Study materials for today (20th May, 2020) .

Go through the followings :

1. Topics 9.5 The Third Law of Motion and 9.6 Conservation of Momentum .
2. Go through activities 9.5 and 9.6 .
3. Go through the examples 9.6 to 9.8 (pages 122 to 126) .
4. Go through the video clips for the topic law of conservation of Momentum .

After that write the following questions :

1. Write the Mathmetical formulation of Law of conservation of Momentum .
2. Practice the examples from the book (Examples 9.6 to 9.8) .

Home work will be uploaded by tomorrow 8 pm (Thursday, 21st May) .

That's all for today . Thanks .

1:40 am ✓

The force exerted on the ball F is,
$F = ma = (20/1000)\ kg \times (-0.02\ m\ s^{-2})$
$= -0.0004\ N.$
The negative sign implies that the frictional force exerted by the table is opposite to the direction of motion of the ball.

9.5 Third Law of Motion

The first two laws of motion tell us how an applied force changes the motion and provide us with a method of determining the force. The third law of motion states that when one object exerts a force on another object, the second object instantaneously exerts a force back on the first. These two forces are always equal in magnitude but opposite in direction. These forces act on different objects and never on the same object. In the game of football sometimes we, while looking at the football and trying to kick it with a greater force, collide with a player of the opposite team. Both feel hurt because each applies a force to the other. In other words, there is a pair of forces and not just one force. The two opposing forces are also known as action and reaction forces.

Let us consider two spring balances connected together as shown in Fig. 9.10. The fixed end of balance B is attached with a rigid support, like a wall. When a force is applied through the free end of spring balance A, it is observed that both the spring balances show the same readings on their scales. It means that the force exerted by spring balance A on balance B is equal but opposite in direction to the force exerted by the balance B on balance A. The force which balance A exerts on balance B is called the *action* and the force of balance B on balance A is called the *reaction*. This gives us an alternative statement of the third law of motion i.e., to every action there is an equal and opposite reaction. However, it must be remembered that the action and reaction always act on two different objects.

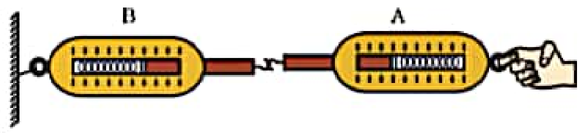

Fig. 9.10: *Action and reaction forces are equal and opposite.*

Suppose you are standing at rest and intend to start walking on a road. You must accelerate, and this requires a force in accordance with the second law of motion. Which is this force? Is it the muscular effort you exert on the road? Is it in the direction we intend to move? No, you push the road below backwards. The road exerts an equal and opposite reaction force on your feet to make you move forward.

It is important to note that even though the action and reaction forces are always equal in magnitude, these forces may not produce accelerations of equal magnitudes. This is because each force acts on a different object that may have a different mass.

When a gun is fired, it exerts a forward force on the bullet. The bullet exerts an equal and opposite reaction force on the gun. This results in the recoil of the gun (Fig. 9.11). Since the gun has a much greater mass than the bullet, the acceleration of the gun is much less than the acceleration of the bullet. The third law of motion can also be illustrated when a sailor jumps out of a rowing boat. As the sailor jumps forward, the force on the boat moves it backwards (Fig. 9.12).

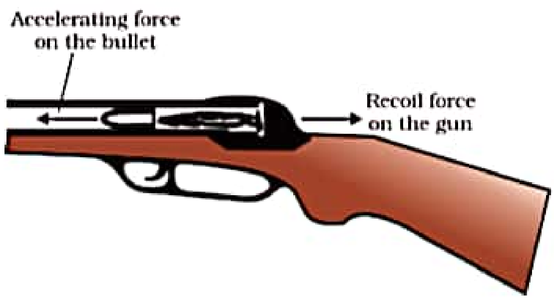

Fig. 9.11: *A forward force on the bullet and recoil of the gun.*

Fig. 9.12: *As the sailor jumps in forward direction, the boat moves backwards.*

Activity 9.4

- Request two children to stand on two separate carts as shown in Fig. 9.13.
- Give them a bag full of sand or some other heavy object. Ask them to play a game of catch with the bag.
- Does each of them receive an instantaneous reaction as a result of throwing the sand bag (action)?
- You can paint a white line on cartwheels to observe the motion of the two carts when the children throw the bag towards each other.

Fig. 9.13

Now, place two children on one cart and one on another cart. The second law of motion can be seen, as this arrangement would show different accelerations for the same force.

