kinetic energy is conserved in the collision
- D The average force exerted on the car is $10 \times 10^4 \text{ N}$

(Total 1 mark)

- (a) **Figure 1** shows a skier descending the ramp of a ski jump. **Figure 2** shows a graph of the distance travelled along the ramp against time, from the time the descent starts until the skier leaves the end of the ramp.

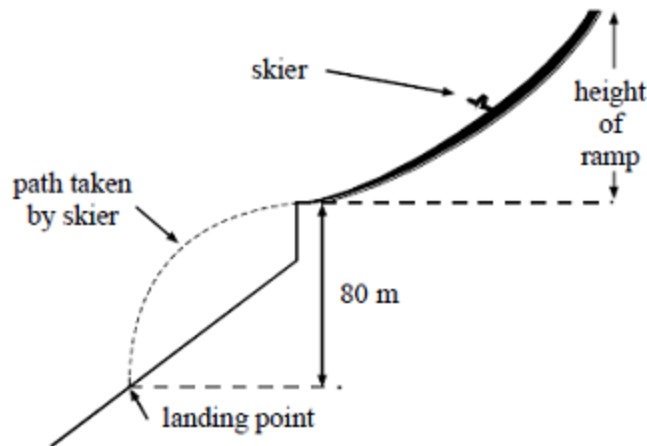


Figure 1

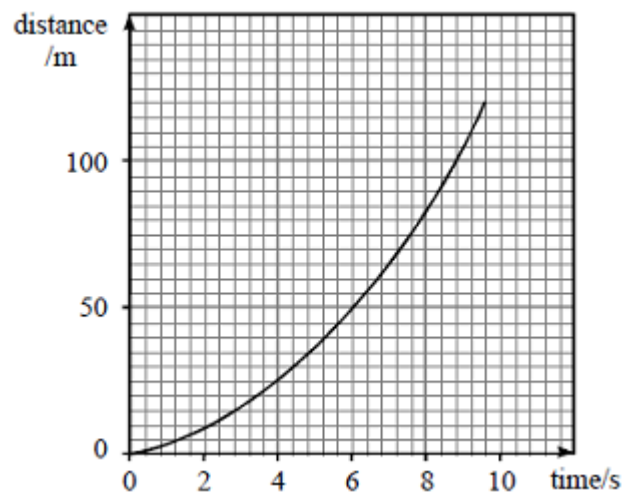


Figure 2

The skier of mass 80 kg (including equipment) skis down the ramp and leaves it horizontally. The skier gains 55% of the available gravitational potential energy as kinetic energy when descending the ramp.

acceleration of free fall, $g = 9.8 \text{ m s}^{-2}$

- (i) One energy transformation which occurs as the skier skis down the ramp is from gravitational potential energy to kinetic energy of the skier. State **two** other energy transformations that occur as the skier skis down the ramp.

- (ii) Use **Figure 2** to show that the speed at which the skier leaves the ramp is about 23 m s^{-1} . Show your reasoning clearly.

(2)

- (iii) Determine the height of the ramp.

(3)

- (b) **Figure 1** shows the path taken by the skier after leaving the ramp. Assuming that there was no lift or drag due to the air during this jump, calculate:

- (i) the time for which the skier was in flight;

(2)

- (ii) the horizontal distance jumped by the skier before landing.

(2)

- (c) On landing the skier has considerable vertical momentum that has to be reduced to zero. The surface on which the skier lands is hard-packed snow. To reduce the force experienced by the skier, the landing surface is angled at 40° to the horizontal.

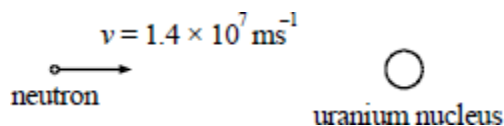
Explain briefly how angling the landing surface reduces the vertical component of the force, experienced by the skier.

