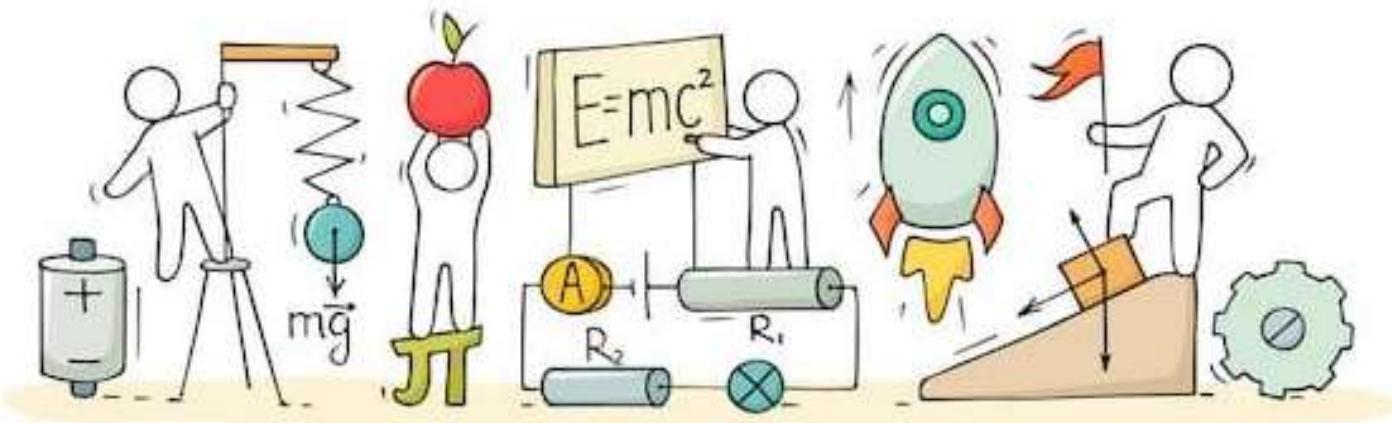


PHYSICS

Chapter 5: Laws of Motion



Laws of Motion

Top Formulae

Momentum	$(p) = \text{mass (m)} \times \text{velocity (v)}$
Net external force	$F = \frac{dp}{dt} = ma$
Impulse	= Force \times time duration = Change in momentum
Law of conservation of linear momentum	$\vec{P}'_A + \vec{P}'_B = \vec{P}_A + \vec{P}_B$
Equilibrium under three concurrent forces	$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$
Maximum value of static friction	$f_{s,\max} = \mu_s R$
Kinetic friction	$f_k = \mu_k R$
In circular motion	$f_c = \frac{mv^2}{R}$
Maximum permissible speed limit for a car to take a turn along a rough road	Along the unbanked road $v = \sqrt{(\mu_s rg)}$ Along the banked road $v_{\max} = \left(Rg \frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta} \right)^{\frac{1}{2}}$

Top Concepts

- Galileo extrapolated simple observations on motion of bodies on inclined planes and arrived at the law of inertia. Newton's first law of motion is the same law as the law of inertia. According to it, an object acted upon by no net force will remain at rest or continue to move with a constant velocity and zero acceleration.
- The tendency of an object to remain at rest or continue to move at a constant velocity is called inertia.
- The frame of reference in which Newton's first law is valid is called the inertial frame of reference.
- The frame of reference in which Newton's first law is not valid is known as non-inertial frame of reference. These are accelerating reference frames.
- The momentum (p) of an object is a vector quantity and is defined as the product of its mass (m) and velocity (v), i.e., $p = mv$.
- Newton's second law: The rate of change of momentum of an object is equal to the net external force and takes place in the direction in which the net force acts.
- The net external force on an object is equal to its mass times the acceleration, i.e. $F = ma$.
- Impulse is the product of average force and time and equals change in momentum.
- Newton's third law of motion: To every action force, there is always an equal and opposite reaction force. OR When an object 1 exerts a force on object 2, the object 2 must exert a force on object 1 which is equal in magnitude and opposite in direction.
- Action and reaction forces act on different bodies, and so they cannot cancel each other.
- Law of conservation of momentum: The total momentum of an isolated system of particles is conserved. The law follows from the second and third laws of motion.
- If an object is at equilibrium, then the net resultant force acting on it is zero.
- The normal reaction is the contact force perpendicular to the surface in contact.
- Tension force is the restoring force in the rigid inextensible string or rope when being pulled down.
- Centripetal force is always directed along the radius towards the center.
- A free body diagram is a diagram showing the chosen body by itself and free of its surroundings.
- Two points for which one should be careful about while drawing free body diagrams are
 1. Include all the forces acting on the body.
 2. Do not include any force which the chosen body exerts on any other body.
- Free body equations represent the two equations of motion framed along two perpendicular axes.

- The maximum value of static friction

$$f_{s,\max} \propto R$$

$$f_{s,\max} = \mu_s R$$

Here, $f_{s,\max}$ is the limiting value of the static friction, R is the normal reaction and μ_s is the coefficient of static friction.

- Static friction increases with the applied force till it reaches a maximum value of $F_{s,\max}$.
- Kinetic friction

$$f_k \propto R$$

$$f_k = \mu_k R$$

Here, f_k is the limiting value of the static friction, R is the normal reaction and

μ_k is the coefficient of kinetic friction.

- The horizontal component of contact force equals the force of friction.
- The limiting value of static friction is greater than the limiting value of kinetic friction.
- The force required to initiate the motion in a body should be greater than the force required to maintain the motion with uniform velocity.
- The direction of frictional force is always opposite to the direction of the relative motion between the two surfaces.

