Newton's First Law & Equilibrium

Block 1: Fundamental Concepts

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1. A particle moves 45 m in 2.5 s. Calculate its speed.

2. Convert 36 km/h into m/s.

3. If a force of 15 N acts East and 22 N acts West, what is the resultant force?

4. **True or False:** An object moving at a constant velocity has a resultant force of zero.

Newton's First Law states that a body will remain at rest or move with constant velocity unless acted upon by a resultant force. When the resultant force is zero ($F_{net} = 0$), the body is in **equilibrium**.

1. For each horizontal scenario, state whether the object is in **equilibrium**:

a) A puck sliding across smooth ice at a steady 5 ms^{-1} in a straight line.

b) A sprinter at the exact moment they push off the blocks to start a race.

c) A crate being pushed at a constant speed where the push force equals the friction.

d) A ball thrown horizontally the moment it leaves the hand (ignore air resistance).

2. A particle P is acted upon by three horizontal forces: 12 N [Right], F N [Left], and 5 N [Right].

a) Find the value of F such that the particle is in equilibrium.

b) If $F = 20$ N, find the magnitude and direction of the resultant force.

3. A particle Q is in equilibrium under the action of three horizontal forces: A N [East], B N [West], and 15 N [East].

a) Write an equation relating A and B.

b) Given that $B = 2A$, find the values of A and B.

4. Aristotle argued that if an arrow is in motion, there must be a force driving the arrow forward, explain why Aristotle was wrong.

5. A block of mass 5 kg is being pushed horizontally with a force of 10 N [Right] against a friction force of 10 N [Left].

a) The block is currently moving at 2 ms^{-1}. Describe its motion over the next 10 seconds.

b) Suddenly, the friction force increases to 12 N while the 10 N push remains. Is the block still in equilibrium? Justify your answer.

6. A particle is subjected to three horizontal forces, F_1, F_2, and F_3.

- $F_1 = (2x + 5)$ N acting to the Right.
- $F_2 = (x - 2)$ N acting to the Left.
- $F_3 = 19$ N acting to the Left.

Calculate the value of x for which the particle remains in equilibrium.

7. A particle is in equilibrium under two horizontal forces:

- $F_1 = (k^2 + 4)$N acting to the Right.
- $F_2 = (5k)$N acting to the Left.

Find the two possible values of k.

8. A particle P is on a rough horizontal surface with a constant resistance R N.

- **Scenario 1:** A force X N [Right] is applied. P moves at a **constant velocity**.
- **Scenario 2:** The force is increased to 120 N [Right]. A second force Y N [Left] must be applied to maintain **equilibrium**.

Given that $Y = 3X$, solve the simultaneous equations to find the values of X, Y, and R.

1.2 Displacement, Velocity & Time

Block 1: Fundamental Concepts

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1. A particle moves from $x = -5$ m to $x = 12$ m. Calculate its change in position.

2. If an object travels at -5 ms^{-1} for 4 seconds, what is its change in position?

3. **True or False:** Displacement is always equal to the total distance traveled.

4. State which of the following are vectors: *Time, Displacement, Speed, Velocity.*

In kinematics, we define position relative to a fixed origin O. The **Initial Displacement** (s_0) is the position at $t = 0$. For constant velocity v, the displacement s at time t is given by:

$$s = vt + s_0.$$

This is the same mathematical form as the linear equation $y = mx + c$, with velocity as gradient and s_0 as the "y-intercept".

1. For each scenario, identify the values of s_0 and v (taking Right as positive):

a) A car starts at the origin and moves Left at 15 ms^{-1}.

b) A ball is held 2 m above the ground (O) and dropped at 0 ms^{-1}.

c) A runner is 10 m behind the start line and runs forward at 6 ms^{-1}.

2. A particle P moves with constant velocity $v = 4 \text{ ms}^{-1}$. At $t = 0$, $s_0 = -10$ m.

a) Write an equation for the displacement s in terms of t.

b) Find the displacement when $t = 5$ s.

c) Find the time t when the particle passes through the origin O.

3. A remote-controlled car starts at a point 3 m to the Right of O. After 8 seconds of moving with constant velocity, it is at a point 21 m to the Left of O.

a) State the values of s_0 and s at $t = 8$.

b) Calculate the velocity v of the car.

4. A student argues: "If an object has a negative velocity, it must be behind the origin." Explain why the student is incorrect, using an example to support your answer.

5. Two particles A and B are moving along the same straight horizontal line.

- Particle A starts at O and moves with velocity 8 ms^{-1}.
- Particle B starts at $s = 50$ m and moves with velocity -2 ms^{-1}.

Calculate the time t at which the particles collide.

