QUESTION ONE: COLLISIONS (8 marks)

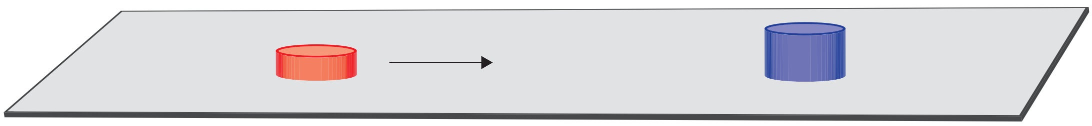
A red puck of mass 2.0×10^{-3} kg is set moving along a long, frictionless track towards a blue puck of mass 4.0×10^{-3} kg. The red puck has a velocity of 21 m s^{-1}, while the blue puck is at rest, but free to move. Both pucks carry a positive charge of 1.5×10^{-6} C. The pucks meet along the line 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 $F = \dfrac{kQ_1Q_2}{r^2}$.

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

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



- 2.0×10^{-3} kg
- 21 m s^{-1}
- +1.5 μC

- 4.0×10^{-3} kg
- +1.5 μC

(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}.

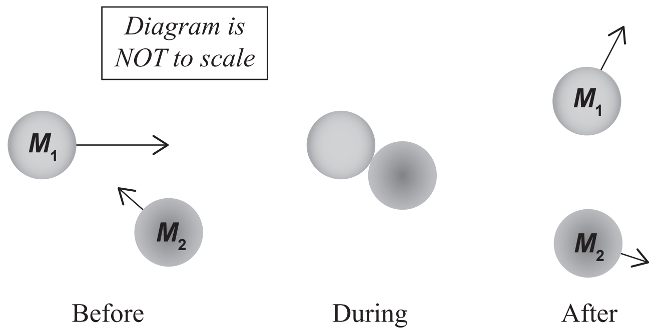
(c) If the pucks are initially 10 m apart, show that the electrostatic potential energy at this separation is negligible compared with the kinetic energy of the moving puck.

(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).

(8)

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.

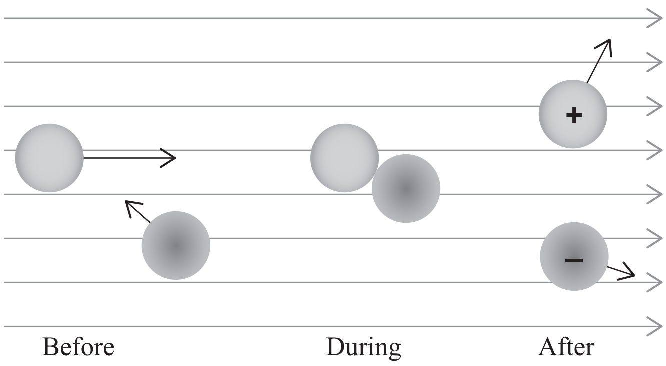
M_1 has a mass of 3.0 kg and an original velocity vector [using coordinates (x,y)] of (2.0,0.0) m s^{-1}. After the collision, M_1 has a velocity vector of (0.50,1.0) m s^{-1}. M_2 has a mass of 5.0 kg and an original velocity vector of (–0.50,0.50) m s^{-1}.

(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.

(8)

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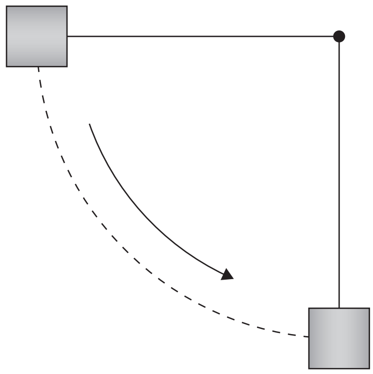
QUESTION THREE: THE SWINGING MASS

A mass m, connected to an inextensible light rope of length L, is allowed to swing down from a horizontal position to the vertical as shown in the diagram.



(a) (i) Show that the maximum tension in the rope is $3mg$.

(ii) Explain why the length of the rope does not affect the maximum tension.

(b) (i) The rope is replaced by a piece of extensible rubber (spring constant k) of the same length, L.

Show that the maximum tension reached in the rubber when the mass is allowed to swing down is given by:

$$T_{\text{max}} = \frac{3mg(L + x)}{L + 2x}$$

where L is the unstretched length of the rubber, and x is the maximum extension of the rubber.

(ii) Explain why, despite the mass falling a greater distance, the maximum tension in the rubber is less than the maximum tension in the rope.

(8)

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 5.00×10^2 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.

(d) Using physical principles, explain why it is a cause for concern if vehicles do not have crumple zones.

(e) Using physical principles, explain how a seat belt can reduce the risk of injury in a collision.

(8)

QUESTION FIVE: MOTION (8 marks)

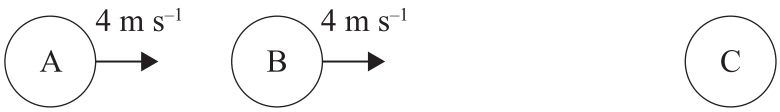
Ball X is released from rest from a height h and hits the ground with speed v m s^{-1}. At precisely the same time as ball X is dropped, ball Y is launched straight up from the ground at v m s^{-1}.

(a) Show that the two balls will pass each other at a point ¼ 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 $2m$.

(d) A pair of balls (both of mass *m*) are sliding along a long, horizontal, frictionless groove towards a stationary third ball (also of mass *m*), as shown in the following diagram.



For the collision of a pair of objects the coefficient of restitution, σ, is calculated by

$$\sigma = \frac{\text{The difference in the velocities after the collision}}{\text{The difference in the velocities before the collision}}$$

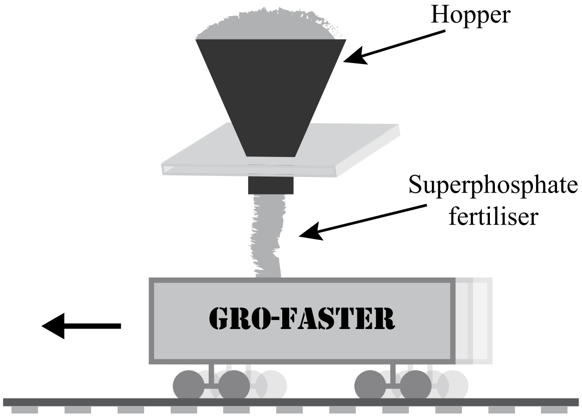
The coefficient of restitution of these balls is 0.4.

Show that there are just three collisions between the balls and that the sum of the final velocities of the three balls is 8 m s^{-1}.

(8)

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.

(c) The density of superphosphate fertiliser is 1.1×10^3 kg m^{-3} and the wagons are 1.5 m wide and 1.5 m high. Estimate the maximum mass of superphosphate that can be transferred in one hour.

(d) In fact, there is some friction, so to keep the wagons rolling at a constant speed, the track slopes downward at an angle θ. The frictional force is given by $F = \mu N$, where μ is the coefficient of friction between the rotating wheel and the track and N is the normal force of the track on the wheel. If the coefficient of friction is 0.005, calculate the angle of the track so that the wagons maintain a constant speed.

(8)