Diagrams

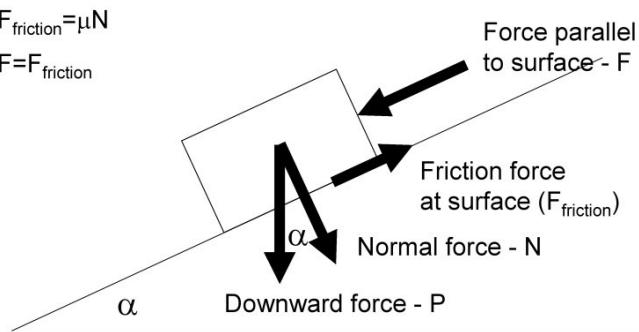
Friction

$$F = P \sin \alpha \quad P \sin \alpha = \mu N = \mu * P \cos \alpha$$

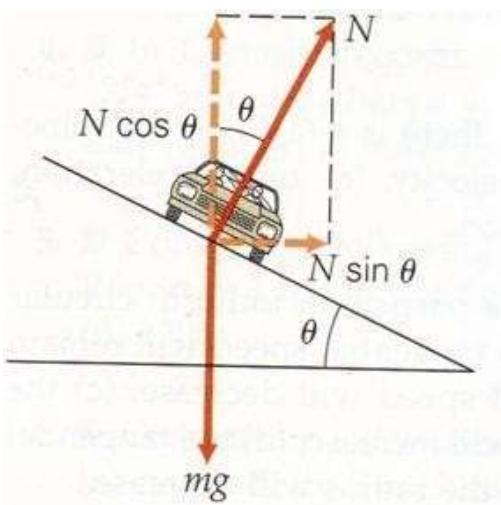
$$N = P \cos \alpha \quad \mu = \sin \alpha / \cos \alpha = \tan \alpha$$

