MODULE 13

MIXED NEWTON'S LAWS WORKED EXAMPLES

These mixed worked examples bring together Newton's laws in realistic situations where forces, motion, and interactions must be considered simultaneously. In real life, motion rarely follows a single law in isolation; pushing, braking, lifting, or even walking often involves several force principles acting together. The aim here is not just to apply formulas, but to develop confidence in identifying forces, interpreting motion logically, and understanding how Newton's laws work as a connected system. Take your time, think carefully, and allow the ideas to settle; that is how real mastery develops.

MISCELLANEOUS WORKED EXAMPLES ON NEWTON'S LAWS OF MOTION

Example 20

(a) A cyclist moving at constant velocity on a level road suddenly stops pedalling. Why the cyclist begins to slow down.

(b) A 0.45kg ball is initially at rest. A player kicks it so that it leaves with velocity18m/s. The contact time is 0.030s. Calculate:

(i) the change in momentum of the ball,

(ii) the average resultant force on the ball during contact.

Solution

(a) When pedalling stops, the driving force reduces greatly (or becomes zero) while resistive forces (air resistance and friction) still act backward. The resultant force becomes backward, so the cyclist decelerates.

(b) The solution of each part is as follows:

(i) $\Delta p = m(v - u) = 0.45kg(18m/s - 0m/s) = 8.1kgm/s$

The change in momentum is 8.1kgm/s.

(ii) Average resultant force $F = \frac{\Delta p}{t} = \frac{8.1\text{kgm/s}}{0.03\text{s}} = 270\text{N}$

The average resultant force is 270N.

Example 21

(a) Kipute says: *"If I throw a ball upward, there must be an upward force acting on it as it rises."*

Is Kipute correct? Explain.

(b) A crate of mass 40kg is on a rough floor. The maximum frictional force available is 180N. A worker pulls the crate with a horizontal force of 220N. When slipping begins, the frictional force becomes constant at 160N.

(i) Explain why the crate is able to move despite the presence of a large frictional force.

(ii) Calculate the acceleration immediately after it starts moving.

(iii) Calculate the velocity after 2.5s from the start of motion.

Solution

(a) Kipute is **not** correct.

Explanation

After the ball leaves the hand, there is no longer any upward push from the hand. The only significant force is weight acting downward due to gravity. The ball continues rising due to its upward velocity, but it has downward acceleration because the resultant force is downward.

(b) The solution of each part is as follows:

(i)

Reason:

The applied pulling force exceeds the maximum frictional force available.

Explanation:

Before the crate starts moving, friction is static and can increase only up to its maximum value of 180N. Since the applied horizontal force is 220N, which is greater than the maximum frictional force, the forces cannot balance. A forward resultant force therefore acts on the crate, causing it to start moving. Once slipping begins, the frictional force reduces to a constant value of 160N, allowing continued motion.

(ii) Once moving, friction$= 160\text{N}$, so resultant force $\text{F} = 220\text{N} - 160\text{N} = 60\text{N}$ forward

$$a = \frac{F}{m} = \frac{60\text{N}}{40\text{kg}} = 1.5\text{m/s}^2$$

The acceleration is 1.5m/s^2.

(iii) $v = u + at = 0\text{m/s} + (1.5\text{m/s}^2)(2.5\text{s}) = 3.75\text{m/s}$

The velocity is 3.75m/s.

Example 22

(a) A bus moving forward at constant velocity suddenly enters a muddy section of road and begins to slow down, even though the driver has not pressed the brakes. Explain why this does not contradict Newton's first law.

(b) A 1200 kg car is moving forward at 24m/s on a straight level road. At the instant the driver removes the foot from the accelerator, the driving force becomes zero. The total resistive force on the car depends on velocity and is given by:

$$R = 600 + 40v$$

(where R is in Newton when v is in m/s)

Assume that during this motion the car continues in a straight line and the only horizontal force on the car is this resistive force acting opposite to the motion.

