

Answer **all** questions.

You are advised to spend approximately **one hour** on this section.

1 (a) State, in words, the relationship between the force acting on a body and the momentum of the body.

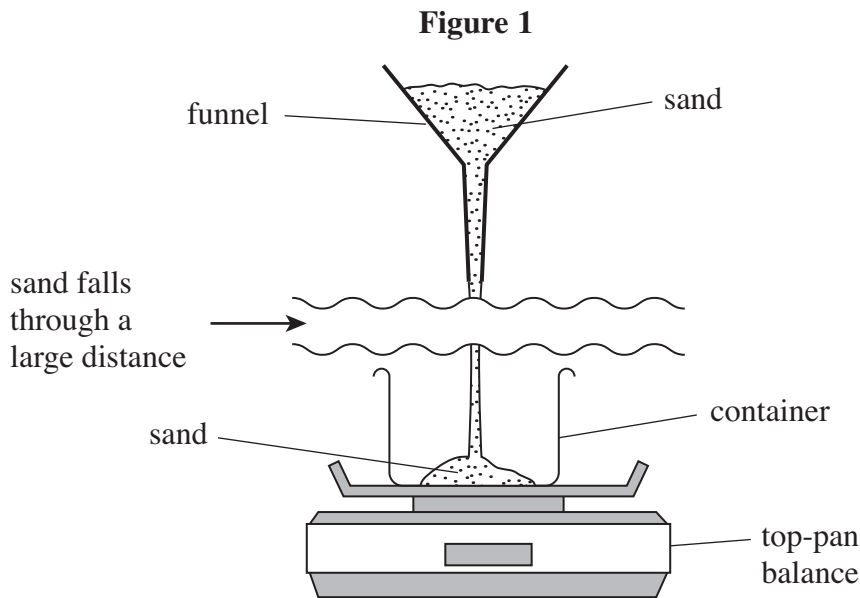
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(1 mark)

1 (b) A container rests on a top-pan balance, which measures mass in kg. A funnel above the container holds some sand. The sand falls at a constant rate of 0.300 kg s^{-1} into the container, having fallen through an average vertical height of 1.60 m. This arrangement is shown in **Figure 1**.



1 (b) (i) Show that the velocity of the sand as it lands in the container is 5.6 m s^{-1} .

(1 mark)

1 (b) (ii) Calculate the magnitude of the momentum of the sand that lands in the container in each second.

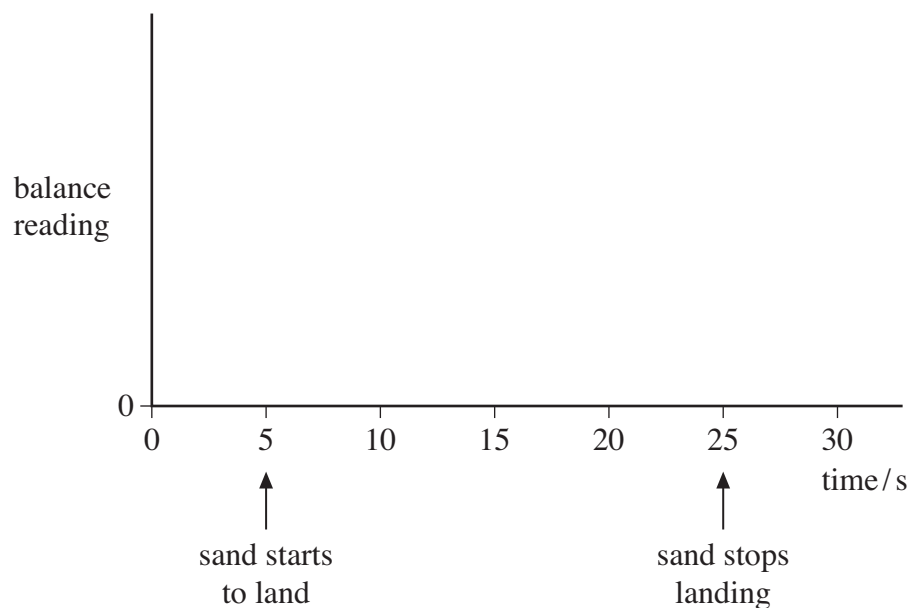
answer = N s
(1 mark)



- 1 (b) (iii) The mass of the container is 0.650 kg. Show that the reading of the balance, 10.0 s after the sand starts landing continuously in the container, will be 3.82 kg. You may assume that the sand comes to rest without rebounding when it lands in the container.