$$F_{\text{friction}} = \mu N$$

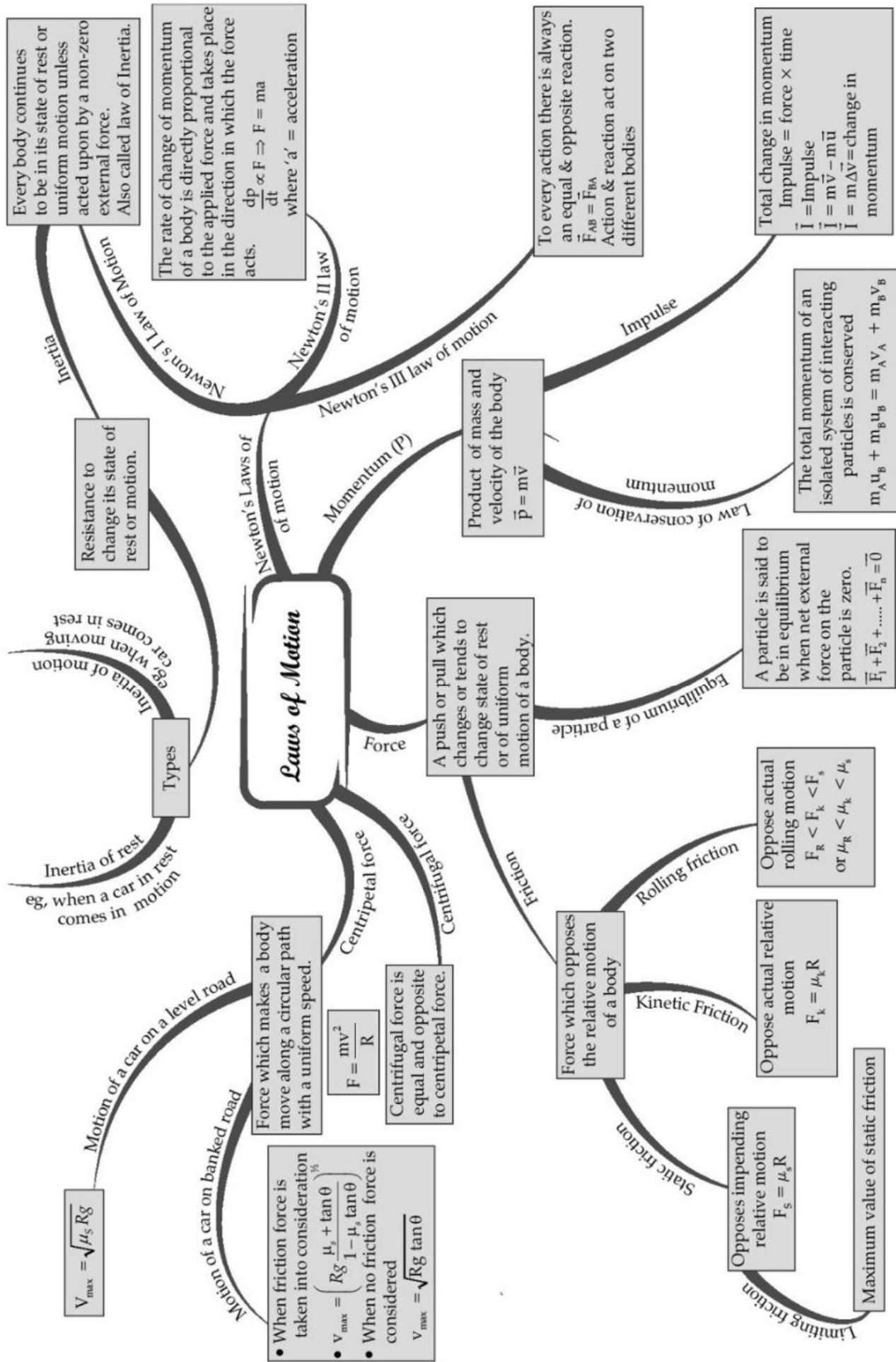
$$F = F_{\text{friction}}$$



Motion on a banked road



CHAPTER - 5 : LAWS OF MOTION



Important Questions

Multiple Choice questions-

1. A spring balance is attached to the ceiling of a lift. A man hangs his bag on the spring and the spring reads 49 N, when the lift is stationary. If the lift moves downwards with an acceleration of 5 m/s, the reading of the spring balance will be
 - (a) 15 N
 - (b) 24 N
 - (c) 49 N
 - (d) 74 N
2. Two forces 6 N and 8 N act at a point O. If the angle between the lines of action of the force is 90° , then their resultant is
 - (a) 14 N
 - (b) 12 N
 - (c) 10 N
 - (d) 48 N
3. A body of mass 15 kg moving with a velocity of 10 m/s has its velocity reduced to 6 m/s in two seconds. The force that produced this change in velocity is
 - (a) 60 N
 - (b) 30 N
 - (c) 45 N
 - (d) 20 N
4. The frame of reference attached to a satellite of the earth is
 - (a) an inertial frame
 - (b) an absolute frame at rest with respect to the stars
 - (c) a non – inertial frame
 - (d) a gravitational frame
5. A machine gun fires a bullet of mass 40 g with a velocity of 1200 ms^{-1} . The man holding it can exert a maximum force on 144 N on the gun. How many bullets can he fire per second at the most?
 - (a) one
 - (b) four

(c) two

(d) three

6. A block of mass M is placed on a flat surface. A force is applied to move it parallel to the surface. The frictional force f developed is proportional to the

(a) square of the mass of the body

(b) mass of the body

(c) reciprocal of the mass of the body

(d) reciprocal of the square of the body

7. A passenger in a moving bus is thrown forward when the bus is suddenly stopped. This is explained

(a) by Newtons first law

(b) by Newtons second law

(c) by Newtons third law

(d) by the principle of conservation of momentum

8. A rocket with a lift-off mass of 3.5×10^5 kg is blasted upwards with an acceleration of 10 m/s^2 . The initial thrust of the blast is (take $g = 10 \text{ m/s}^2$)

(a) $1.75 \times 10^{5\text{N}}$

(b) $3.5 \times 10^{5\text{N}}$

(c) $7.0 \times 10^{5\text{N}}$

(d) $14.0 \times 10^{5\text{N}}$

9. A gun of mass 1000 kg fires a projectile of mass 1 kg with a horizontal velocity of 100 m/s . The velocity of recoil of the gun in the horizontal direction is

(a) 5 m/s

(b) 0.1 m/s

(c) 15 m/s

(d) 20 m/s

10. A body is sliding down a rough inclined plane which makes an angle of 30 degree with the horizontal. If the co-efficient of friction is 0.26 , the acceleration in m/s^2 is

(a) 1.95

(b) 2.78

(c) 3.47

(d) 4.6

Very Short:

1. (a) Why do we beat dusty blankets with a stick to remove dust particles?
(b) A stone when thrown on a glass window smashes the window pane to pieces. But a bullet fired from a gun passes through it making a hole. Why?
2. (a) If you jerk a piece of paper from under a book quick enough, the book will not move, why?
(b) Passengers sitting or standing in a moving bus fall in forward direction when the bus suddenly stops. Why?
3. (a) Why passengers are thrown outward when a bus in which they are travelling suddenly takes a turn around a circular road?
(b) Is any force required to move a body with constant velocity?
4. (a) Why a one rupee coin placed on a revolving table flies off tangentially?
(b) Why mud flies off tangentially to the wheel of a cycle?
5. (a) When the electric current is switched off, why the blades of a fan keep on moving for some time?
(b) Why the passengers fall backward when a bus starts moving suddenly?
6. (a) A body of mass m is moving on a horizontal table with constant velocity. What is the force on the table?
(b) Name a factor on which the inertia of a body depends.
7. (a) Rocket works on which principle of conservation?
(b) Is the relation $F = ma$ applicable to the motion of a rocket?
8. (a) Will a person while firing a bullet from a gun experience a backward jerk? Why?
(b) A bomb explodes in mid-air into two equal fragments. What is the relation between the directions of their motion? Answer:
9. (a) What happens to the acceleration of an object if the net force on it is doubled?
(b) An electron moving with a certain velocity collides against a stationary proton and sticks to it. Is the law of conservation of linear momentum true in this case?
10. (a) According to Newton's third law of motion, every force is accompanied by an equal (in magnitude) and opposite (in direction) force called reaction, then how can a movement take place?
(b) You can move a brick easily by pushing it with your foot on a smooth floor, but, if you kick it, then your foot is hurt. Why?

Short Questions:

1. (a) A learner shooter fired a shot from his rifle and his shoulder got injured in the process. What mistake did he commit?
(b) When the horse suddenly stops, the rider falls in the forward direction. Why? Explain it.
2. (a) Newton's first law of motion is the law of Inertia. Explain.
(b) What happens to a stone tied to the end of a string and whirled in a circle if the string suddenly breaks? Explain why?
3. (a) An astronaut accidentally gets separated out of his small spaceship accelerating in inter-stellar space at a constant rate of 100 ms^{-2} . What is the acceleration of the astronaut at the instant after he is outside the spaceship?
(b) How is it that a stone dropped from a certain height falls much more rapidly as compared to a parachute under similar conditions?
4. (a) When a man jumps out of a boat, then it is pushed away. Why?
(b) Explain how lubricants reduce friction?
5. Two boys on ice-skates hold a rope between them. One boy is much heavier than the other. The lightweight boy pulls on the rope. How will they move?
6. Explain why ball bearings are used in machinery?
7. Why a horse has to apply more force to start a cart than to keep it moving? Explain.
8. Sand is thrown on tracks or roads covered with snow. Explain why?

