Newton's Second Law

6.5.4.2.2 · Physics · revision notes

Newton's Second Law links resultant force, mass and acceleration: F = m a. You need to use it in calculations, estimate forces in everyday road transport, explain inertial mass (Higher), and describe the required practical on force, mass and acceleration.

Key facts

- F = m a (resultant force = mass × acceleration)
- a ∝ F (at constant mass)
- Always use the RESULTANT force
- Grade 8+ only Inertial mass = force ÷ acceleration
- Units: F in N, m in kg, a in m/s^2
- a ∝ 1/m (at constant force)
- Acceleration is in the direction of the resultant force
- ~ means 'approximately'; car mass ~1000 kg

Notes

The law

- The acceleration of an object is **proportional** to the resultant force acting on it, and **inversely proportional** to its mass: a ∝ F and a ∝ 1/m (∝ means 'is proportional to').
- resultant force = mass × acceleration: **F = m a**
- F in newtons (N), m in kilograms (kg), a in metres per second squared (m/s^2).
- The acceleration is in the same direction as the resultant force.
- Always use the **resultant** force. Example: thrust 5000 N forwards and drag 1400 N backwards give F = 3600 N.

Inertial mass Grade 8+ only

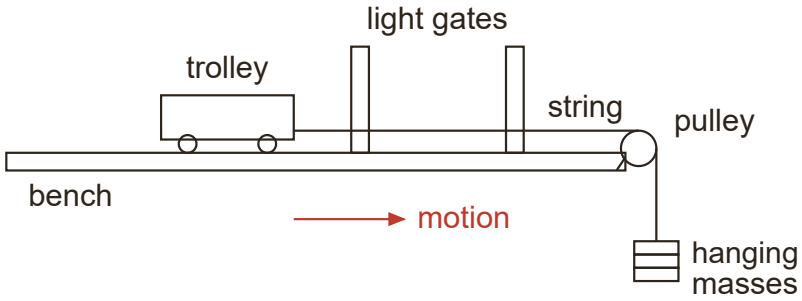
- Inertial mass is a measure of how difficult it is to change the velocity of an object.
- Inertial mass is defined as the ratio of force over acceleration: m = F ÷ a.
- A larger mass needs a larger force to give it the same acceleration.

Estimating in road transport Grade 5+ only

- The symbol ~ means 'approximately'.
- Useful rough values: car mass ~1000 kg; a car speeding up at ~3 m/s^2; a car braking hard at ~6 m/s^2.
- Example: to accelerate a car at ~3 m/s^2 needs a resultant force of ~1000 × 3 = ~3000 N.

Required practical: force, mass and acceleration

- A trolley on a bench is pulled by a string that passes over a pulley to a hanging mass. The weight of the hanging mass is the accelerating force.
- Measure the acceleration with light gates and a data logger, or by timing the trolley over marked distances.
- With two light gates, the data logger measures the speed at each gate and the time between them: $a = (v_2 - v_1) \div t$.



The weight of the hanging masses accelerates the trolley; the light gates measure the acceleration.

- To vary the force at constant mass: move masses from the trolley to the hanger, so the total mass being accelerated stays the same.
- To vary the mass at constant force: add masses to the trolley and keep the hanging mass the same.
- Keep the same: the distance between the light gates and the release point. Release the trolley from rest each time.
- Repeat each reading at least three times and calculate a mean acceleration.
- Results: a graph of acceleration against force is a straight line through the origin, so $a \propto F$. Acceleration decreases as mass increases.

How to answer each type of question

Calculate with F = m a

2 marks | Grade 4

1. Check the mass is in kg.
2. Write F = m a, or its rearranged form, and substitute.
3. Give the unit.

Example. A resultant force of 450 N acts on a motorbike and rider. Their total mass is 300 kg. Calculate their acceleration.

Model answer.

$a = 450 \div 300$ (1)

$a = 1.5\ m/s^2$ (1)

Two-step: acceleration from a velocity change, then force

4 marks | Grade 6

1. Use a = Δv ÷ t to find the acceleration.
2. Use F = m a to find the resultant force.
3. Give each answer with its unit.