(3)

(Total 14 marks)

20

The figure below shows a neutron of mass $1.7 \times 10^{-27} \text{ kg}$ about to collide inelastically with a stationary uranium nucleus of mass $4.0 \times 10^{-25} \text{ kg}$. During the collision, the neutron will be absorbed by the uranium nucleus.



- (a) Calculate the velocity of the uranium nucleus immediately after the neutron has been absorbed.

(3)

- (b) Collisions between neutrons and uranium nuclei can also be elastic. State, and explain briefly, how the speed of the uranium nucleus after impact would be different in the case of an elastic collision.

Do not perform any further calculations.

(3)

- (c) Using the data at the beginning of the question, calculate the kinetic energy of the neutron before it collides with the uranium nucleus.

(3)

(Total 9 marks)

21

- (a) Collisions can be described as *elastic* or *inelastic*. State what is meant by an inelastic collision.

(1)

- (b) A ball of mass 0.12 kg strikes a stationary cricket bat with a speed of 18 m s^{-1} . The ball is in contact with the bat for 0.14 s and returns along its original path with a speed of 15 m s^{-1} .

Calculate

- (i) the momentum of the ball before the collision,

- (ii) the momentum of the ball after the collision,

- (iii) the total change of momentum of the ball,

- (iv) the average force acting on the ball during contact with the bat,

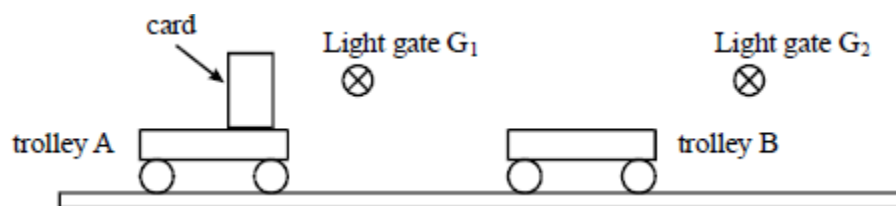
- (v) the kinetic energy lost by the ball as a result of the collision,

(6)

(Total 7 marks)

22

The simplified diagram shows an experimental arrangement to investigate the collision of two trolleys.



In the experiment, trolley A is travelling at speed v . It collides with and sticks to, the initially stationary trolley B.

- (a) State the measurements you would need to take so that you could determine the speed of

- (i) trolley A before the collision,

- (ii) trolleys A and B after the collision.

(3)

- (b) Explain how you would verify that momentum was conserved in this collision, indicating what other measurements would be required.

(2)

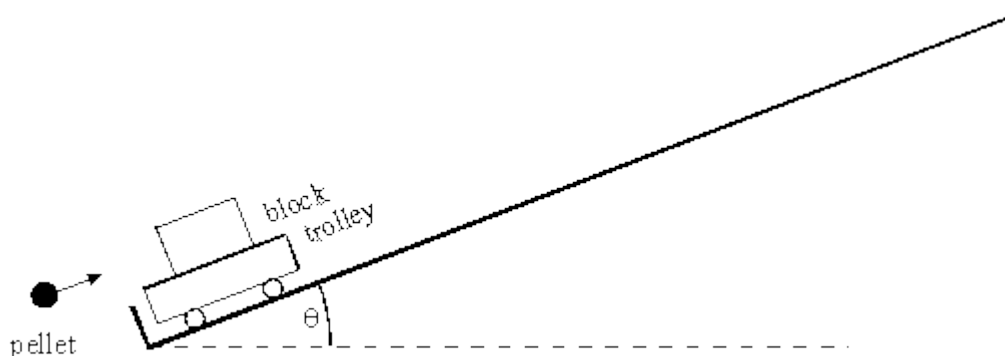
- (c) State and explain what you would do to minimise the effects of friction on the motion of the trolleys.

(2)

(Total 7 marks)

23

The diagram represents part of an experiment that is being used to estimate the speed of an air gun pellet.



The pellet which is moving parallel to the track, strikes the block, embedding itself. The trolley and the block then move along the track, rising a vertical height, h .

- (a) Using energy considerations explain how the speed of the trolley and block immediately after it has been struck by the pellet, may be determined from measurements of h . Assume frictional forces are negligible.

