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CONSERVATION OF MOMENTUM

Learner Note: Always draw a diagram of the situation, before and after the collision. Place all the numerical values on the diagram and remember to SELECT A DIRECTION AS POSITIVE OR NEGATIVE.

SECTION A: TYPICAL EXAM QUESTIONS

Question 1: 15 minutes (Taken from DoE Paper 1 Additional Exemplar 2008)

New cars have a crumple zone to help minimise injuries during accidents. In addition seat belts, air bags and padded interiors can reduce the chance of death or serious injury.

1.1 Use principles in Physics to explain how air bags can reduce the chance of death or injury.

(3)

1.2 In a crash test, a car of mass $1,2 \times 10^3$ kg collides with a wall and rebounds as illustrated below. The initial and final velocities of the car are $12 \text{ m}\cdot\text{s}^{-1}$ to the left and $2 \text{ m}\cdot\text{s}^{-1}$ to the right respectively. The collision lasts 0,1 s.

Calculate the:

1.2.1 Impulse of the car during the accident

(4)

1.2.2 Average force exerted on the car

(3)

1.3 How will the magnitude of the force exerted on the car be affected if the time interval of the collision remains 0,1 s, but the car does not bounce off the wall? Write down only INCREASES, DECREASES or REMAINS THE SAME. Explain your answer.

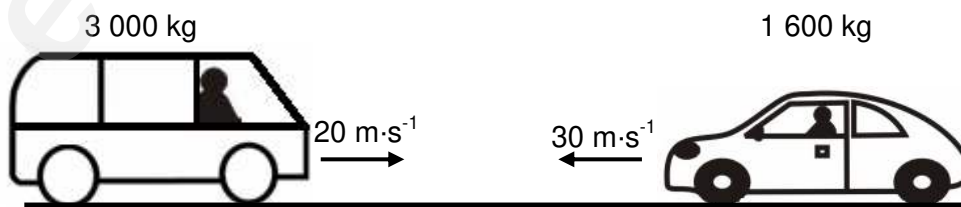
(2)

[12]

(Remember that impulse is equal to the change in momentum. If you use the change in momentum to work out the impulse, the units must be $\text{N}\cdot\text{s}$ even though you used mass and the change in the velocity.)

Question 2: 15 minutes (Taken from DoE Paper 1 Exemplar 2008)

Collisions happen on the roads in our country daily. In one of these collisions, a car of mass 1 600 kg, travelling at a speed of $30 \text{ m}\cdot\text{s}^{-1}$ to the left, collides head-on with a minibus of mass 3 000 kg, travelling at $20 \text{ m}\cdot\text{s}^{-1}$ to the right. The two vehicles move together as a unit in a straight line after the collision.



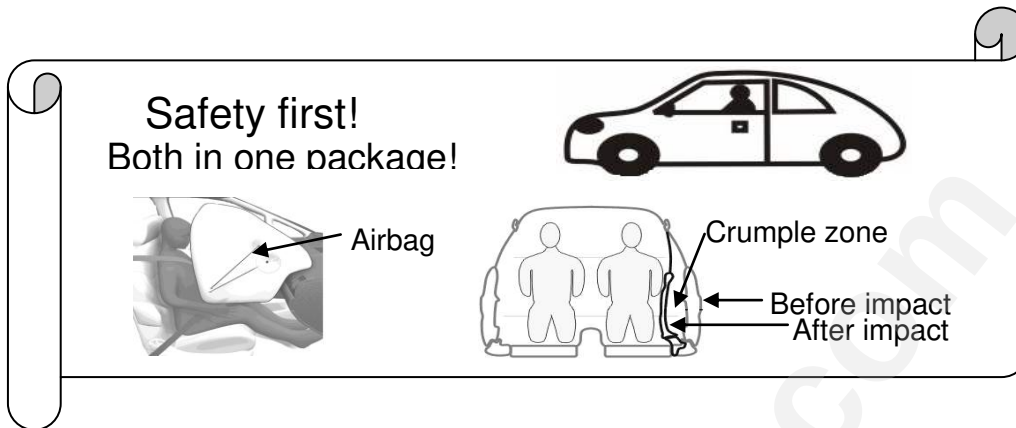
2.1 Calculate the velocity of the two vehicles after the collision.

(6)

2.2 Do the necessary calculations to show that the collision was inelastic.

(6)

2.3 The billboard below advertises a car from a certain manufacturer.



Use your knowledge of momentum and impulse to justify how the safety features mentioned in the advertisement contribute to the safety of passengers.