The cart shown in this activity can be constructed by using a 12 mm or 18 mm thick plywood board of about 50 cm × 100 cm with two pairs of hard ball-bearing wheels (skate wheels are good to use). Skateboards are not as effective because it is difficult to maintain straight-line motion.

9.6 Conservation of Momentum

Suppose two objects (two balls A and B, say) of masses m_A and m_B are travelling in the same direction along a straight line at different velocities u_A and u_B, respectively [Fig. 9.14(a)]. And there are no other external unbalanced forces acting on them. Let $u_A > u_B$ and the two balls collide with each other as shown in Fig. 9.14(b). During collision which lasts for a time t, the ball A exerts a force F_{AB} on ball B and the ball B exerts a force F_{BA} on ball A. Suppose v_A and v_B are the velocities of the two balls A and B after the collision, respectively [Fig. 9.14(c)].

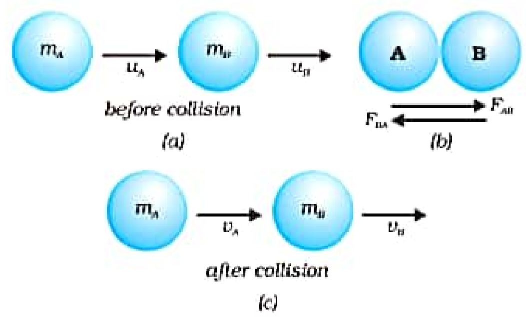

Fig. 9.14: *Conservation of momentum in collision of two balls.*

From Eq. (9.1), the momenta (plural of momentum) of ball A before and after the collision are $m_A u_A$ and $m_A v_A$, respectively. The rate of change of its momentum (or F_{AB}, action) during the collision will be $m_A \frac{(v_A - u_A)}{t}$.

Similarly, the rate of change of momentum of ball B (= F_{BA} or reaction) during the collision will be $m_B \frac{(v_B - u_B)}{t}$.

According to the third law of motion, the force F_{AB} exerted by ball A on ball B (action) and the force F_{BA} exerted by the ball B on ball A (reaction) must be equal and opposite to each other. Therefore,

$$F_{AB} = -F_{BA} \tag{9.6}$$

or $$m_A \frac{(v_A - u_A)}{t} = -m_B \frac{(v_B - u_B)}{t}.$$

This gives,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B \tag{9.7}$$

Since $(m_A u_A + m_B u_B)$ is the total momentum of the two balls A and B before the collision and $(m_A v_A + m_B v_B)$ is their total momentum after the collision, from Eq. (9.7) we observe that the total momentum of the two balls remains unchanged or conserved provided no other external force acts.

As a result of this ideal collision experiment, we say that the sum of momenta of the two objects before collision is equal to the sum of momenta after the collision provided there is no external unbalanced force acting on them. This is known as the law of conservation of momentum. This statement can alternatively be given as the total momentum of the two objects is unchanged or conserved by the collision.

Activity 9.5

- Take a big rubber balloon and inflate it fully. Tie its neck using a thread. Also using adhesive tape, fix a straw on the surface of this balloon.
- Pass a thread through the straw and hold one end of the thread in your hand or fix it on the wall.
- Ask your friend to hold the other end of the thread or fix it on a wall at some distance. This arrangement is shown in Fig. 9.15.
- Now remove the thread tied on the neck of balloon. Let the air escape from the mouth of the balloon.
- Observe the direction in which the straw moves.

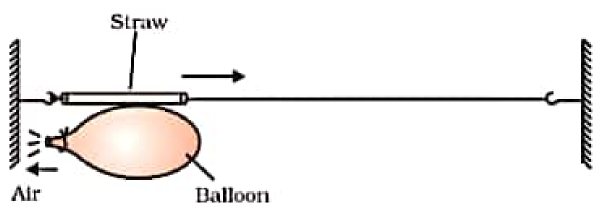

Fig. 9.15

Activity 9.6

- Take a test tube of good quality glass material and put a small amount of water in it. Place a stop cork at the mouth of it.
- Now suspend the test tube horizontally by two strings or wires as shown in Fig. 9.16.
- Heat the test tube with a burner until water vaporises and the cork blows out.
- Observe that the test tube recoils in the direction opposite to the direction of the cork.

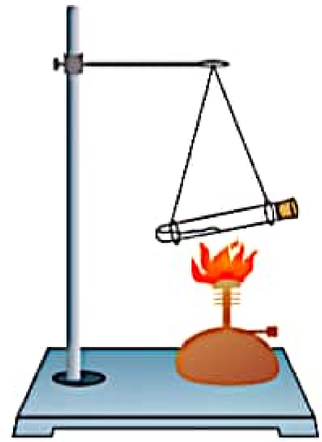

Fig. 9.16

- Also, observe the difference in the velocity the cork appears to have and that of the recoiling test tube.