(3 marks)

- 1 (c) It takes 20.0 s for all of the sand to fall into the container. On the axes below, sketch a graph to show how the reading of the balance will change over a 30.0 s period, where $t = 5.0$ s is the time at which the sand starts to land in the container. No further calculations are required and values need not be shown on the vertical axis of the graph.



(3 marks)

9

Turn over ►



QUESTION ONE: COLLISIONS (8 marks)

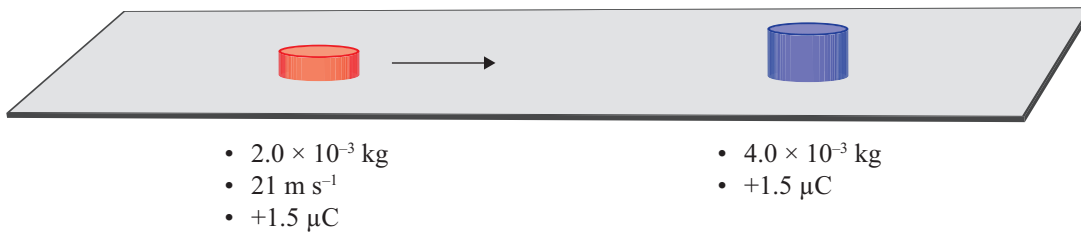
A red puck of mass 2.0×10^{-3} kg is set moving along a long, frictionless track towards a blue puck of mass 4.0×10^{-3} kg. The red puck has a velocity of 21 m s^{-1} , while the blue puck is at rest, but free to move. Both pucks carry a positive charge of 1.5×10^{-6} C. The pucks meet along the line of their centre of mass in an elastic interaction.

The charges cause an electrostatic force between the two pucks.

When they are separated by a distance r , the repulsive force is given by $F = \frac{kQ_1Q_2}{r^2}$.

The electric potential energy is given by $E_p = \frac{kQ_1Q_2}{r}$.

Q_1 and Q_2 are the two charges and k is a constant ($= 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-1}$).



(a) Describe (without calculations) the motion of each puck as it interacts with the other.

(b) At the instant of closest approach, both pucks have the same velocity.

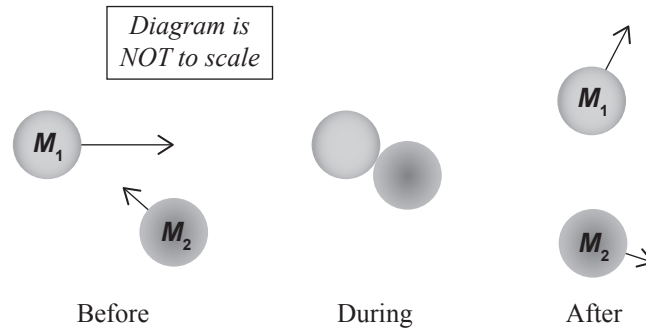
Explain why this is so, and show that the velocity is 7.0 m s^{-1} .

- (c) If the pucks are initially 10 m apart, show that the electrostatic potential energy at this separation is negligible compared with the kinetic energy of the moving puck.

- (d) By considering the kinetic and electrostatic energies, calculate the distance of closest approach.

- (e) Calculate the final velocities of the pucks (when they are a long distance apart).

QUESTION TWO: COLLISIONS



The diagram above represents the motion of a pair of discs sliding (with only linear motion prior to the collision) on a frictionless surface, shown before they collide, at the point of collision and shortly after the collision. The discs have the same radii but are made of materials of different densities.