(3)

(b) The following data is collected from the experiment

mass of trolley and block	0.50 kg
mass of pellet	0.0020 kg
speed of trolley and block immediately after impact	0.40 m s^{-1}

Calculate

(i) the momentum of the trolley and block immediately after impact,

(ii) the speed of the pellet just before impact.

(4)

(c) (i) State what is meant by an inelastic collision.

(ii) Use the data from part (b) to show that the collision between the pellet and block is inelastic.

(4)

(Total 11 marks)

Mark schemes

1	(a) Attempt to determine area under graph or statement that area under needed or $0.5 \times 15 \times 10^{-3} \times 66$ ✓ 0.495 (N s)✓ <i>condone power of 10 error</i>	2
	(b) Momentum before = $0.045 \times 7.1 = 0.320$ (N s) <u>down</u>✓ Momentum after = $0.045 \times 3.9 = 0.175$ (N s) <u>upwards</u>✓ <u>Change = 0.495 (N s) ✓</u>	3
	(c) Initial KE on impact = $0.5 \times 0.045 \times 7.1^2 = 1.13$ (J) or Ke after impact = 0.342 (J)✓ Fractional change ke after / ke before = 0.30✓ Use of their fractional change cubed✓ Percentage change after 3 bounces = $0.3^3 \times 100$ (%) = 2.7%✓	4
	(d) As ball falls momentum of ball toward the Earth (always) = momentum of Earth toward the ball✓ On impact the momentum of both ball and Earth become zero✓ After impact momentum of ball away from Earth = momentum of Earth in opposite direction✓	3
		[12]
2	A	[1]
3	D	[1]
4	C	[1]
5	D	[1]
6	A	[1]
7	B	[1]

8	C				[1]
9	A				[1]
10	D				[1]
11	D				[1]
12	(a) 32.5×0.156 or 65×0.156 : any mass $\times$ velocity	C1			
	10.07/10.1/10 ignore sf				
	kg ms ⁻¹ (accept Ns)	A1			
		B1	3		
	(b) their a/3.80 ($\times 10^{-3}$) ignore power of 10 error				
	2670 (N) ecf	C1			
		A1	2		[5]
13	D				[1]
14	(a) (i) points plotted correctly (1) (1) (deduct one for each incorrect) sensible scales chosen (1) line of best fit (1)				
	(ii) change in momentum [or impulse] (1) (accept 0.8)				
					max 4
	(b) area under graph = 0.80 ± 0.05 (1) (kgms ⁻¹)				
	$v = \frac{\Delta mv}{m}$ (1) = 1.6 ms ⁻¹				
	alternative: state average force = 0.10(N) (1) leading to correct derivation of 1.6ms ⁻¹ (1)				

(c) (i) $\Delta mv = 0$ [or statement] **(1)** $v = 0.40\text{ms}^{-1}$ **(1)**

(ii) kinetic energy = 0.16 J **(1)**

(iii) initial kinetic energy = 0.64 (J) **(1)**
kinetic energy lost so inelastic **(1)**

5

[11]

15

(a) (i) equation showing momentum before = momentum after **(1)**
correct use of sign **(1)**

(ii) no external forces (on any system of colliding bodies) **(1)**

3

(b) (i) (by conservation of momentum $m_1v_1 + m_2v_2 = 0$)

$$0.25 \times 2.2 = (-)0.50v_2 \text{ **(1)**}$$

$$v_2 = (-)1.1(0)\text{ms}^{-1} \text{ **(1)**}$$

(ii) = total k.e. = $\frac{1}{2} \times 0.25 \times 2.2^2 + \frac{1}{2} \times 0.5 \times 1.1^2$ **(1)**

$$= 0.91\text{J} \text{ **(1)**}$$

4

(c) (i) mass of air per second = ρAv **(1)**
correct justification, incl ref to time **(1)**