(3)
[15]

SECTION B: SOLUTIONS AND HINTS

Question 1:

- 1.1 When the airbag inflates during a collision, the contact time of a passenger/driver with an air bag is longer than without an airbag ✓ and thus the force on the passenger/driver is reduced ✓ according to $F_{net} = \Delta p / \Delta t$ ✓. (3)

1.2.1 Take to the right as negative:

$$F_{net} \Delta t = \Delta p = mv_f - mv_i \checkmark$$

$$F_{net} \Delta t = 1,2 \times 10^3 (-2 - 12) \checkmark$$

$$= -1,68 \times 10^4$$

OR

Impulse = $1,68 \times 10^4$ N·s ✓ to the right or away from wall ✓

$$v_f = v_i + a \Delta t$$

$$-2 = 12 + a(0,1)$$

$$a = -140 \text{ m} \cdot \text{s}^{-2}$$

$$= 140 \text{ m} \cdot \text{s}^{-2} \text{ to the right}$$

$$F_{net} = ma$$

$$= (1,2 \times 10^3)(-140) \checkmark$$

$$= -1,68 \times 10^5$$

$$F_{net} = 1,68 \times 10^5 \text{ N to the right}$$

$$\text{Impulse} = F_{net} \Delta t \checkmark$$

$$= (1,68 \times 10^5)(0,1) \checkmark$$

$$= 1,68 \times 10^4 \text{ N} \cdot \text{s} \checkmark \text{ to the right or away from wall}$$

(4)

1.2.2 $F_{net} \Delta t = \Delta p = -1,68 \times 10^4$

$$F_{net}(0,1) = -1,68 \times 10^4 \checkmark$$

$$F_{net} = -1,68 \times 10^5 \text{ N}$$

$$F_{net} = 1,68 \times 10^5 \text{ N to the right} \checkmark$$

OR

Take to the right as negative:

$$v_f = v_i + a \Delta t$$

$$-2 = 12 + a(0,1)$$

$$a = -140 \text{ m} \cdot \text{s}^{-2}$$

$$F_{net} = ma$$

$$= (1,2 \times 10^3)(-140) \checkmark$$

$$= -1,68 \times 10^5$$

$$F_{\text{net}} = 1,68 \times 10^5 \text{ N} \checkmark \text{ to the right or away from the wall} \checkmark \quad (3)$$

1.3 Decreases $\checkmark$

The final velocity of the car is zero and thus Δp decreases $\checkmark$

(2)

[12]

(Remember the selection of a direction and the integration of equations of motion in this section.)

Learner Note: Copy the equation off the information sheet as given. Then only substitute into the equation and then manipulate the equation to make the unknown the subject of the formula.

2.1 Consider motion to the right as positive:

$$p_{\text{before}} = p_{\text{after}} \checkmark$$

$$m_1 v_{i1} + m_2 v_{i2} = (m_1 + m_2) v_f$$

$$(1\,600)(30) \checkmark + (3\,000)(-20) \checkmark = (1\,600 + 3\,000) v_f \checkmark$$

$$48\,000 - 60\,000 = (4\,600) v_f$$

$$v_f = -2,6 \text{ m} \cdot \text{s}^{-1} \therefore v_f = 2,6 \text{ m} \cdot \text{s}^{-1} \checkmark \text{ to the right} \checkmark \quad (6)$$

2.2 Before collision:

$$E_k = \frac{1}{2} m_1 v_{i1}^2 + \frac{1}{2} m_2 v_{i2}^2 \checkmark = \frac{1}{2} (1\,600)(30)^2 + \frac{1}{2} (3\,000)(16)^2 \checkmark$$

$$= 720\,000 + 384\,000 = 1,104 \times 10^6 \text{ J} \checkmark$$

After collision:

$$E_k = \frac{1}{2} m_1 v_{f1}^2 + \frac{1}{2} m_2 v_{f2}^2 = \frac{1}{2} (1\,600 + 3\,000)(2,6)^2 \checkmark = 384\,000$$

$$= 5\,980 \text{ J} \checkmark$$

E_k before collision not equal to E_k after collision – thus the collision is inelastic $\checkmark \quad (6)$

2.3 During a collision, the crumple zone/ airbag increases the time during which momentum changes $\checkmark$ and according to the equation

$$F_{\text{net}} = \frac{\Delta p}{\Delta t} \checkmark \text{ the force during impact will decrease. } \checkmark \quad (3)$$

SECTION C: ADDITIONAL CONTENT NOTES

Momentum and Impulse

Momentum is a vector quantity and has the unit: $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$.

$$p = mv$$

The principle of conservation of linear momentum:

The total linear momentum of an isolated system remains constant in magnitude and direction.

E.g. If these two balls have exploded apart from rest

●	●
←	→
$v_1 = -2\text{m}\cdot\text{s}^{-1}$	$v_2 = ?$
$m_1 = 2\text{ kg}$	$m_2 = 2,2\text{ kg}$
$p_{\text{before collision}} = p_{\text{after collision}}$	
0	$= m_1v_1 + m_2v_2$
0	$= 2(-2) + 2,2\cdot v_2$
4	$= 2,2\cdot v_2$
v_2	$= 1,82\text{ m}\cdot\text{s}^{-1}$

Impulse:

The applied resultant force is equal to the rate of change of momentum (impulse), and this change is in the direction of the force applied.

Therefore

$$F_{\text{res}}\Delta t = m\Delta v$$

Be very careful of sign conventions!

We need to know the difference between elastic and inelastic collisions.

In an *elastic collision* kinetic energy and momentum are conserved.

