A LEVEL MATHS 9709 · PAPER 4 MECHANICS · 4.4 · ~5 MIN READ

Newton's laws of motion

Newton's three laws, F = ma along the line of motion, weight, motion on rough and smooth slopes, lifts, and connected particles: towing systems and particles joined by a string over a pulley.

Newton's three laws | Resultant force = ma | Weight mg | Lifts | Inclined planes with friction | Car and trailer | Pulleys | Connected particles

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Paper tag = **where it is examined** FORMULA LIST (MF19) given in the exam M1 A1 B1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Resultant force = mass × acceleration,** along the direction of motion. Perpendicular to the motion, the forces balance.
- **Connected particles:** write F = ma for each particle separately, then solve together. Treat the whole system as one body only for forces external to it.
- **A light inextensible string over a smooth pulley** has the same tension on both sides, and both particles have the same size of acceleration.
- **Newton's third law:** the force A exerts on B is equal and opposite to the force B exerts on A. These act on different bodies.

BY THE END YOU CAN

- Apply Newton's laws to the motion of a particle in a straight line, including on inclined planes.
- Solve problems involving connected particles: towing and pulley systems.
- Use the suvat equations with accelerations found from F = ma.

Riyaz Sir

1 F = ma

Single particles

$$F_{resultant} = ma \ ; \ W = mg \ (g = 10 \text{ m s}^{-2})$$

resultant in the direction of the acceleration

- **Method:** draw the forces, choose the direction of acceleration as positive, write "forward forces − backward forces = ma".

WORKED EXAMPLE

A man of mass 70 kg stands in a lift moving upwards with acceleration 0.8 m s^{-2}. Find the normal reaction from the floor.

1. R − 700 = 70 × 0.8 M1 A1
2. **R = 756 N** A1

WORKED EXAMPLE

A particle of mass 3 kg slides down a rough plane inclined at 30°, with μ = 0.2. Find its acceleration.

1. R = 30 cos 30° = 25.98 N; F = 0.2R = 5.196 N M1
2. 30 sin 30° − 5.196 = 3a M1
3. **a = 3.27 m s^{-2}** A1

COMMON MISTAKE

Including the weight in the "along the slope" equation as mg instead of mg sin α. Resolve first.

2 Connected particles

Towing

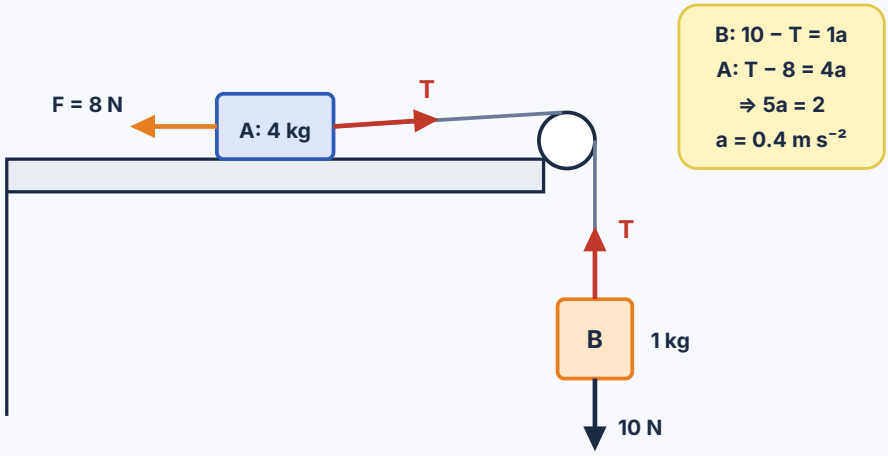
WORKED EXAMPLE

A car of mass 1200 kg tows a trailer of mass 400 kg with a light rigid towbar. The driving force is 2400 N and the resistances are 400 N on the car and 200 N on the trailer. Find the acceleration and the tension in the towbar.

1. whole system: 2400 − 600 = 1600a ⇒ **a = 1.125 m s^{-2}** M1 A1
2. trailer: T − 200 = 400 × 1.125 ⇒ **T = 650 N** M1 A1
3. **check with the car: 2400 − 400 − 650 = 1350 = 1200 × 1.125** ✓

- **Braking:** if the car brakes, the towbar may be in thrust (pushing). A negative tension means thrust.

Pulleys



Light inextensible string, smooth pulley: same tension and same acceleration.

A on a rough table and B hanging: same tension, same acceleration.

WORKED EXAMPLE

Particle A (4 kg) is on a rough horizontal table where friction is 8 N. A light string runs over a smooth pulley at the edge to particle B (1 kg), hanging freely. Find the acceleration and the tension.

1. B: 10 − T = 1a M1
2. A: T − 8 = 4a M1
3. **adding: 2 = 5a ⇒ a = 0.4 m s⁻², T = 9.6 N** A1 A1

- **After the string breaks** (or B hits the floor), each particle moves on its own: A decelerates under friction only. Use the speed at that moment as the new u.

COMMON MISTAKE

Using one equation for the whole pulley system with mg of both particles. The weights act in different directions, so write one equation per particle. Also, "B hits the ground" doesn't stop A immediately.

LINKING QUESTION

The forces are resolved as in Forces and equilibrium; the resulting motion uses Kinematics; and the same problems can be done with energy.

Test yourself — cover the answers first

QUICK CHECK

1. A 5 kg particle accelerates at 2 m s^{-2}. What is the resultant force?
2. A lift accelerates downwards. Is R more or less than mg?
3. What does "smooth pulley" let you assume?
4. State Newton's third law.
5. A towbar force comes out negative. What is it?

EXAM-STYLE

6. Particles of masses 3 kg and 2 kg hang on either side of a smooth pulley and are released from rest. Find a and T.
7. In the pulley question above (A on the table), B is 0.5 m above the floor when released. Find B's speed as it hits the floor.
8. A 2 kg block is pushed up a smooth slope inclined at 20° by a 15 N force parallel to the slope. Find a.

Show answers

1. 10 N
2. less
3. the tension is the same on both sides
4. if A exerts a force on B, B exerts an equal and opposite force on A
5. a thrust
6. $30 - T = 3a$, $T - 20 = 2a \Rightarrow a = 2\ \text{m s}^{-2}$, $T = 24$ N
7. $v^2 = 2 \times 0.4 \times 0.5 = 0.4 \Rightarrow v = 0.632\ \text{m s}^{-1}$
8. $15 - 20 \sin 20° = 2a \Rightarrow a = 4.08\ \text{m s}^{-2}$

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