Laws of Motion

Case Study Based Questions

Read the following passages and answer the questions that follow:

1. The product of force and time which is the change in momentum of the body remains a measurable quantity. This product is called impulse.
Impulse = Force x time duration
= Change in momentum
Large force acting for a short time to produce a finite change in momentum is called an impulsive 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. The two opposing forces are also known as action and reaction forces.
(A) A bird is sitting on the floor of a wire cage and the cage is in the hand of a boy. The bird starts flying in the cage. Will the boy experience any change in the weight of the cage?
(B) A nucleus is at rest in the laboratory frame of reference. Show that if it disintegrates into two smaller nuclei, the products must move in opposite directions.
(C) A ball of mass m strikes a wall at an angle of 30° with velocity v and is reflected at the same angle without any loss of speed. What is the magnitude of impulse imparted to the ball by the wall and what is the direction of the force of the wall due to the ball?

Ans. (A) When the bird starts flying inside the cage the weight of the bird is no more experienced as air inside is in free contact with atmospheric air. Hence, the cage will appear lighter.
(B) Let m_1 and m_2 be the respective masses of the parent nucleus and the two daughter nuclei. The parent nucleus is at rest. Initial momentum of the system (parent nucleus) = 0
Let v_1 and v_2 be the respective velocities ofthe daughter nuclei having masses m_1 and m_1.
Total linear momentum of the system after
disintegration = $m_1V_1 + m_2 V_2$
According to the law of conservation of momentum:

Total initial momentum = Total final momentum

$$0 = m_1 v_1 + m_2 v_2$$

$$v_1 = \frac{-m_2 v_2}{m_1}$$

Here, the negative sign indicates that the fragments of the parent nucleus move in directions opposite to each other.

(C)

$$\vec{p_i} = mv \sin 30° \hat{i} - mv \cos 30° \hat{j}$$

$$\vec{p_i} = mv \sin 30 \hat{i} - mv \cos 30 \hat{j}$$

$$\Delta \vec{p} = \vec{p_f} - \vec{p_i}$$

$$= -mv \sin 30° \hat{i} = -mv \hat{i}$$

$$|\Delta \vec{p}| = -mv$$

Negative sign of the impulse shows that it is along a negative x-direction. Since impulse and force are in the same direction, the force on the ball is along the negative direction of the x-axis. Hence, the force on the wall will be along the positive x-axis.

2. When two bodies are in contact, each experiences a contact force by the other. The component of the contact force parallel to the surfaces in contact, which opposes impending or actual relative motion between the two bodies in contact is opposed by static friction. Kinetic friction opposes actual relative motion between two bodies in contact. There is a yet another type of friction which opposes rolling motion of one body over the surface of another body. It is called rolling friction. We often regard friction as something undesirable. However in many practical situations friction is critically needed.

(A) What is the direction of friction?

(a) Friction always acts tangential to the surface in contact.

(b) Friction acts normal to the surface in contact.

(c) Direction depends upon weight of body which moves over surface of another body.

(d) None of these.

(B) Which one of the following statement is not correct about friction?

(a) Friction is an self adjusting force.

(b) Force of friction is independent of area of contact as long as normal reaction remains same.

(c) Sliding friction is greater than static friction.

(d) Limiting friction is the maximum static friction.

(C) An automobile is moving on a horizontal road with a speed v. If the coefficient of friction between the tyres and the road is H. What is the shortest distance in which the automobile can be stopped?

(a) $\frac{v^2}{\mu g}$ (b) $\frac{2v^2}{\mu g}$

(c) $\frac{v^2}{4\mu g}$ (d) $\frac{v^2}{2\mu g}$

(D) What will be the maximum acceleration of the train in which a box lying on the floor will remain stationary? Given that the coefficient of friction between the box and trains floor is 0.15. ($g = 10\ m/s^2$)

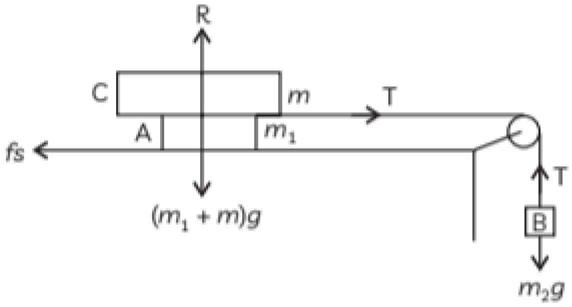
(a) 2 m/s^2

(c) 1 m/s^2

(b) 2.5 m/s^2

(d) 1.5 m/s^2

(E) In figure, the masses of blocks A & B are 10 kg and 15 kg. Calculate the minimum mass of C which may stop A from slipping. Coefficient of friction between block A and table is 0.2.



(a) 5 kg

(b) 15 kg

(c) 25 kg

(d) 35 kg

Ans. (A) (a) friction always acts tangential to the surface in contact.

Explanation: When two surfaces are in contact and are moving relative to each other, the frictional force acts in the tangen- tial direction to the surface of contact.

(B) (c) Sliding friction is greater than static friction.

Explanation: While sliding, the points of contact between two surfaces do not get enough time to get interlocked, whereas more interlocking takes place when the surfaces are not moving over each other. Therefore, sliding friction is less than static friction.