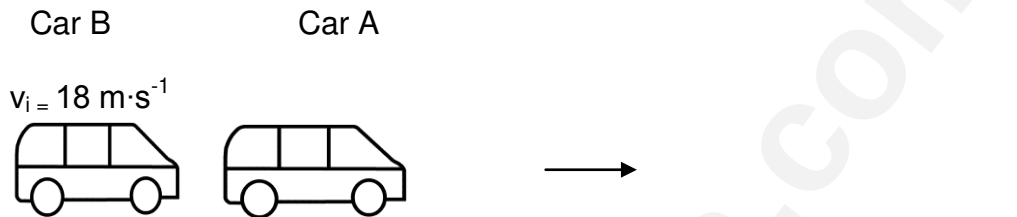
In an *inelastic collision*, momentum is conserved, but not kinetic energy.

The conservation of kinetic energy is determined by calculating the total kinetic energy of all parts of the closed system before the collision and comparing that to the total kinetic energy of all the parts of the closed system after the collision.

SECTION D: HOMEWORK

Question 1 – 13 minutes (Taken from DoE PI Nov 2008)

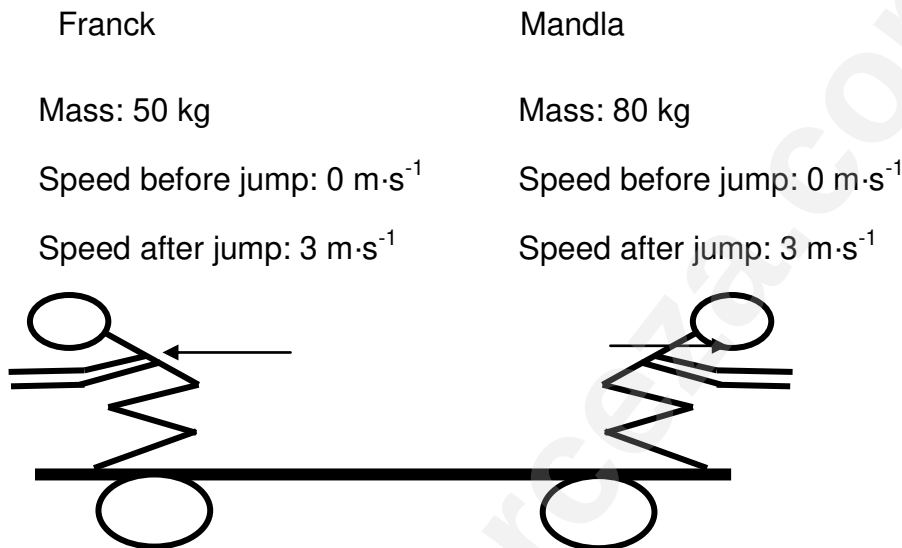
The most common reasons for rear-end collisions are too short a following distance, speeding and failing brakes. The sketch below represents one such collision. Car A of mass $1\,000\text{ kg}$, stationary at a traffic light, is hit from behind by Car B of mass $1\,200\text{ kg}$, travelling at $18\text{ m}\cdot\text{s}^{-1}$. Immediately after the collision Car A moves forward at $12\text{ m}\cdot\text{s}^{-1}$.



- 1.1 Assume that linear momentum is conserved during this collision. Calculate the speed of Car B immediately after the collision. (4)
 - 1.2 Modern cars are designed to crumple partially on impact. Explain why the assumption made in QUESTION 1.1 may NOT be valid in this case. (2)
 - 1.3 A traffic officer appears at the scene of the accident and mentions the dangers of a head-on collision. He mentions that for cars involved in a head-on collision, the risk of injury for passengers in a heavier car would be less than for passengers in a lighter car. Use principles of Physics to explain why the statement made by the traffic officer is correct. (3)
- [9]**

Question 2 – 17 minutes (Taken from Gauteng Prelim Paper PI 2009)

Two boys Franck and Mandla have masses of 50 kg and 80 kg respectively. They stand on a stationary trolley of mass 180 kg. The trolley is free to move in a horizontal plane either to the left or to the right. The boys simultaneously jump off the trolley in opposite directions from each end of the trolley. Both the boys leave the trolley with an initial speed of $3 \text{ m}\cdot\text{s}^{-1}$ relative to the ground.



Calculate the magnitude and direction of the velocity at which the trolley starts to move immediately after the boys have jumped off the trolley. (6)

2.2 Give a reason why the velocity of the trolley calculated in 2.1 does not remain constant after the boys have jumped off. (2)

2.3 Explain, using Newton's second Law, why the trolley moves in the direction as calculated in question 2.1 as above. (4)

2.4 The time it takes for Mandla to push against the trolley with his legs is 0.2 s. During this time the trolley exerts a force on Mandla. Calculate the magnitude of the force the trolley exerts on Mandla during the time it takes for Mandla to push against the trolley. (3)

2.5 Explain why Mandla accelerates towards the right if the force exerted on Mandla by the trolley and the force Mandla exerts on the trolley has the same magnitude but act in opposite directions to each other. (2)

[17]