# 8 Newton's Laws of Motion

## 8.1 Force and Acceleration

An **air track** allows motion to be observed in the absence of friction.

- The **glider** on the air track floats on a **cushion of air**.
- Provided the track is level, the glider **moves at constant velocity** along the track because friction is absent.

**Newton's first law of motion**: Objects either stay at rest or moves with constant velocity unless acted on by a force.

An object moving at constant velocity is either

- Acted on by no forces, or
- The forces acting on it are **balanced**.

The inverse is true: when an object is acted on by a resultant force, the result is to change the objects velocity.

**Newton's second law of motion**: $F$ is proportional to $ma$.

By defining the **newton** as the amount of force that will give an object of mass 1kg an acceleration of $1\text{ms}^{-2}$, the proportional statement can be written as

$$F = ma$$

### Weight

The force of gravity on an object is its **weight**.

The acceleration of a falling object acted on by gravity only is $g$. Because the force of is the only force acting on it, its weight can be given by

$$W = mg$$

- When an object is in **equilibrium**, the **support force** on it is equal and opposite to its weight.
- An object placed on a **weighting balance** exerts a force on the balance equal to the weight of the object. Thus the balance measures the weight of the object.

The mass of an object is a measure of its **inertia** - its resistance to change of motion.

- More force is needed to give an object a certain acceleration than to give an object with less mass the same acceleration.

## 8.2 Using $F = ma$

When an object is acted on by two unequal forces acting in **opposite direction**, the object accelerates in the direction of the larger force.

If $F_1 > F_2$

$$\text{resultant force } F_1 - F_2 = ma$$

## 8.3 Terminal Speed

Any object moving through a fluid experiences a force that drags on it due to the fluid.

The **drag force** depends on

- The **shape** of the object.
  - The faster an object travels in a fluid, the greater the drag force on it.
- Its **speed**.
- The **viscosity** of the fluid.
  - Viscosity is a measure of how easily the fluid flows past a surface.

### Motion of an Object Falling in a Fluid

1. The speed of an object **released from rest** in a fluid **increases as it falls**.
2. So the **drag force** on it due to the fluid increases.
3. The **resultant force** on the object is the difference between the force of gravity on it and the drag force.
4. As the drag force increases, the **resultant force decreases**, so the acceleration becomes less as it falls.
5. If it continues falling, it attains **terminal speed** when the drag force on it is equal and opposite to its weight.

At any instance, the resultant force $F = mg - D$ where $D$ is the drag force.

Therefore the acceleration of the object is

$$\frac{mg - D}{m} = g - \frac{D}{m}$$

- **Initial acceleration** is $g$ because the speed is zero, therefore the drag force is zero.
- At the **terminal speed**, the potential energy of the object is transferred into internal internal energy of the fluid by the drag force.

### Motion of a Powered Vehicle

- $F_E$ represents the **motive force** provided by the engine.
- $F_R$ represents the sum of the **resistive force** opposing the motion of the vehicle.
- The **resultant force** on it is $F_E - F_R$.

Therefore its acceleration is

$$a = \frac{F_E - F_R}{m}$$

The **terminal speed** is reached when $F_R$ becomes equal and opposite to $F_E$, and $a = 0$.

## 8.4 On the Road

- **Thinking distance** is the distance travelled by a vehicle in the time it takes the driver to react.

  For a vehicle moving at constant speed $v$, the thinking distance

  $$s_1 = vt_0$$

  where $t_0$ is the **reaction time** of the driver.

- **Braking distance** is the distance travelled by a car in the time it takes to stop safely - from when the brakes are first applied.

  Assuming **constant deceleration** $a$, to zero speed from speed $u$.

  $$s_2 = \frac{u^2}{2a}$$

$$\begin{aligned} \textbf{stopping distance} &= \text{thinking distance} + \text{braking distance} \\ &= ut_0 + \frac{u^2}{2a} \end{aligned}$$

### Skidding

Friction between the tyres and the road **prevent slipping** so the wheels roll along the roll.

- If the driver **accelerates too fast**, the wheels skid.
- This is because there is an **upper limit** to the amount of friction between the tyres and the road.

### Testing Friction

To measure the **limiting friction** between the underside of a block and the surface it is on

1. Pull the block with an increasing force until it slides.
2. The limiting frictional force on the block is equal to the pull force just before the sliding occurs.

## 8.5 Vehicle Safety

The **effect of a collision** of a vehicle can be measured in terms of the acceleration or deceleration of the vehicle, expressed in terms of $g$.

When objects collide, they are in contact with each other force a certain time.

- The shorter the contact time, the greater the impact force for the same initial velocities of the objects.
- If two vehicles collide and remain tangled together, they exert forces on each other **until they are moving at the same velocity**.

The **impact time** $t$ is the duration of the impact force.

$$\text{Impact time } t = \frac{2s}{u+v}$$
$$\text{Acceleration } a = \frac{v-u}{t}$$
$$\text{Impact force } F = ma$$

### Car Safety Features

The **impact force** is lessened if the **impact time is greater**. Design features increase the impact time to reduce the impact force.

- **Vehicle bumpers** give way a little in a **low-speed impact** and so increase impact time. Impact force is reduced as a result.
- **Crumple zones** - The **engine compartment** of a car is designed to give way in a front-end impact.
  - If the engine compartment were rigid, the impact time would be very short, so the impact force would be very large.
- **Seat belts** restrains the wearer from **crashing into the vehicle frame** after the vehicle suddenly stops in a front-end impact.
  - The restraining force on the wearer is much less than the impact force would be if the wearer hit the vehicle frame.
  - With the seat belt on, the wearer is **stopped more gradually** than without it.
- **Collapsible steering wheel** lessen the impact force if the driver makes contact with the steering wheel as a result of the steering wheel collapsing in the impact.
- **Air bags** acts as a cushion and increase the impact time on the person, reducing the force on the person.
  - The force of the impact is **spread over the contact area** - so the pressure on the body is less.