6. A particle moves with constant velocity v.

- At $t = 2$, $s = 7$ m.
- At $t = 5$, $s = -8$ m.

Form two simultaneous equations using $s = s_0 + vt$ and solve them to find s_0 and v.

7. A particle starts at $s_0 = k$ and moves with velocity $v = (k - 3)$ ms^{-1}. After 4 seconds, the particle is at the origin. Find the value of k.

1.3 Newton's Second Law

Block 1: Fundamental Concepts

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1. State Newton's First Law.

2. A particle has a resultant force of zero. Describe its motion.

3. Convert 72 km/h into m/s.

4. Define the term *Resultant Force*.

Newton's Second Law states that the acceleration (a) of an object is directly proportional to the resultant force (F) acting on it:

$$F = ma.$$

1. A block of mass 4 kg is acted upon by a resultant force of 12 N.

a) Calculate the acceleration of the block.

b) If the force is doubled, what happens to the acceleration?

2. A car of mass 1200 kg is travelling at a velocity of 20 ms^{-1}. The driver applies the brakes, providing a constant braking force of 3000 N.

a) State the magnitude of the resultant force acting on the car.

b) Calculate the deceleration of the car.

3. A particle of mass 0.5 kg is pulled along a smooth horizontal surface by a force of 10 N [Right]. A resistance force of F N [Left] also acts on the particle.

a) Given the acceleration is 4 ms^{-2} [Right], find the value of F.

b) If F increases to 12 N, describe the resulting motion (calculate the new a).

4. A crate of mass m kg is pushed with a force of 50 N against a friction force of 10 N. The crate accelerates at 2.5 ms^{-2}. Calculate the mass of the crate.

5. An object is moving to the Right. A force is applied to the Left.

a) Is the object in equilibrium? Justify your answer.

b) Does the object immediately start moving to the Left? Explain your reasoning using Newton's Second Law.

6. A particle of mass 2 kg is subjected to two forces:

- $F_1 = (3k + 1)$ N acting Right.
- $F_2 = (k - 5)$ N acting Left.

Given the particle accelerates Right at 5 ms^{-2}, find the value of k.

7. A van of mass 2000 kg experiences a driving force of D N and a resistance force of R N.

- When $D = 800$, the van moves at a constant velocity.
- When D is increased to 1200, the van begins to accelerate.

Calculate the acceleration in the second scenario.

1.4 Newton's Third Law

Block 1: Fundamental Concepts

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1. State the formula for Newton's Second Law.
2. A car of mass 1500 kg decelerates at 2 ms^{-2}. Calculate the braking force.
3. What is the resultant force on an object moving at a constant velocity?
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Newton's Third Law of Motion: Whenever one object exerts a force on a second object, the second object exerts a force of equal magnitude and opposite direction on the first.

1. A block of mass 8 kg rests in equilibrium on a horizontal floor.

a) State the weight of the block (take $g = 10$ ms^{-2}).

b) Using Newton's Third Law, find the magnitude of the Normal Contact Force R.

2. A crate of mass 20 kg is suspended at rest by a single vertical rope.

a) Draw a diagram showing the weight and the tension T acting on the crate.

b) State the value of the tension in the rope.

3. A box of mass 5 kg is being pulled across a smooth horizontal floor by a horizontal rope with a tension of 15 N.

a) Calculate the acceleration of the box.

b) State the magnitude of the Normal Contact Force R acting on the box.

4. A man of mass 80 kg stands in a lift. The lift is stationary.

a) Calculate the Normal Contact Force R exerted by the floor on the man.

b) The lift begins to accelerate upwards at 1.5 ms^{-2}. By considering $F = ma$, calculate the new value of R.

5. A lamp of mass m is hanging from a ceiling by a chain. The tension in the chain is 49 N. Calculate the mass of the lamp.

6. A block of mass 10 kg is on a horizontal surface. A vertical string is attached to the top of the block and pulled upwards with a tension $T = 30$ N. The block remains on the floor.

a) Calculate the magnitude of the Normal Contact Force R now acting on the block.

b) Find the minimum tension T required to lift the block off the floor.

7. Two blocks, P and Q, are in contact on a smooth horizontal surface. A horizontal force of 30 N is applied to block P (5 kg), which in turn pushes block Q (10 kg).

a) Treat P and Q as a single particle of mass 15 kg to find the acceleration.

b) Now consider block Q in isolation. Use its acceleration to find the contact force exerted by block P onto block Q.

1.5 Momentum

Block 1: Fundamental Concepts

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1. A car of mass 1200 kg moves at 15 ms^{-1}. Calculate its momentum.
2. State Newton's Third Law.
3. An object of mass 2 kg is acted on by a 10 N force for 3 s. Calculate its change in velocity.
4. If a particle moves with velocity -4 ms^{-1}, what is the direction of its momentum?