(C)

(d) $\frac{v^2}{2\mu g}$

Explanation: Let 'm' be the mass of the vehicle. So, frictional force experienced by the vehicle on its tyres is f = umg So, the acceleration of the vehicle due to this frictional force is, a = - μg (acceleration is directed opposite to the motion of the vehicle) Now using,

$$v^2 = u^2 + 2as$$

$$\Rightarrow \quad 0 = v^2 - 2\,\mu g s$$

[initial velocity = v, final velocity = 0]

So, $$s = \frac{v^2}{(2\mu g)}$$

(D) (d) 1.5 m/s

Explanation: Given, μ = 0.15, g = 10

$a_{max} = \mu_s g$

= 0.15 x 10

= 1.5 ms^{-2}

(E) (b) 15 kg

Explanation: Let the mass of block C is m For block A,

$R = (m_1 + m)$

$T = f_s = \mu R = \mu(m + m_1)g$

To avoid slippling of A, for block B

$T = m_2 g$

or

$\mu(m+m_1) = m_2 g$

0.2(m + 10)=5

m = 15 kg

3. The first law of motion refers to the simple case when the net external force on a body is zero. The second law of motion refers to the general situation when there is a net external force acting on the body. It relates the net external force to the acceleration of the body. The following common experiences indicate the importance of momentum for considering the effect of force on motion. Suppose a light-weight vehicle (say a small car) and a heavy weight vehicle (say a loaded truck) are parked on a horizontal road. We all know that a much greater force is needed to push the truck than the car to bring them to the same speed at the same time. Similarly, a greater opposing force is needed to stop a heavy body than a light body at the same time, if they are moving with the same speed. Speed is another important parameter to consider. A bullet fired by a gun can easily pierce human tissue before it stops, resulting in casualty. The same bullet fired with moderate speed will not cause much damage. Thus, for a given mass, the greater the speed, the greater is the opposing force needed to stop the body in a certain time. The greater the change in the momentum in a given time, the greater is the force that needs to be applied.

(A) Momentum of a body is defined to be the product of:

(a) its mass and velocity square

(b) its mass and acceleration

(c) its mass and velocity

(d) its mass and applied force

(B) The rate of a change of a particle's momentum p is given by the force acting on the particle, refers to:

(a) Newton's first law of motion

(b) Newton's second law of motion

(c) Newton's third law of motion

(d) None of the above

(C) A bullet of mass 0.04 kg moving with a speed of 90 ms^1 enters a heavy wooden block and is stopped after a distance of 60 cm. The average resistive force exerted by the block on the bullet is:

(a) 270 N

(b) 450 N

(c) 375 N

(d) 540 N

(D) The motion of a particle of mass m is

described by $y = ut + \frac{1}{2}gt^2$. The force

acting on the particle will be:

(a) $\frac{mg}{4}$ (b) $\frac{mg}{2}$

(c) mg (d) $4\,mg$

(E) A rope of length 10 m and linear density 0.5 kg/m is lying length wise on a smooth horizontal floor. It is pulled by a force of 25 N. The tension in the rope at a point 6 m away from the point of application is:

(a) 5 N

(b) 10 N

(c) 15 N

(d) 20 N

Ans. (A) (c) its mass and velocity

Explanation: p = mxv Momentum is the product of mass and velocity. It is a vector quantity having both magnitude and direction. The unit of momentum in SI unit is Kg.ms"[1].

(B) (b) Newton's second law of motion

Explanation: Because the law of conservation of momentum may be de- duced from the concept of action and reaction, which asserts that every force has a reciprocating equal and opposite force, it is based on Newton's third law. When you push against a wall, it pushes back with the same amount of force.

(C) (a) 270 N

Explanation: The mass of the bullet is m = 0.04 kg.

The initial speed of the bullet is u = 90 m/s

The final velocity of the bullet is v = 0

The bullet will stop at a distance is s = 60 cm

Now.

$$v^2 = u^2 + 2as$$

or $$a = \frac{-u^2}{2s} = \frac{-(90)^2}{2 \times 0.6} = -6750$$

or $$a = -\,6750 \text{ m/s}^2$$

Again,

$$F = ma$$

or $$F = 0.04 \times (-\,6750) = -\,270$$

or $$F = -\,270 \text{ N}$$

(D) (c) mg

Explanation: $v = u + \frac{1}{2} \times gt^2$

Differentiate y with respect to t which gives velocity as

$$\frac{dy}{dt} = v$$

$$\frac{dv}{dt} = u + \frac{1}{2} g(2t)$$

$$v = u + gt \quad \text{...(i)}$$

Differentiate v with respect to t which gives velocity as

$$\frac{d^2y}{dt^2} = \frac{dv}{dt} = a$$

$$\frac{dv}{dt} = 0 + g$$

$$a = g \quad \text{...(ii)}$$

We know that force acting on a mass m is given by F = ma

Now from Eq. (ii), substitute a = g.

Hence, F = mg

(E) (b) 10 N

Explanation: Here total mass of the rope, m = 10 x 0.5 = 5 kg

Acceleration of the rope, $a = \frac{25}{5} = 5 \text{ m/s}^2$

The mass of remaining rope 10 – 6 = 4 m is

$m_r = 4 \times 0.5 = 2$ kg

The tension will be

$$T = m_r a$$

$$= 5 \times 2 = 10 \text{ N}$$