Find:

(i) The initial deceleration at v = 24 m/s.

(ii) The velocity after 5.0 s (treat the deceleration as constant and equal to the initial value).

(iii) The distance covered in the 5.0 s

(iv) Predict qualitatively what happens to acceleration as v increases further, and why.

(v) Explain briefly why treating the deceleration as constant is an approximation, and state whether the true velocity after 5.0 s would be greater or smaller than your answer.

Solution

(a) Newton's First Law states that if the resultant force on a body is zero, its velocity remains constant. In the muddy section of road, the resistive forces (friction and drag) increase, so the resultant force on the bus is no longer zero. The backward resultant force produces a backward acceleration (deceleration), causing the bus to slow down. This behaviour therefore agrees with Newton's First law rather than contradicting it.

(b)Given: Resistive force: $R = 600 + 40v$

(i) Initial deceleration at v = 24 m/s

$$R = 600 + 40(24)$$

$$R = 600 + 960$$

$$R = 1560 \text{ N (acting backward)}$$

Since the resistive force oppose the motion, it is negative.

Thus, the resultant force on the car is: $F = -1560N$

Using Newton's second law: $F = ma$

$$a = F / m$$

$$a = \frac{-1560N}{1200kg}\ ;\ a = -1.30\ m/s^2$$

So the initial deceleration has is 1.30 m/s². (Negative sign is omitted in the final answer because it has been contained in the word deceleration).

(ii) Velocity after 5.0 s

Using: $v = u + at$

$$v = 24m/s + (-1.3m/s^2)(5s)$$
$$v = 17.5m/s$$

The velocity is $17.5\ m/s$.

(iii) Distance covered in 5.0 s

Using: $s = ut + ½at^2$

$$s = 24m/s(5s) + ½(-1.3m/s^2)(5s)^2$$
$$s = 103.75m$$

The distance covered is $103.75m$.

(iv) As v increases, R increases, so the resultant force decreases, and hence acceleration decreases. Eventually the car may approach a constant velocity where engine force equals resistive force and acceleration becomes zero.

(v) The deceleration is not truly constant because the resistive force depends on velocity. As the car slows down, v decreases, so the resistive force becomes smaller and the deceleration decreases with time. Treating the deceleration as constant therefore overestimates the slowing effect. Hence, the true velocity after 5.0 s would be **greater than 17.5 m/s**.

Example 23

(a) A passenger standing in a daladala feels as if a "force pushes them forward" when the driver suddenly applies the brakes. Explain why this feeling occurs, and state the actual direction of the resultant force on the passenger at the beginning of braking.

(b) A 1500kg car is moving forward with velocity 28m/s on a straight level road. The driver applies the brakes and the car comes to rest in 7.0 s. During braking, the total resistive force on the car may be treated as constant. Find:

(i) the acceleration of the car,

(ii) the resultant force acting on the car,

(iii) the distance travelled while braking,

(iv) the change in momentum of the car.

(v) Use your results to explain why doubling the braking time reduces the average braking force.

Solution

(a)

Reason:

The feeling occurs because of **inertia**. When the daladala begins to slow down, the passenger's body tends to maintain its original forward velocity.

Explanation:

At the instant braking starts, the daladala experiences a backward resultant force and begins to decelerate. The passenger, however, initially continues moving forward at the original velocity due to inertia. Relative to the decelerating daladala, this makes the passenger appear to move forward, creating the sensation of being "pushed" forward. In reality, no forward force acts on the passenger; instead, a **backward resultant force** must act on the passenger to reduce their forward velocity and bring them to rest with the vehicle.

(b) The solution of each part is as follows:

(i) Acceleration

$$a = \frac{v - u}{t}$$

Substituting given values:

$$a = \frac{(0\ \mathrm{m/s} - 28\ \mathrm{m/s})}{(7.0\ \mathrm{s})} = -4.0\ \mathrm{m/s^2}$$

So the car's acceleration is $-4.0\ \mathrm{m/s^2}$.