Long Questions:

1. (a) State and prove impulse-momentum Theorem..
(b) Prove that Newton's Second law is the real law of motion.
2. Derive the general expression for the velocity of a rocket in flight and obtain the expression for the thrust acting on it.
3. (a) Define inertia. What are its different types? Give examples.
(b) Explain Newton's First law of motion. Why do we call it the law of inertia?
(c) State Newton's Second law of motion. How does it help to measure force? Also, state the units of force.
4. (a) State Newton's Third law of motion. Discuss its consequences.
(b) State the law of conservation of linear momentum and illustrate it with examples.
(c) Define the terms – momentum and impulse. What are their units in the S.I. system?

Assertion Reason Questions:

1. **Directions:** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

- (a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.
- (b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
- (c) Assertion is correct, reason is incorrect
- (d) Assertion is incorrect, reason is correct.

Assertion: On a rainy day, it is difficult to drive a car or bus at high speed.

Reason: The value of coefficient of friction is lowered due to wetting of the surface.

2. **Directions:** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

- (a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.
- (b) Assertion is correct, reason is correct; reason is not a correct explanation for assertion
- (c) Assertion is correct, reason is incorrect
- (d) Assertion is incorrect, reason is correct.

Assertion: For the motion of electron around nucleus, Newton's second law is used.

Reason: Newton's second law can be used for motion of any object.

Case Study Questions:

1. This principle is a consequence of Newton's second and third laws of motion. In an isolated system (i.e., a system having no external force), mutual forces (called internal forces) between pairs of particles in the system causes momentum change in individual particles. Let a bomb be at rest, then its momentum will be zero. If the bomb explodes into two equal parts, then the parts fly off in exactly opposite directions with same speed, so that the total momentum is still zero. Here, no external force is applied on the system of particles (bomb).

- i. A bullet of mass 10 g is fired from a gun of mass 1 kg with recoil velocity of gun 5 m/s. The muzzle velocity will be
 - (a) 30 km/min
 - (b) 60 km/min
 - (c) 30 m/s
 - (d) 500 m/s
- ii. A shell of mass 10 kg is moving with a velocity of 10 ms^{-1} when it blasts and forms two parts of mass 9 kg and 1 kg respectively. If the first mass is stationary, the velocity of the second is
 - (a) 1 m s^{-1}

(b) 10m s^{-1}

(c) 100m s^{-1}

(d) 1000m s^{-1}

iii. A bullet of mass 0.1kg is fired with a speed of 100 ms^{-1} . The mass of gun being 50kg , then the velocity of recoil becomes

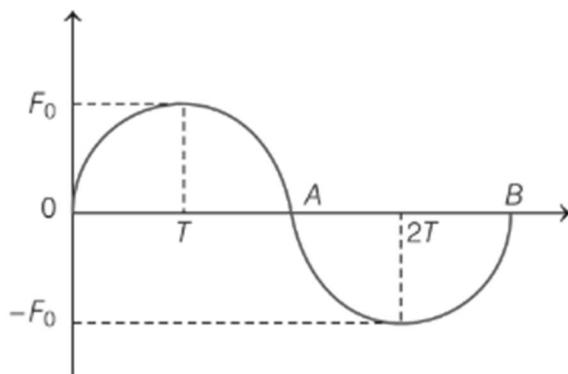
(a) 0.05 m s^{-1}

(b) 0.5 m s^{-1}

(c) 0.1 m s^{-1}

(d) 0.2 m s^{-1}

iv. A unidirectional force F varying with time T as shown in the figure acts on a body initially at rest for a short duration $2T$. Then, the velocity acquired by the body is



(a) $\frac{\pi F_0 T}{4\text{ m}}$

(b) $\frac{\pi F_0 T}{2\text{ m}}$

(c) $\frac{F_0 T}{4\text{ m}}$

(d) Zero

v. Two masses of M and $4M$ are moving with equal kinetic energy. The ratio of their linear momenta is

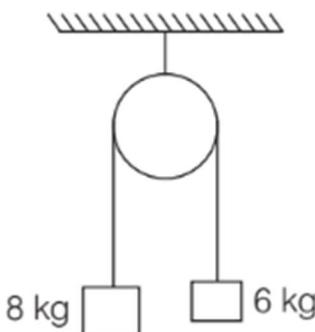
(a) $1 : 8$

(b) $1 : 4$

(c) $1 : 2$

(d) $4 : 1$

2. When bodies are in contact, there are mutual contact forces satisfying the third law of motion. The component of contact force normal to the surfaces in contact is called normal reaction. The component parallel to the surfaces in contact is called friction.



In the above figure, 8kg and 6kg are hanging stationary from a rough pulley and are about to move. They are stationary due to roughness of the pulley.

- i. Which force is acting between pulley? and rope?
 - (a) Gravitational force
 - (b) Tension force
 - (c) Frictional force
 - (d) Buoyant force
- ii. The normal reaction acting on the system is
 - (a) 8 g
 - (b) 6 g
 - (c) 2 g
 - (d) 14 g
- iii. The tension is more on side having mass of
 - (a) 8kg
 - (b) 6kg
 - (c) Same on both
 - (d) Nothing can be said
- iv. The force of friction acting on the rope is
 - (a) 20 N
 - (b) 30 N
 - (c) 40 N
 - (d) 50 N
- v. Coefficient of friction of the pulley is
 - (a) $\frac{1}{6}$

- (b) $\frac{1}{7}$
- (c) $\frac{1}{5}$
- (d) $\frac{1}{4}$

✓ **Answer Key:**

Multiple Choice Answers-

1. Answer: (b) 24 N
2. Answer: (c) 10 N
3. Answer: (b) 30 N
4. Answer: (c) a non – inertial frame
5. Answer: (d) three
6. Answer: (b) mass of the body
7. Answer: (a) by Newtons first law
8. Answer: (c) 7.0×10^{5N}
9. Answer: (b) 0.1 m/s
10. Answer: (b) 2.78

Very Short Answers:

1. Answer:
 - (a) It is done due to inertia of rest.
 - (b) This is due to the inertia of rest.
2. Answer:
 - (a) It is due to the inertia of rest.
 - (b) This is due to the inertia of motion.
3. Answer:
 - (a) This is due to the inertia of direction.
 - (b) No.
4. Answer:
 - (a) This is due to the inertia of direction.
 - (b) This is due to the inertia of direction.
5. Answer:

(a) This is due to the inertia of motion.