Example 9.6 A bullet of mass 20 g is horizontally fired with a velocity 150 m s^{-1} from a pistol of mass 2 kg. What is the recoil velocity of the pistol?

Solution:

We have the mass of bullet, m_1 = 20 g (= 0.02 kg) and the mass of the pistol, m_2 = 2 kg; initial velocities of the bullet (u_1) and pistol (u_2) = 0, respectively. The final velocity of the bullet, v_1 = + 150 m s^{-1}. The direction of bullet is taken from left to right (positive, by convention, Fig. 9.17). Let v be the recoil velocity of the pistol.

Total momenta of the pistol and bullet before the fire, when the gun is at rest

$= (2 + 0.02)\ \text{kg} \times 0\ \text{m s}^{-1}$

$= 0\ \text{kg m s}^{-1}$

Total momenta of the pistol and bullet after it is fired

$= 0.02\ \text{kg} \times (+\ 150\ \text{m s}^{-1}) + 2\ \text{kg} \times v\ \text{m s}^{-1}$

$= (3 + 2v)\ \text{kg m s}^{-1}$

According to the law of conservation of momentum

Total momenta after the fire = Total momenta before the fire

$3 + 2v = 0$

$\Rightarrow v = -\ 1.5\ \text{m s}^{-1}$.

Negative sign indicates that the direction in which the pistol would recoil is opposite to that of bullet, that is, right to left.

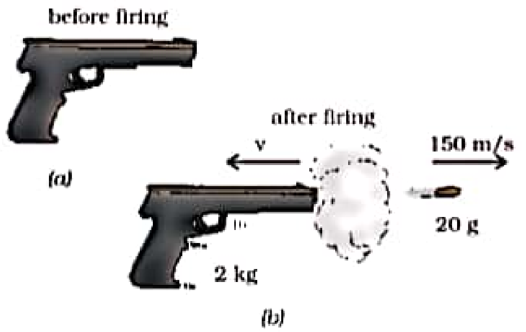

Fig. 9.17: *Recoil of a pistol*

Example 9.7 A girl of mass 40 kg jumps with a horizontal velocity of 5 m s^{-1} onto a stationary cart with frictionless wheels. The mass of the cart is 3 kg. What is her velocity as the cart starts moving? Assume that there is no external unbalanced force working in the horizontal direction.

Solution:

Let v be the velocity of the girl on the cart as the cart starts moving.

The total momenta of the girl and cart before the interaction

$= 40\ \text{kg} \times 5\ \text{m s}^{-1} + 3\ \text{kg} \times 0\ \text{m s}^{-1}$

$= 200\ \text{kg m s}^{-1}$.

Total momenta after the interaction

$= (40 + 3)\ \text{kg} \times v\ \text{m s}^{-1}$

$= 43\ v\ \text{kg m s}^{-1}$.

According to the law of conservation of momentum, the total momentum is conserved during the interaction. That is,

$43\ v = 200$

$\Rightarrow v = 200/43 = +\ 4.65\ \text{m s}^{-1}$.

The girl on cart would move with a velocity of 4.65 m s^{-1} in the direction in which the girl jumped (Fig. 9.18).