(ii) Resultant force

$$F = ma$$

Substituting:

$$F = (1500\ \mathrm{kg})(-4.0\ \mathrm{m/s^2}) = -6000\mathrm{N}$$

So the resultant force is 6000N backward.

(iii) Braking distance

$$s = ut + ½at^2$$

Substituting:

$$s = (28\ \mathrm{m/s})(7.0\ \mathrm{s}) + \tfrac{1}{2}(-4.0\ \mathrm{m/s^2})(7.0\ \mathrm{s})^2 = 98\mathrm{m}$$

The braking distance is 98m.

(iv) Change in momentum

$$\Delta p = m(v - u)$$

$$\Delta p = (1500\ \mathrm{kg})(0\ \mathrm{m/s} - 28\ \mathrm{m/s})$$

$$\Delta p = (1500\ \mathrm{kg})(-28\ \mathrm{m/s}) = -42000\ \mathrm{kgm/s}$$

So the momentum **decreases** by 42000 kgm/s.

Alternative solution

Resultant force can be given by:

$$F = \frac{\Delta p}{\Delta t}$$

From which, the change in momentum can be given as:

$$\Delta p = F\Delta t$$

Where: $F = -6000\mathrm{N},\ \Delta t = 7\mathrm{s}$

Substituting:

$\Delta p = -6000\mathrm{N} \times 7\mathrm{s} = -42000\mathrm{Ns} = -42000\ \mathrm{kgm/s}$ (the negative sign implies the decrease in momentum)

(v) Explanation about doubling braking time:

The change in momentum needed to stop the car is fixed: it is $\Delta p = -42000\ \mathrm{kg\ m/s}$. The average resultant braking force, however, depends on how quickly this momentum change occurs:

$$\text{Average force} = \frac{\text{change in momentum}}{\text{time}}$$

If the stopping time is doubled while the same momentum change is required, then average force becomes half, because the same Δp is spread over a larger time. This is why increasing braking time reduces the average force experienced.

Example 24

(a) A driver says: *"Even when my engine is very powerful, the car does not accelerate much at high velocity, and may eventually continue moving with constant velocity."* Explain why this statement is physically reasonable.

(b) A car of mass 1000kg moves along a straight, level road. The engine provides a constant driving force of 2500N forward. The total resistive force opposing the motion depends on the velocity and is given by:

$$R = 500 + 40v$$

(where R is in Newton when v is in m/s)

Assume that the motion remains in a straight line and that these are the only horizontal forces acting on the car. Find:

(i) the acceleration of the car at v = 10m/s,

(ii) the resistive force when the acceleration becomes zero,

(iii) the velocity at which the car moves with constant velocity.

Solution

(a)

Reason:

Because the acceleration of the car depends on the **resultant force**, not on the engine force alone.

Explanation:

As the car's velocity increases, resistive forces such as air resistance increase. Although the engine continues to provide a large forward force, the increasing resistive force reduces the resultant forward force acting on the car. According to Newton's second law, a smaller resultant force produces a smaller acceleration.

At sufficiently high velocity, the resistive force may become equal to the engine force, making the resultant force zero and causing the acceleration to fall to zero, leading to the constant velocity.

(b) The solution of each part is as follows:

(i) Using: $\text{Resultant force F} = \text{Driving force} - \text{Resistive force}$

Where:

$\text{Driving force} = 2500\text{N}$ (forward)

$\text{Resistive force R} = 500 + 40\text{v}$ (backward); with $\text{v} = 10\text{m/s}, \text{R} = 500 + 40 \times 10 = 900\text{N}$

It follows that:

$$\text{F} = 2500\text{N} - 900\text{N} = 1600\text{N (forward)}$$

Then using: $\text{F} = \text{ma or a} = \frac{\text{F}}{\text{m}}$

Substituting:

$$\text{a} = \frac{1600\text{N}}{1000\text{kg}}$$

$$\text{a} = 1.6\text{m/s}^2$$

So the acceleration when $\text{v} = 10\text{m/s}$ is 1.6m/s^2.