(b) This is due to the inertia of rest.

6. Answer:

(a) mg i.e., equal to the weight of the body.

(b) Mass.

7. Answer:

(a) Law of conservation of linear momentum.

(b) No.

8. Answer:

(a) Yes, it is due to the law of conservation of linear momentum.

(b) The two fragments will fly off in two opposite directions.

9. Answer:

(a) As $a = \frac{F}{m}$ i.e., $a \propto F$, so acceleration will be doubled when m the force is doubled.

(b) Yes, it is true.

10. Answer:

(a) As the action and reaction never act on the same body, so the motion is possible.

(b) As Ft remains constant, so if t is reduced, then F will be increased and hence hurt our foot.

Short Questions Answers:

1. Answer:

(a) We know that a gun recoils i.e. moves back after firing. To avoid injury to the shoulder, the gun must be held tightly against the shoulder. The learner shooter might have not held it tightly against his shoulder and hence the gun must have injured his shoulder after firing.

(b) When the horse suddenly stops, the rider falls in forward direction due to the inertia of motion.

Explanation: The lower portion of the rider comes to rest along with the horse while the upper portion of the rider continues to move forward. Hence, he falls forward.

2. Answer:

(a) According to Newton's first law of motion, a body can't change its state of rest or of uniform motion along a straight line unless an external force acts on it. It means that the natural tendency of the material body is to continue in the state of rest or that of uniform motion which is termed as inertia. Thus, Newton's first law is the law of inertia.

(b) The stone flies off tangentially to the circle along a straight line at the point where the string breaks. It is due to the inertia of direction. When the string breaks, the force acting on the stone ceases. In the absence of force, the stone flies away in the direction of instantaneous velocity which is along the tangent to the circular path.

3. Answer:

(a) According to Newton's first law of motion, the moment he is out of the spaceship, there is no external force on the astronaut, thus his acceleration is zero. Here we are assuming that he is out of the gravitational field of heavenly bodies i.e. there are no nearby stars to exert a gravitational force on him and the small spaceship exerts a negligible gravitational attraction on him.

(b) As the surface area of a parachute is much larger as compared to the surface area of a stone, so the air resistance, i. e. fluid friction in the case of the parachute is much larger than in the case of stone. Hence the parachute falls slowly.

4. Answer:

(a) This is due to Newton's third law of motion. When the man jumps out of the boat, he applies a force on it in the backward direction, and in turn, the reaction of the boat on the man pushes him out of the boat.

(b) The lubricants spread as a thin layer between the two surfaces. The motion now is between the surface and the lubricant layer which changes the dry friction into wet friction. As wet friction is less than dry friction, hence lubricants reduce friction.

5. Answer: The light-weight boy is doing the action on the heavy boy by pulling the rope.

According to Newton's third law, equal and opposite force (reaction) also acts on the light boy. As the mass of the boy pulling the rope is lesser, so the acceleration produced in him will be more. Thus, both the boys move toward each other and the lighter boy will move faster.

6. Answer: We know that rolling friction is much lesser than sliding friction, so we convert the sliding friction into rolling friction which is done using ball bearings that are placed in between the axle and the hub of the wheel. The ball bearings tend to roll around the axle as the wheel turns and as such the frictional force is reduced.

7. Answer: Static friction comes into play when the horse applies force to start the motion in the cart. On the other hand, kinetic friction comes into play when the cart is moving.

Also, we know that the static friction is greater than the kinetic friction, so the horse has to apply more force to start a cart than to keep it moving.

8. Answer: When the roads (or tracks) are covered with snow, then there is a considerable reduction of frictional force between the tires of the vehicles and the road (or between the track and the wheels of the vehicle or train) which leads to the skidding of the vehicles.

(or trains). Thus, driving is not safe. When sand is thrown on the snow-covered roads (or tracks), then the force of friction increases, so safe driving is possible.

Long Questions Answers:

1. Answer:

1. It states that the impulse of force on a body is equal to the change in momentum of the body.

$$\text{i.e. } J = F_t = P_2 - P_1$$

Proof: From Newton's Second law of motion, we know that

$$F = \frac{dp}{dt} \text{ or } Fdt = dp \quad \dots (i)$$

Let P_1 and P_2 be the linear momenta of the body at time $t = 0$ and t respectively.

∴ integrating equation (i) within these limits, we get

$$\int_0^t F dt = \int_{P_1}^{P_2} dp$$

$$\text{or } F \int_0^t dt = \int_{P_1}^{P_2} p^* dp$$

$$\text{or } F[t]_0^t = [p]_{P_1}^{P_2}$$

$$Ft = p_2 - p_1$$

$$\text{or } J = p_2 - p_1 .$$

Hence proved.

2. Proof: If we can show that Newton's first and third laws are contained in the second law, then we can say that it is the real law of motion.

1. First law is contained in second law: According to Newton's second law of motion,

$$F = ma \dots (i)$$

where m = mass of the body on which an external force F is applied and a = acceleration produced in it.

If $F = 0$, then from equation (1), we get

$$ma = 0, \text{ but as } m \neq 0$$

$$\therefore a = 0$$

which means that there will be no acceleration in the body if no external force is applied. This shows that a body at rest will remain at rest and a body in uniform motion will

continue to move along the same straight line in the absence of an external force. This is the statement of Newton's first law of motion. Hence, the First law of motion is contained in the Second law of motion.