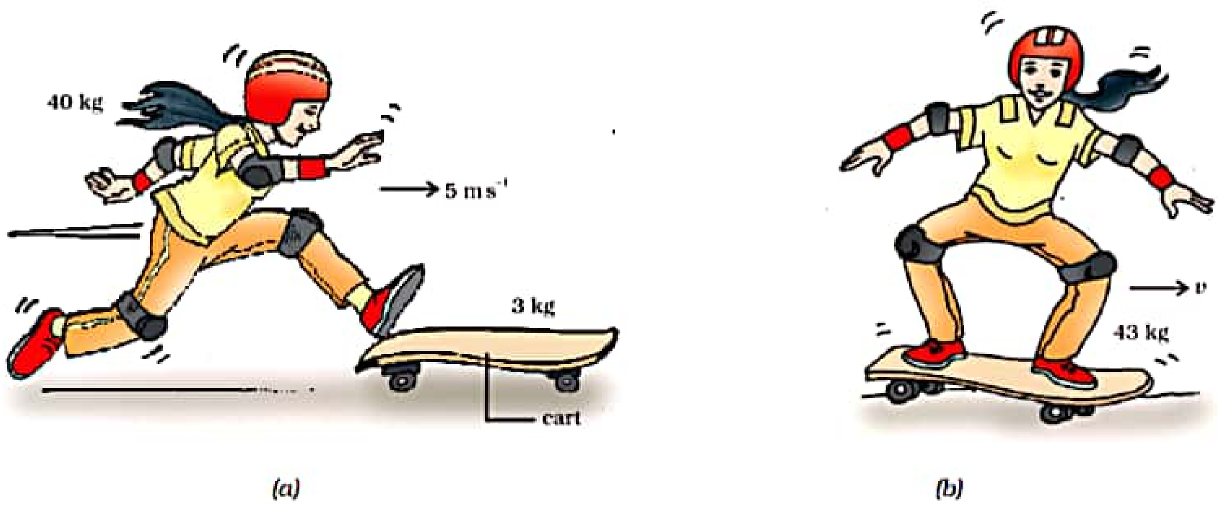

Fig. 9.18: *The girl jumps onto the cart.*

Example 9.8 Two hockey players of opposite teams, while trying to hit a hockey ball on the ground collide and immediately become entangled. One has a mass of 60 kg and was moving with a velocity 5.0 m s^{-1} while the other has a mass of 55 kg and was moving faster with a velocity 6.0 m s^{-1} towards the first player. In which direction and with what velocity will they move after they become entangled? Assume that the frictional force acting between the feet of the two players and ground is negligible.

Solution:

Let the first player be moving from left to right. By convention left to right is taken as the positive direction and thus right to left is the negative direction (Fig. 9.19). If symbols m and u represent the mass and initial velocity of the two players, respectively. Subscripts 1 and 2 in these physical quantities refer to the two hockey players. Thus,

m_1 = 60 kg; u_1 = + 5 m s^{-1}; and

m_2 = 55 kg; u_2 = – 6 m s^{-1}.

The total momentum of the two players before the collision

= 60 kg × (+ 5 m s^{-1}) + 55 kg × (– 6 m s^{-1})

= – 30 kg m s^{-1}

If υ is the velocity of the two entangled players after the collision, the total momentum then

= $(m_1 + m_2) \times \upsilon$

= (60 + 55) kg × υ m s^{-1}

= 115 × υ kg m s^{-1}.

Equating the momenta of the system before and after collision, in accordance with the law of conservation of momentum, we get

υ = – 30/115

= – 0.26 m s^{-1}.

Thus, the two entangled players would move with velocity 0.26 m s^{-1} from right to left, that is, in the direction the second player was moving before the collision.

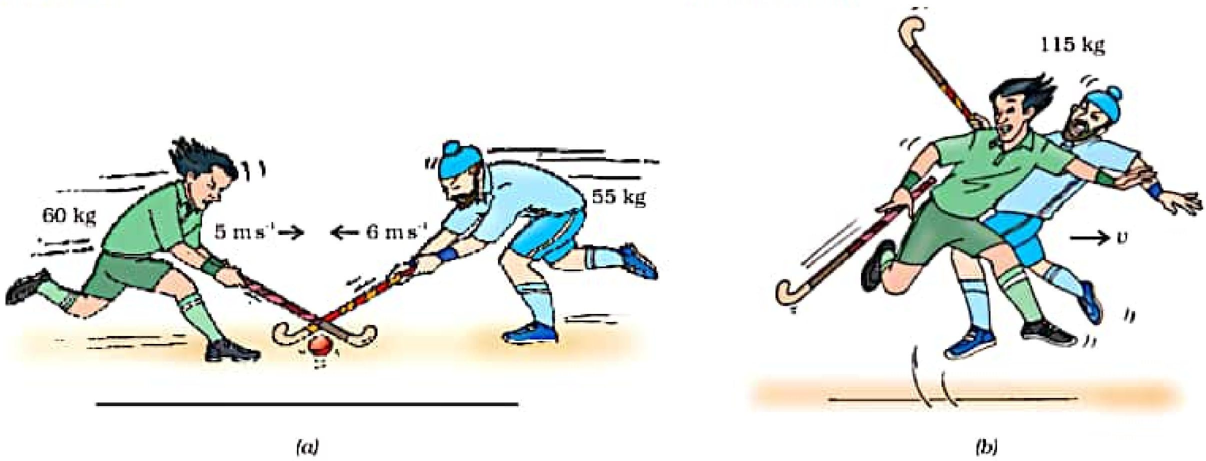

Fig. 9.19: A collision of two hockey players: (a) before collision and (b) after collision.

Questions

1. *If action is always equal to the reaction, explain how a horse can pull a cart.*
2. *Explain, why is it difficult for a fireman to hold a hose, which ejects large amounts of water at a high velocity.*
3. *From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 m s^{-1}. Calculate the initial recoil velocity of the rifle.*