Example. A car of mass 1100 kg accelerates from rest to 18 m/s in 6.0 s.
Calculate the resultant force on the car.

Model answer.

a = (18 − 0) ÷ 6.0 (1)

a = 3.0 m/s^2 (1)

F = 1100 × 3.0 (1)

F = 3300 N (1)

Describe the required practical

4 to 6 marks | Grade 5

1. Describe the apparatus: trolley, string, pulley, hanging masses, light gates.
2. Say how the force is changed while the mass is kept constant.
3. Say how the acceleration is measured, and that readings are repeated.
4. Say what graph is plotted.

Example. Describe how a student could investigate how the acceleration of a trolley depends on the resultant force on it, keeping the mass constant.

Model answer.

Attach the trolley by a string over a pulley at the end of the bench to a mass hanger (1).

Measure the acceleration using light gates and a data logger (or time the trolley over measured distances) (1).

The weight of the hanging masses is the force; change it by moving masses from the trolley to the hanger (1)

which keeps the total mass constant (1).

Use at least five different forces and repeat each reading to calculate a mean (1).

Plot a graph of acceleration against force (1).

Estimate a force in road transport

3 marks | Grade 7

1. State a sensible value for any quantity not given (e.g. car mass ~1000 kg).
2. Find the acceleration if needed.
3. Use F = m a and round sensibly.

Example. Estimate the braking force needed for a car to decelerate from 30 m/s to rest in about 5 s.

Model answer.

mass of car ~1000 kg (1)

deceleration = 30 ÷ 5 = 6 m/s^2 (1)

F ≈ 1000 × 6 ≈ 6000 N (1)

Explain using inertial mass

2 marks | Grade 8

1. Say that a greater mass is more difficult to accelerate (greater inertial mass).
2. Use a = F ÷ m to compare the accelerations.

Example. The same resultant force is applied to an empty shopping trolley and to a full one. Use the idea of inertial mass to explain why the full trolley has a smaller acceleration.

Model answer.

The full trolley has a greater (inertial) mass, so it is more difficult to change its velocity (1).

a = F ÷ m, so with the same force, the greater mass has a smaller acceleration (1).

Don’t lose marks

- Using one of the forces instead of the resultant force.
- Using a weight in N as if it were a mass in kg. If a weight is given, use m = W ÷ g.
- Using a mass in grams: convert to kg first.
- In the practical, adding new masses to the hanger, which changes the total mass as well as the force.
- Saying acceleration is proportional to mass. It is inversely proportional.

More tips

Memory tricks

- Formula triangle: F on top, m and a underneath.
- Direction check: the acceleration always points the same way as the resultant force.
- In the practical, moving masses from the trolley to the hanger changes the force without changing the total mass, so it is a fair test.
- Rough values for estimates: car ~1000 kg, person ~70 kg.

Exam technique

- F = m a is on the Physics Equations Sheet: pick it, rearrange it and use it.
- In estimates, state the values you assumed (e.g. 'mass of car ≈ 1000 kg') and use ~ or 'about' in your answer.
- In practical questions, name the independent, dependent and control variables clearly.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4 — **Calculate force using F = m a**
For example, 1200 kg × 2.5 m/s^2 = 3000 N.

Grade 5 — **Find mass or acceleration using F = ma**
a = F ÷ m and m = F ÷ a.

Grade 5 — **Describe how acceleration depends on force and mass**
Acceleration is proportional to the resultant force and inversely proportional to the mass.

Grade 5 — **Describe the acceleration required practical**
Vary the force (or the mass) on a trolley and measure its acceleration, e.g. with light gates.

Grade 5 — **Estimate forces in everyday road transport**
For example, a car of mass ~1000 kg decelerating at ~6 m/s^2 needs ~6000 N.

Grade 6 — **Use the resultant force in F = ma**
Find the resultant first, e.g. thrust minus drag, then divide by the mass.

Grade 8 — **Explain inertial mass**
Inertial mass is a measure of how difficult it is to change an object's velocity: force ÷ acceleration.

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