2. Third law is contained in second law: Consider an isolated system of two bodies A and B. Let them act and react internally.

Let F_{AB} = force applied on body A by body B

and F_{BA} = force applied on body B by body A

It $\frac{dp_A}{dt}$ = rate of change of momentum of body A

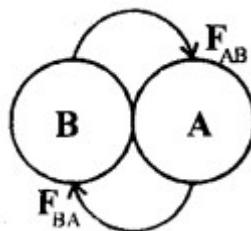
and

$\frac{dp_B}{dt}$ = rate of change of momentum of body B

Then according to Newton's second law of motion,

$$F_{AB} = \frac{dp_A}{dt} \quad \dots \dots (2)$$

$$F_{BA} = \frac{dp_B}{dt} \quad \dots \dots (3)$$



(2) and (3) gives

$$\begin{aligned} F_{AB} + F_{BA} &= \frac{d}{dt}(p_A) + \frac{d}{dt}(p_B) \\ &= \frac{d}{dt}(p_A + p_B) \end{aligned}$$

As no external force acts on the system (\because it is isolated), therefore according to Newton's second law of motion,

$$\frac{d}{dt}(p_1 + p_2) = 0 \text{ or}$$

$$F_{AB} + F_{BA} = 0$$

$$\text{or, } F_{AB} = -F_{BA}$$

or

Action = – Reaction,

which means that action and reaction are equal and opposite. It is the statement of Newton's 3rd law of motion. Thus 3rd law is contained in the second law of motion.

As both First and Third Law is contained in Second law, so Second law is the real law of motion.

2. Answer:

The working of a rocket is based upon the principle of conservation of momentum.

Consider the flight of the rocket in outer space where no external forces act on it.

Let m_0 = initial mass of rocket with fuel.

V_u = initial velocity of the rocket,

m = mass of the rocket at any instant t .

v = velocity of the rocket at that instant.

dm = mass of the gases ejected by the rocket, in a small-time dt .

u = velocity of exhaust gases,

DV = increase in the velocity of the rocket in a time dt .

\therefore Change in the momentum of exhaust gases = $dm \cdot u$

Change in momentum of rocket = $-(m - dm) dv$.

A negative sign shows that the rocket is moving in a direction opposite to the motion of exhaust gases.

Applying the law of conservation of linear momentum,

$$dm \cdot u = -(m - dm) dv \dots (1)$$

As dm being very small as compared to m , so it can be neglected, Thus, eqn. (1) reduces to

$$dm \cdot u = -m dv$$

or

$$dv = -u \frac{dm}{m} \dots (2)$$

Instantaneous velocity of the rocket:

At $t = 0$, mass of rocket = m_0 , velocity of rocket = v_0 .

At $t = t$, mass of rocket = m , velocity of rocket = v .

\therefore Integrating Eqn. (1) within these limits, we get

$$\int_{v_0}^v dv = - \int_{m_0}^m u \frac{dm}{m}$$

In actual practice, the velocity of exhaust gases nearly remains constant.

$$\therefore \int_{v_0}^v dv = - u \int_{m_0}^m \frac{dm}{m}$$

or $[u]_{v_0}^v = - [\log_e m]_{m_0}^m$

or $v - v_0 = - u (\log_e m - \log_e m_0)$
 $= u (\log_e m_0 - \log_e m)$

$$= u \log_e \left(\frac{m_0}{m} \right)$$

or $v = v_0 + u \log_e \left(\frac{m_0}{m} \right) \dots (3)$

equation (3) gives the instantaneous velocity of the rocket. In general $v_0 = 0$ at $t = 0$,

\therefore Eqn. (3) reduces to

$$v = u \log_e \frac{m_0}{m} \dots (4)$$

From Eqn. (4), we conclude that the velocity of the rocket at any instant depends upon:

- speed (u) of the exhaust gases.
- Log of the ratio of initial mass (m_0) of the rocket to its mass (m) at that instant of time.

Upthrust on the rocket (F): It is the upward force exerted on the rocket by the expulsion of exhaust gases. It is obtained as follows:

Dividing Eqn. (2) by dt , we get

$$\frac{dv}{dt} = - \frac{u}{m} \frac{dm}{dt}$$

or $m \frac{dv}{dt} = - u \frac{dm}{dt}$

But $\frac{dv}{dt} = a$, is the instantaneous acceleration

$$\therefore ma = -u \frac{dm}{dt}$$

$$\text{or } F = -u \frac{dm}{dt} \quad \dots (5)$$

where $F = ma$ is the instantaneous force (thrust).

From Eqn. (5), we conclude that the thrust (F) on the rocket at any instant is the product of the velocity of exhaust gases and the rate of combustion of fuel at that instant. Here negative sign shows that the thrust and velocity of exhaust gases are in opposite direction.

3. Answer:

(a) The tendency of bodies to remain in their state of rest or uniform motion along a straight line in the absence of an external force is called inertia.

Inertia is of the following three types:

1. The inertia of rest: When a body continues to lie at the same position with respect to its surrounding, it is said to possess inertia of rest. This situation may be changed only by the application of external force. For example, if a cot or sofa is lying in a particular place in the house, it will remain there even after days or years unless someone removes (by applying force) the same from its position. This is an example of the inertia of rest.

2. The inertia of motion: When a body is moved on a frictionless surface or a body is thrown in a vacuum, it will continue to move along its original path unless acted upon by an external force. In actual situations, air or floor etc. exert friction on the moving bodies so we are unable to visualize a force-free motion. This type of inertia when a body continues to move is called the inertia of direction.

3. In the above examples it is found that the direction of motion of the body or particle also does not change unless an external force acts on it. This tendency to preserve the direction of motion is called the inertia of direction.