(ii) The acceleration becomes zero, when the resultant force is zero.

Now from: Resultant force $F = \text{Driving force} - \text{Resistive force}$

When $F = 0;$ Resistive force $=$ Driving force

But: Driving force $= 2500\text{N}$

Hence, the resistive force when the acceleration becomes zero is 2500N.

(iii) Constant velocity implies zero acceleration and from (ii) above, acceleration is zero when resistive force, R is 2500N.

Using the resistive force expression:

$$R = 500 + 40v$$

Substituting:

$$2500 = 500 + 40v$$

From which: $v = 50\text{m/s}$

So the constant velocity is 50m/s.

Example 25

(a) A driver says: *"If my car is moving forward, the resultant force on it must be forward."*

Explain why this statement is physically incorrect.

(b) Mr. Akilikubwa is driving a 1500kg car to school along a straight, level road at a steady velocity of 22m/s. As he approaches the school gate, a goat suddenly starts crossing the road ahead. However, being briefly absorbed in thought about the Physics lesson he is about to teach, he delays applying the brakes for 0.60s.

During this reaction time, the car continues to move forward with the same velocity. After the delay, he applies the brakes, and from that moment the resultant force acting on the car is constant and equal to 4500N, acting backward, until the car comes to rest. Find:

(i) the deceleration during braking,

(ii) the time taken to stop after braking begins,

(iii) the braking distance,

(iv) the total stopping distance from the moment Mr. Akilikubwa first sees the goat.

(v) Explain, using your results, why reaction time can be as important as braking strength.

Solution

(a)

Reason:

Because the direction of the resultant force is the direction of **acceleration**, not necessarily the direction of **velocity**.

Explanation:

A body can move forward while slowing down. In that case, its velocity is forward but its acceleration is backward. Since the resultant force is in the direction of acceleration (Newton's second law), the resultant force can be backward even while the car is still moving forward. Therefore, forward motion does not require a forward resultant force.

(b) The solution of each part is as follows:

(i) Using Newton's second law:

$$\mathrm{F = ma \ or \ a = \frac{F}{m}}$$

Substituting:

$$a = \frac{-4500\text{N}}{1500\text{kg}}$$

$$a = -3.0\text{m/s}^2$$

So the deceleration is 3.0m/s^2.

(ii) During braking: $u = 22\text{m/s}, v = 0\text{m/s}, a = -3.0\text{m/s}^2$

Using: $v = u + at$

$$0\text{m/s} = 22\text{m/s} + (-3.0\text{m/s}^2)t$$

From which: $t = 7.33\text{s}$

So the braking time is 7.33s.

(iii) Using: $s = ut + ½at^2$

$$s = (22\text{m/s})(7.33\text{s}) + ½(-3.0\text{m/s}^2)(7.33\text{s})^2 = 80.66\text{m}$$

The braking distance is 80.66m.

(iv) Total stopping distance = Reaction distance + Braking distance

But during reaction, acceleration is zero, so velocity remains 22m/s.

So reaction distance = velocity × reaction time = $(22\text{m/s}) \times (0.60\text{s}) =$ 13.2m

Total stopping distance = $13.2\text{m} + 80.66\text{m} = 93.86\text{m}$

So the total stopping distance is 93.86m.

(v) From the results, the car travels **13.2m** before braking even begins. This distance depends only on reaction time and initial velocity, not on braking force. Even if the brakes are very strong, a long reaction time adds a significant distance to the stopping distance. Therefore, improving reaction time (alertness, attention) can reduce total stopping distance just as meaningfully as improving braking strength.