(ii) momentum per second (= $Mv = v^2 A\rho$) = $v^2 A\rho$ **(1)**

(iii) force = rate of change of momentum (hence given result) **(1)**
upward force on helicopter equals (from Newton third law)
downward force on air **(1)**

5

(d) $v^2 A\rho = \frac{mg}{2}$ (for 50% support) **(1)**

$$v^2 \times 180 \times 1.3 = \frac{2500 \times 9.81}{2} \text{ **(1)**}$$

gives $v = 7.2\text{ms}^{-1}$ **(1)** (or 7.3, g taken as 10)

if not 50% of weight, max 1 / 3 provided all correct otherwise (gives 10.2)

3

[15]

16

B

[1]

- (a) (i) momentum before (a collision) = momentum after (a collision)
or
 there is no change in momentum (when bodies collide)

C1

reasonably rigorous statement including
 reference to total momentum etc. **and**
 lack of external force or in a closed system or isolated system

A1

(2)

- (ii) in an elastic collision the (total) KE remains constant
or
 in an inelastic collision the (total) KE is reduced (not just changed)

B1

(1)

- (b) the incident particle stops (loses all its momentum or KE)

M1

the stationary particle moves off with the **same** velocity (speed) as the incident
 particle (gains **same** momentum or KE as incident particle had)

M1

no other possibility would conserve both momentum and KE
or

original total momentum = mv = final momentum

and original KE = $\frac{1}{2}mv^2$ = final KE

A1

(3)

- (c) (i) $130 \times 1.8 = 4.0 \times 10^4 v$
or clear appreciation that momentum = mv

C1

e.g. an incorrect momentum equation

$5.9 (5.85) \times 10^{-3} \text{ m s}^{-1}$ (in opposite direction to that of the astronaut)

A1

(2)

(ii) energy change / time

C1

energy change of astronaut = 211 J

C1

or

power = Fv

C1

force = 390 N from $F = ma$

(need to use $v = 1.8 / 2$ to obtain average power 350 W)

C1

power = total energy / time = $211 / 0.6 = 350 - 352$ W

A1

(3)

(iii) any two sensible comments

e.g. momentum of astronaut and spacecraft reduced to zero
rope stores elastic energy
momentum of astronaut becomes equal and opposite to original
astronaut and spacecraft move toward one another
the astronaut and spacecraft are 'reunited'
taut rope produces a force toward the spacecraft
velocity of astronaut and of spacecraft will be reversed
rope acting like a spring

not astronaut pulled along at a constant speed

B2

(2)

[13]

18

A

[1]

19

(a) (i) (kinetic) energy of air / snow (pushing it out of the way)
(**not** internal energy)

B1

melting / internal energy of snow / ice

or internal energy of air / skis (condone heat)

award 1 mark only for "heat and sound"

award zero marks for sound alone even if explained

B1

(2)

(ii) clear attempt to draw tangent to graph at end of run

B1

correct co-ordinates and manipulation for tangent
or use of 2 points on curve $\geq t = 7\text{s}$

(no unit penalty) (no significant figure penalty)

B1

(2)

(iii) potential energy loss = $100 / 55 \times \text{KE}$

B1

final KE = $0.5 \times m \times 23^2$

or

equates any KE to mgh

C1

height = 49 m allow e.c.f. from (ii)

A1

(3)

(b) (i) $s = \frac{1}{2}at^2$ **or** $s = ut + \frac{1}{2}at^2$ **or** correct numerical equivalent

C1

4.0 s or 4.04 s

A1

(2)

(ii) $s = vt$ or numerical equivalent

C1

92 m – 93 m

allow e.c.f. from (a)(ii) and (b)(i)

A1

(2)

(c) force is lower because $F = \frac{\Delta(mv)}{t}$

B1

skier has vertical momentum after landing

B1

change in momentum is reduced

B1

or

$$F = \frac{\Delta(mv)}{t}$$

B1

skier takes longer time to reduce (vertical) momentum

B1

compare with time when surface is flat

B1

or

$$F = \frac{\text{work done}}{s}$$

B1

skier moves though longer distance (vertically) to come to rest

B1

compare with distance to come to rest when surface is flat

B1

or

$$F = ma$$

B1

time to come to rest (vertically) is increased

B1

acceleration is reduced

allow 1 mark for idea that “(vertical) component of normal reaction is reduced”