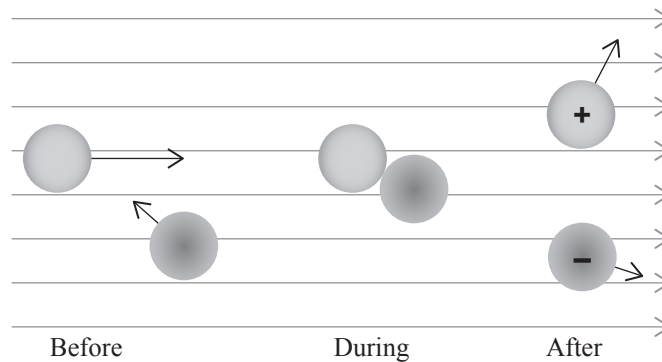
M_1 has a mass of 3.0 kg and an original velocity vector [using coordinates (x,y)] of $(2.0,0.0)$ m s⁻¹. After the collision, M_1 has a velocity vector of $(0.50,1.0)$ m s⁻¹. M_2 has a mass of 5.0 kg and an original velocity vector of $(-0.50,0.50)$ m s⁻¹.

- (a) Show that the velocity vector of M_2 immediately after the collision is $(0.40,-0.10)$ m s⁻¹.

- (b) Show that the collision is inelastic and explain how the collision does not violate the principle of conservation of energy.

- (c) Describe and explain the motion (both linear and rotational) of each disc after the collision, assuming that there is friction between the edges of the discs.

- (d) When the discs collide, there is a separation of charge, as shown below.



If the collision takes place inside a region of uniform electric field (as shown above), describe how the motion of the discs might be affected both before and after the collision.

You may use diagrams to assist your answer.

QUESTION FOUR: CRUMPLE ZONES

Crumple zones are parts of a vehicle that are designed to deform during a collision, converting kinetic energy into heat of deformation.

As a test, a 2.20 kg model truck moving at 8.33 m s^{-1} collides with the back of a stationary 1.50 kg model car that is fitted with a crumple zone.

Immediately after the collision, the model car is moving at 5.55 m s^{-1} .

- (a) If the model truck is not damaged and a constant force of $5.00 \times 10^2 \text{ N}$ was exerted during the collision, calculate the maximum change in length of the model car as a result of the collision.

Explain all working.

- (b) State the major assumption you had to make in order to complete (a) above, and give reasons why the assumption is unlikely to be correct.

- (c) Calculate the time the two vehicles are in contact.

QUESTION FIVE: MOTION (8 marks)

Ball X is released from rest from a height h and hits the ground with speed $v \text{ m s}^{-1}$. At precisely the same time as ball X is dropped, ball Y is launched straight up from the ground at $v \text{ m s}^{-1}$.

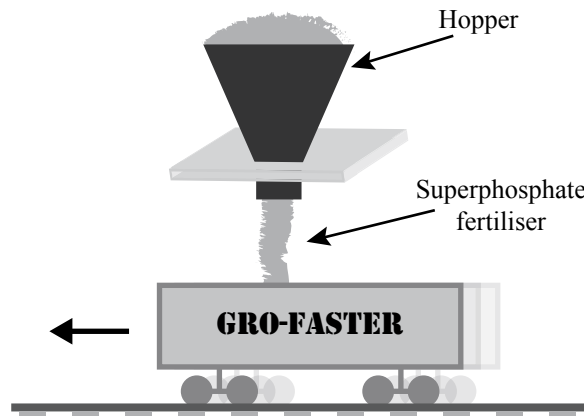
- (a) Show that the two balls will pass each other at a point $\frac{1}{4}h$ from the release point of ball X.

- (b) Use physical principles to explain this result.

- (c) A ball of mass m makes a head-on elastic collision with a stationary second ball of mass M and rebounds with a speed equal to one-third its original speed. Show that the mass of the second ball is equal to $2m$.

QUESTION SIX: “GRO-FASTER” FERTILISER FACTORY (8 marks)

At the “Gro-Faster” fertiliser factory, superphosphate fertiliser is transferred from a hopper into railway wagons, which are directly under the hopper as the superphosphate is released (see diagram below). An empty railway wagon has a mass of 2.20×10^4 kg and each wagon has a speed of 1.25 m s^{-1} as it approaches the hopper. Wagons are not connected with each other.



1.5×10^4 kg of superphosphate fertiliser are transferred from the hopper to each wagon.

- (a) Calculate the momentum and velocity of a wagon after the superphosphate has been transferred, ignoring friction.

- (b) One wagon has a hole in its floor, which allows some of the superphosphate to fall below the wagon as it rolls along the track. Discuss the effect, if any, this will have on the motion of the wagon, ignoring friction.