Example 26

(a) Why is it safer to land on sand than on concrete when falling from the same height, even though the person comes to rest in both cases?

(b) A 70 kg person running forward at 6.0m/s falls and is brought to rest.

Case I: stopping time is 0.10s.

Case II: stopping time is 0.40s.

Calculate:

(i) the change in momentum in each case,

(ii) the average resultant force magnitude in each case,

(iii) the ratio of the forces.

(iv) Comment on what the results imply about injury risk.

Solution

(a) The momentum change needed to come to rest is the same in both cases. However, soft ground deforms during impact, increasing the stopping time. Since the average resultant force equals the change in momentum divided by the stopping time, a longer stopping time results into a smaller force during impact.

(b) The solution of each part is as follows:

(i) $\Delta p = m(v - u) = 70(0 - 6.0) = -420\ \text{kgm/s}$

So in each case, the momentum decreases by 420kgm/s.

(ii) Using average force, $F = \frac{\Delta p}{\Delta t}$

$$\textbf{Case I}: F_1 = \frac{420\text{kgm/s}}{0.10\text{s}} = 4200\text{N}$$

$$\textbf{Case II}: F_2 = \frac{420\text{kgm/s}}{0.40\text{s}} = 1050\text{N}$$

(iii) $\frac{F_1}{F_2} = \frac{4200}{1050} = 4$

(iv) The shorter stopping time produces four times the average force, increasing injury risk.

Example 27

(a) **Kipute** and **Kipanga** are revising Newton's laws of motion after class. Kipanga says:

"If an object is moving in a circle at constant speed, then there is no acceleration, because acceleration only occurs when speed changes."

However, Kipute disagrees**.** Who is correct? Explain why.

(b) A ball of mass 0.30kg is moving horizontally at 8.0m/s. It strikes a wall and rebounds along the same line with velocity 6.0m/s in the opposite direction. The contact time is 0.040s. Calculate:

(i) the change in momentum of the ball,

(ii) the average resultant force on the ball during contact and its direction.

(iii) Using your answers in (i) and (ii), explain why the force on the ball during contact is opposite to its initial direction of motion, even though the ball rebounds with a smaller velocity than it had before impact.

Solution

(a) **Correct student:** Kipute

Reason:
Acceleration depends on the change of **velocity**, not only on the change of speed.

Explanation:
Velocity is a vector quantity, so it changes when either its magnitude (speed) or its direction changes. In circular motion, even though the speed remains constant, the direction of motion changes continuously. Because the direction of velocity is changing at every instant, the velocity is changing, and therefore the object has acceleration.

(b) The solution of each part is as follows:

(i) Take the initial direction as positive: $u = +8.0\text{m/s}, v = -6.0\text{m/s}$

It follows that:

$$\Delta p = m(v - u) = 0.3\text{kg}(-6\text{m/s} - 8\text{m/s}) = 0.3\text{kg}(-14\text{m/s}) = -4.2\text{kgm/s}$$

The change in momentum is -4.2kgm/s; (the negative sign shows that the change in momentum is directed opposite to the original direction of motion of the ball).

(ii) Average force $F = \frac{\Delta p}{t} = \frac{-4.2\text{kgm/s}}{0.04\text{s}} = -105\text{N}$

The magnitude of the average resultant force is 105N, and its direction is opposite to the ball's initial direction of motion.

(iii)

Reason:
The direction of the resultant force depends on the direction of the change in momentum, not on the final velocity alone.

Explanation:
Before impact, the ball's momentum is in the direction of its initial motion. After rebounding, its momentum is in the opposite direction. Therefore, the change in momentum is directed opposite to the initial motion. Since the average resultant force acts in the direction of the change in momentum, the force during contact must be opposite to the initial direction of motion, even though the rebound velocity is smaller.

If the ideas now feel familiar and connected, you are ready! Let us understand and enjoy them even more in the Digging Deeper Exercise in the next module.