Momentum (p): A vector quantity defined as the product of mass and velocity.

$$p = mv.$$

Principle of Conservation of Linear Momentum: In the absence of external forces, the total momentum of a system before a collision is equal to the total momentum after the collision.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

1. A particle A of mass 2 kg moving at 6 ms^{-1} [Right] collides with a stationary particle B of mass 4 kg. After the collision, the particles coalesce (stick together).

a) Calculate the total momentum before the collision.

b) Find the common velocity of the particles after the collision.

2. A truck of mass 5000 kg moving at 10 ms^{-1} collides with a car of mass 1000 kg moving at 2 ms^{-1} **in the same direction**. After the collision, the truck's speed reduces to 8 ms^{-1}.

a) Calculate the velocity of the car after the impact.

b) State whether the car's momentum increased or decreased.

3. Two ice skaters, P (60 kg) and Q (80 kg), are standing still on smooth ice. They push away from each other. P moves off with a velocity of -2 ms^{-1}.

a) State the total initial momentum of the system.

b) Calculate the velocity of skater Q.

4. A bullet of mass 0.05 kg is fired into a wooden block of mass 4.95 kg which is at rest. The bullet becomes embedded in the block and they move together at 2 ms^{-1}. Calculate the initial speed of the bullet.

5. Particle X (3 kg) moving at 8 ms^{-1} collides head-on with Particle Y (5 kg) moving at 4 ms^{-1} in the opposite direction.

a) Taking X's initial direction as positive, write an expression for the total initial momentum.

b) If X is brought to rest by the collision, calculate the final velocity of Y.

6. A ball of mass 0.4 kg hits a vertical wall at 15 ms^{-1} and rebounds at 10 ms^{-1}.

a) Calculate the change in momentum (Impulse) of the ball. (Hint: Watch your signs for direction!).

b) If the ball was in contact with the wall for 0.1 s, find the average force exerted by the wall.

7. A particle of mass m moving with velocity u collides with a stationary particle of mass km. The particles coalesce. Show that the final velocity of the combined mass is

$$\frac{u}{1+k}.$$

8. An explosion breaks a stationary object into two fragments of masses M_1 and M_2. Show that the ratio of their velocities is inversely proportional to the ratio of their masses ($v_1/v_2 = -M_2/M_1$).

1.6 Work and Energy

Block 1: Fundamental Concepts

1. Define momentum and state its units.
2. A force of 25 N acts on a mass of 5 kg. Calculate the acceleration.
3. State the principle of conservation of momentum.
4. Convert 54 km/h into m/s.

Work (W_D): When a constant driving force D moves an object through a displacement s in the direction of the force, the work done is:

$$W_D = Ds$$

Kinetic Energy (K): The energy an object possesses due to its motion. For a mass m moving with velocity v:

$$K = \frac{1}{2}mv^2$$

Work-Energy Principle: The work done by the resultant driving force is equal to the change in kinetic energy of the object ($W_D = \Delta K$).

1. A constant driving force of 40 N acts on a crate, moving it a distance of 15 m along a smooth horizontal floor. Calculate the work done by the force.

2. A particle of mass 0.5 kg is moving with a velocity of 12 ms^{-1}.

a) Calculate its kinetic energy.

b) If the velocity is doubled, by what factor does the kinetic energy increase?

3. A car of mass 1000 kg starts from rest. A constant driving force of 500 N acts on the car over a distance of 200 m.

a) Calculate the work done by the driving force.

b) Using the work-energy principle, find the final kinetic energy of the car.

c) Calculate the final velocity of the car.

4. A block of mass 4 kg is initially moving at 3 ms^{-1}. A driving force F is applied in the direction of motion over a distance of 10 m, increasing its speed to 7 ms^{-1}.

a) Calculate the initial and final kinetic energy of the block.

b) Find the work done on the block.

c) Calculate the magnitude of the driving force D.

5. A student applies a horizontal force of 100 N to a heavy stationary wall.

a) How much work is done on the wall?

b) Does the wall gain any kinetic energy?

6. A motorbike of mass m accelerates from 12 ms^{-1} to a velocity v by a constant driving force D. By ignoring any resistance forces, the work done by the driving force is the change in kinetic energy of the car.

a) Write an expression for the work done in terms of D and s.

b) Use $Ds = \Delta K$ to show that the equation $v^2 = u^2 + 2as$.

7. A toy boat of mass 2 kg is moving at 4 ms^{-1}. A motor provides a driving force of 10 N for 3 seconds. Ignore any resistance forces.

a) Calculate the acceleration and the distance traveled during these 3 seconds.

b) Calculate the work done by the motor.

c) Verify that the work done equals the change in kinetic energy.