(b) According to the First law of motion, “Everybody continues to be in the state of rest or of uniform motion along a straight line until it is acted upon by an external force.”

It means that if a book lying on a table, it will remain there for days or years together unless force is applied on it from outside to pick it.

Similarly, if a body is moving along a straight line with some speed, it will continue to do so until some external force is applied to it to change its direction of motion.

Thus, First law tells us the following:

It tells us about the tendency of bodies to remain in the state of rest or of motion and the bodies by themselves can neither change the state of rest nor of uniform motion. This tendency is called inertia. To break the inertia of rest or motion or direction, we need an external force. Thus the definition of the first law matches with the definition of inertia and hence first law is called the law of inertia.

The first law of motion also provides the definition of another important physical quantity called force. Thus force is that agency which changes or tends to change the state of rest or of uniform motion of a body along a straight line.

(c) It states that the time rate of change of momentum of a body is directly proportional to the force applied to it.

$$\begin{aligned}
 \text{i.e. mathematically, } F &\propto \frac{d}{dt}(\vec{p}) \\
 &\propto \frac{d}{dt}(m \cdot) \\
 &\propto m \frac{dv}{dt} \\
 &\propto ma \\
 \text{or} \qquad F &= kma \qquad \dots (1)
 \end{aligned}$$

where $a = \frac{dv}{dt}$ = acceleration produced in the body of mass m.

k = proportionality constant which depends on the system of units chosen to measure F, m, and a.

In the S.I. system, k = 1,

$$\therefore F = ma$$

The magnitude of the force is given by

$$F = ma \dots (2)$$

Note: We have assumed that the magnitude of velocity is smaller and much less than the speed of light. Only under this condition Eqns. (1) and (2) hold good.

The definition of the Second law and its mathematical form is given in Eqn. (2) provide us a mean of measuring force.

One can easily find the change in velocity of a body in a certain interval of time. Both velocity and time can be easily measured. Thus, by knowing the mass of the body one can determine both change in momentum as well as the acceleration of the body produced by an external force. If the force is increased, the rate of change of momentum is also found to increase. So also, is the acceleration. Now with known values of m and we can find F.

Units of force: Force in S.I. units is measured in newton or N. From Eqn. (1) or (2) we can see that a newton of force is that force which produces 1 ms^{-2} acceleration in the body of mass 1 kg.

$$1 \text{ newton} = 1 \text{ kilogram} \times 1 \text{ metre}/(\text{second})^2$$

or

$$1 \text{ N} = 1 \text{ kg} \times 1 \text{ ms}^{-2} = 1 \text{ kg ms}^{-2}$$

In CGS system force is measured in dyne

$$1 \text{ dyne} = 1 \text{ gram} \times 1 \text{ cm/s}^2 = 1 \text{ g cm s}^{-2}$$

$$\begin{aligned} \text{Since } 1 \text{ N} &= 1 \text{ kg m s}^{-2} = 1000 \text{ g} \times 100 \text{ cm s}^{-2} \\ &= 10^5 \text{ g cm s}^{-2} = 10^5 \text{ dyne} \end{aligned}$$

$$1 \text{ N} = 10^5 \text{ dyne}$$

or

$$1 \text{ dyne} = 10^5 \text{ N}$$

Gravitational Unit: If a falling mass of 1 kg is accelerated towards the Earth with 9.8 ms^{-2} , then the force generated is called 1 kg wt (1-kilogram weight) force. It is the S.I. gravitational unit of force.

We know that the earth accelerates the mass with $g = 9.8 \text{ ms}^{-2}$

$$1 \text{ Kg wt} = 1 \text{ kg} \times 9.8 \text{ ms}^{-2} = 9.8 \text{ N}$$

C.G.S. gravitational unit is gf or g wt.

$$\begin{aligned} 1 \text{ gf} &= 1 \text{ g} \times 980 \text{ cms}^{-2} \\ &= 980 \text{ dyne} \end{aligned}$$

4. Answer:

(a) Newton's Third law of motion states that "to every action, there is always an equal and opposite reaction."

So, if a body 1 applies a force F_{12} on body 2 (action), then body 2 also applies a force F_{21} on body 1 but in opposite direction, then

$$F_{21} = -F_{12}$$

In terms of magnitude

$$|F_{21}| = |-F_{12}|$$

It is very important to note that F_{12} and F_{21} though are equal in magnitude and opposite in direction yet act on different points or else no motion will be possible.

For example, hands pull up a chest expander (spring), and spring in turn exerts a force on the arms. A football when pressed reacts on the foot with the same force and so on.

The most important consequence of the third law of motion is the law of conservation of linear momentum and its application in collision problems.

Since $F_{12} = -F_{21}$

and $F = m \frac{\Delta v}{\Delta t}$

$$\therefore m_1 \frac{\Delta v_1}{\Delta t} = -m_2 \frac{\Delta v_2}{\Delta t}$$

Here Δt is the time for which the bodies come in contact during impact. This is the same for the two bodies of masses m_1 and m_2 and having velocity changes Δv_1 and Δv_2 respectively. Therefore,

$$m_1 \Delta v_1 = -m_2 \Delta v_2$$

or

$$m_1 \Delta v_1 + m_2 \Delta v_2 = 0$$

Let u_1 , u_2 and v_1 and v_2 be initial and final velocities of the two masses before and after collision, then

$$m_1(v_1 - u_1) = -m_2(v_2 - u_2)$$

or

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Momentum before impact = momentum after impact

This is the law of conservation of momentum.

(b) 'The linear momentum of an isolated system always remains the same provided no external force is applied on it.' This is the law of conservation of linear momentum.

The linear momentum of a body = mass \times velocity

$$p = mv$$

If a system has several bodies initially at rest then initial momentum = 0.