B1

(3)

[14]

20

- (a) conservation of momentum equation or statement quoted or used even with incorrect data

C1

$$1.4 \times 10^7 \times 1.7 \times 10^{-27} = 401.7 \times 10^{-27} \times v$$

C1

$$5.9(3) \times 10^4 \text{ m s}^{-1}$$

A1

(3)

- (b) neutron will rebound / have velocity / momentum to the left

B1

momentum transferred to the uranium will be greater

B1

velocity of uranium will be greater

(no loss of kinetic energy argument gets the final mark only)

B1

(3)

- (c) $KE = \frac{1}{2}mv^2$ seen or used

C1

$$0.5 \times 1.7 \times 10^{-27} \times (1.4 \times 10^7)^2$$

C1

$$1.7 \times 10^{-13} \text{ J } (1.67 - 10^{-13} \text{ J})$$

A1

(3)

[9]**21**

- (a) kinetic energy is not conserved **(1)**

(1)

- (b) (i) ($p = mv$ gives) $p = 0.12 \times 18 = 2.2 \text{ N s}$ **(1)** (2.16 N s)

(ii) $p = 0.12 \times (-15) = -1.8 \text{ N s}$ **(1)**

(iii) $\Delta p = 2.2 - (-1.8) = 4.0 \text{ N s}$ (3.96 N s) **(1)**
(allow e.c.f. from(i) and(ii))

(iv) $\left(F = \frac{\Delta(mv)}{\Delta t} \text{ gives} \right) F = \frac{3.96}{0.14}$ **(1)**
= 28 N **(1)** (28.3 N)
(allow e.c.f. from (iii))

(v) ($E_k = \frac{1}{2}mv^2$ gives) $E_k = 0.5 \times 0.12 \times (18^2 - 15^2) = 5.9 \text{ J}$ **(1)**

(6)

[7]

22

- (a) (i) length of card
[or distance travelled by trolley A] **(1)**
time at which first light gate is obscured
[or time taken to travel the distance] **(1)**
- (ii) time at which second light gate is obscured
[or distance travelled after collision and time taken] **(1)**

3

- (b) momentum = mass $\times$ velocity **(1)**
mass of each trolley **(1)**
(check whether) $p_{\text{initial}} = p_{\text{final}}$ **(1)**

max 2

- (c) incline the ramps **(1)**
until component of weight balances friction **(1)**
[or identify where the friction occurs **(1)**
sensible method of reducing **(1)**]

2

[7]**23**

- (a) kinetic energy changes to potential energy **(1)**
potential energy calculated by measuring h **(1)**
equate kinetic energy to potential energy to find speed **(1)**
[or use h to find s **(1)**
use $g \sin \theta$ for a **(1)**
use $v^2 = u^2 + 2as$ **(1)**
[or use h to find s **(1)**
time to travel s and calculate v_{av} **(1)**
 $v = 2v_{\text{av}}$ **(1)**]
- (b) (i) $p (= mv) = 0.5(0) \times 0.4(0) = 0.2(0)$ **(1)** N s (or kg m s⁻¹) **(1)**
- (ii) (use of $m_p v_p = m_t v_t$ gives) $0.002(0) v = 0.2(0)$ **(1)**
 $v = 100 \text{ m s}^{-1}$ **(1)**
- (c) (i) kinetic energy is not conserved **(1)**
- (ii) initial kinetic energy = $\frac{1}{2} \times 0.002 \times 100^2 = 10 \text{ (J)}$ **(1)**
- final kinetic energy = $\frac{1}{2} \times 0.5 \times 0.4^2 = 0.040 \text{ (J)}$ **(1)**
- hence change in kinetic energy **(1)**
- (allow C.E. for value of v from (b))

3

4

4

[11]