The final momentum = $p_1 + p_2 + p_3 + \dots$

According to law of conservation of linear momentum

$$p_1 + p_2 + p_3 + \dots = 0$$

Linear momentum is a vector quantity and is measured. in kg ms^{-1} or Ns.

For example, a gun and a bullet make a system in which both are initially at rest. When the bullet of mass m is

fired with muzzle velocity v , the gun of mass M gets a recoil velocity V . Since the initial linear momentum of the system is zero.

$$MV + mv = 0$$

or

$$MV = -mv$$

Thus, gun moves in the opposite direction to that of the bullet.

(c) The total quantity of motion possessed by the body is called is momentum.

Mathematically, it is equal to the product of the mass of the body and the velocity of the body.

In linear motion, this term is called linear momentum P .

It is a vector quantity.

$$p = mv$$

The units of linear momentum are kg ms^{-1} or NS in S.I. units.

Impulse: The action or impact of force is called the impulse of force. Mathematically, impulse J is equal to the product of the force F acting on the body and the time for which the force acts on it. Thus

$$J = F \times t = Ft$$

J is a vector quantity and is measured in Ns or kg ms^{-1}

The action of force or impulse is increased if the force acts for a smaller interval.

Assertion Reason Answer:

1. (a) Assertion is correct, reason is correct; reason is a correct explanation for assertion.

Explanation:

On a rainy day, the roads are wet. Wetting of roads lowers the coefficient of friction between the types and the road. Therefore, grip on a road of car reduces and thus chances of skidding increases.

2. (c) Assertion is correct, reason is incorrect+

Explanation:

Newton's second law cannot be used for any object.

Case Study Answer:

1. i (d) 500 m/s

Explanation:

Conservation of linear momentum gives

$$m_1 v_1 + m_2 v_2 = 0$$

$$m_1 v_1 = -m_2 v_2$$

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

$$\text{Given, } m_1 = 10 \text{ g} = \left(\frac{10}{1000} \right) \text{ kg}$$

$$m_2 = 1 \text{ kg} \text{ and } v_2 = -5 \text{ m/s}$$

∴ Velocity of muzzle,

$$v_1 = \frac{+1 \times 5}{10/1000} = 500 \text{ m/s}$$

ii (c) 100 m s^{-1}

Explanation:

Given that, $v_1 = 10 \text{ m s}^{-1}$,

$$m_1 = 10 \text{ kg}, v_2 = 0,$$

$$m_2 = 9 \text{ kg}, v_3 = v,$$

$$m_3 = 1 \text{ kg}$$

According to conservation of momentum,

$$m_1 v_1 = m_2 v_2 + m_3 v_3$$

$$10 \times 10 = 9 \times 0 + 1 \times v \Rightarrow v = 100 \text{ ms}^{-1}$$

iii (d) 0.2 m s^{-1}

Explanation:

From the law of conservation of momentum, Initial momentum = Final momentum

$$\Rightarrow m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$\therefore 0.1 \times 0 + 50 \times 0 = 0.1 \times 100 + 50 (-v_2)$$

$$\Rightarrow 0 = 10 - 50v_2$$

$$\therefore v_2 = \frac{10}{50} = 0.2 \text{ ms}^{-1}$$

iv (d) Zero

Explanation:

From 0 to T, area is positive and from T to 2T, area is negative, so net area is zero. Hence, there is no change in momentum.

v (c) 1 : 2

Explanation:

Two masses are moving with equal kinetic energy.

$$\frac{1}{2} M v_1^2 = \frac{1}{2} 4M v_2^2$$

or $\frac{v_1}{v_2} = 2$

The ratio of linear momentum is

$$\frac{p_1}{p_2} = \frac{M v_1}{4 M v_2}$$

or $\frac{p_1}{p_2} = \frac{1}{4} \left(\frac{v_1}{v_2} \right)$

or $\frac{p_1}{p_2} = \frac{2}{4} = \frac{1}{2}$

$$\Rightarrow p_1 : p_2 = 1 : 2$$

2. i (c) Frictional force

Explanation:

Frictional force acts between pulley and rope.

ii (d) 14 g

Explanation:

The reaction force is

$$R = T_1 T_2 = (8 + 6) g = 14 g$$

iii (d) Nothing can be said

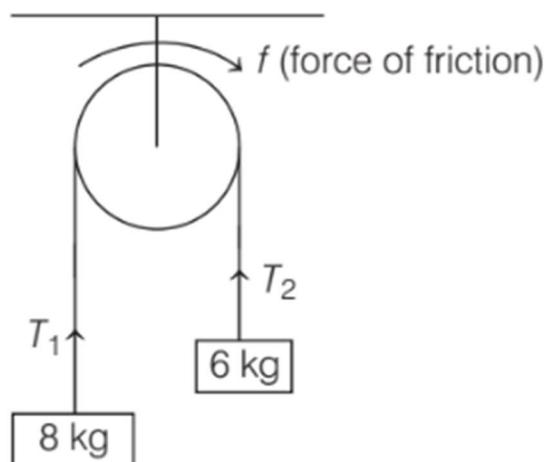
Explanation:

As, tension, $T = mg \Rightarrow T \propto m$

So, the side having 8 kg mass will have more tension.

iv (a) 20 N

Explanation:



Due to friction, tension at all points of the thread is not alike.

$$\begin{aligned}
 T_1 - T_2 &= f \\
 \Rightarrow f &= 8g - 6g = 2g \\
 &= 20 \text{ N} \quad (\because g = 10 \text{ ms}^{-2})
 \end{aligned}$$

iv (b) $\frac{1}{7}$

Explanation:

$$\begin{aligned}
 \text{As, } \mu R &= f = 20 \text{ N} \\
 \mu &= \frac{20}{R} = \frac{20}{14 \times 10} = \frac{1}{7} \quad (\because R = mg)
 \end{aligned}$$