7 On the Move

7.1 Speed and Velocity

- **Displacement** is distance in a given direction.
- **Speed** is defined as change of distance per unit time.
- **Velocity** is defined as change in displacement per unit time, or
  - Velocity is speed in a given direction.

The unit of speed and velocity is the metre per unit second ms^{-1}.

An object moving at **constant speed** travels equal distance in equal times.

- For an object which travels distance s in time t at constant speed.

$$\text{speed } v = \frac{s}{t}$$
$$\text{distance travelled } s = vt$$

- For an object moving at constant speed on a circle of radius r, its speed

$$v = \frac{2\pi r}{T}$$

For an object moving at **changing speed** that travels a distance Δs in time Δt

$$v = \frac{\Delta s}{\Delta t}$$

The **delta notation** Δ means a change of something.

Distance-time Graphs

A distance-time graph is a graph of distance against time.

- For an object moving at **constant speed**, its distance-time graph is a **straight line with constant gradient**.

$$\text{speed } = \frac{s}{t} = \text{gradient of line}$$

- For and object moving at **changing speed**, the gradient of the line changes.
  - The gradient of the line at any point can be found by drawing a **tangent to the line** at that point.
  - Then measuring the gradient of the tangent.

Velocity

An object moving at **constant velocity** moves at the same speed without changing its direction of motion.

- If an object changes its **direction of motion** or its **speed** or both, its velocity changes.
- The velocity of an object moving on a **circular path** at constant speed **changes continuously** because its direction of motion changes continuously.

An object travelling along a straight line has two possible directions, so the **displacement-time graph** can have a negative gradient when the object moves in the **negative direction**.

7.2 Acceleration

Acceleration is defined as change of velocity per unit time, the unit of acceleration is metre per second per second ms^{-2}.

- Acceleration is a vector.
- **Deceleration values** are negative and signify that velocity **decreases with respect to time**.

Uniform Acceleration

Uniform acceleration is where the velocity of an object **moving along a straight line changes at a constant rate** such that the acceleration is constant.

For an object that **accelerates uniformly** from velocity u to velocity v in time t along a straight line.

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

Non-uniform Acceleration

Non-uniform acceleration is where the direction of motion of an object changes, or its speed changes, at a **varying rate**.

It can be seen from a **velocity-time graph** because the gradient is not constant.

$$\text{Acceleration} = \text{gradient of the line on the velocity-time graph}$$

7.3 Motion Along a Straight Line at Constant Acceleration

Consider an object that **accelerates uniformly** from initial velocity u to final velocity v in time t without change of direction.

From the definition of acceleration $a = \frac{v - u}{t}$

$$v = u + at \tag{1}$$

From $s = \bar{v} \times t$ and $\bar{v} = \dfrac{u+v}{2}$

$$s = \frac{(u+v)t}{2} \tag{2}$$

Combining (1) and (2):

$$s = ut + \frac{1}{2}at^2 \tag{3}$$

Multiply $a = \dfrac{v-u}{t}$ and $s = \dfrac{(u+v)t}{2}$

$$v^2 = u^2 + 2as \tag{4}$$

Finding Displacement using a Velocity-time Graph

Consider an object moving at **constant velocity**. The displacement in time t is

$$s = vt$$

so the displacement is represented on graph by the **area under the line** between the start and time t which is a rectangle with width t and height v.

Consider an object moving at **constant acceleration** a.

$$s = \frac{(u+v)t}{2}$$

so the displacement is represented on graph by the **area under the curve** between the start and time t which is a trapezium with area $(u+v)t/2$.

Consider an object moving at a **changing acceleration**.

1. Let v represent the velocity at time t and $v + \delta v$ represent the velocity a short time later at $t + \delta t$.
2. Because δv is small compared with velocity v, the displacement δs in the short time interval δt is $v\delta t$.
3. By considering the whole area under the line in strips of similar width, the **total displacement** from the start to time t is represented by the sum of the area of every strip, which is the **total area under the line**.

Therefore whatever the shape of the line of a velocity time graph.

$$\text{displacement} = \text{area under the line of a velocity-time graph}$$

7.4 Free Fall

Acceleration Due to Gravity

1. Use a **vertical metre rule** to provide a scale.
2. Take a **video clip** of a ball's flight after being <u>released from rest</u>.

3. Use the video to measure the **time of descent** of the ball and the **distance fallen** by the ball from rest.
4. Since $s = ut + \frac{1}{2}at^2$ and $u = 0$, we have $s = \frac{1}{2}at^2$.
5. Plot a graph of s against t^2.
6. The acceleration due to gravity is $2 \times$ gradient.

Since there are no external forces acting on the object apart from the force of gravity, this value of acceleration is known as **the acceleration of free fall** and is represented by the symbol g.

$$g \approx 9.8\text{ms}^{-2}$$

7.5 Motion Graphs

For a **velocity-time graph**

- The **gradient of the line** represents the object's **acceleration**.
- The **area under the line** represents the **displacement** of the object from its starting position.

7.7 Projectile Motion 1

A **projectile** is any object acted on only by the force of gravity.

- The acceleration of the object is **always equal to g** and is **always downwards**, because the force of gravity acts downwards.
  - The acceleration only affects the **vertical motion** of the object.
- The horizontal velocity of the object is constant because the acceleration of the object does not have a horizontal component.
- The motions in the horizontal and vertical directions are **independent of each other**.

$$\begin{aligned} v &= u - gt \\ y &= ut - \frac{1}{2}gt^2 \end{aligned}$$

Horizontal Projection

If the initial projection of an object projected off a cliff is horizontal.

- Its **path through the air** becomes steeper as it drops.
- The faster it is projected, the further away it will fall into the sea.
- The time taken for it to fall into the sea **does not depend on how fast it is projected**.

If ball A is released from rest and ball B is projected horizontally.

- The **horizontal position** of B changes by equal distances per unit time.

  - The horizontal component of B's velocity is constant.
- The **vertical position** of A and B changes at the same rate - at any instant A is at the same level as B.
  - A and B has the same vertical component of velocity at any instant.

For an object projected horizontally with initial velocity U.

$$v_x = Ut$$
$$v_y = \frac{1}{2}gt^2$$

7.8 Projectile Motion 2

Any form of motion where an object experiences a **constant acceleration** in a different direction to its velocity will be like projectile motion.

- The path of a ball rolling across an **inclined board**.
- The path of a beam of electrons directed between two oppositely charged parallel plates.

Their paths are **parabolic** because it is subjected to constant acceleration acting in a different direction to its velocity.

Drag Force

A projectile moving through air experiences a force that **drags on it** because of the **resistance of the air** it passes through.

- Caused by **friction between layers** of air near the projectile's surface where air flows over the surface.
- Acts in the **opposite direction to the direction of motion**
- Has a **horizontal component** that reduces both the horizontal speed of the projectile and its range.
- Has a **vertical component** that reduces the maximum height of the projectile if its initial direction is above the horizontal and makes its descent steeper than its ascent.

The **shape of the project** its affects the drag force, and may also cause a **lift force**.

- The shape of the projectile causes the air to flow faster over the top of the object than underneath it.
- As a result, the pressure of the air on the top surface is less than that on the bottom surface.
- The pressure difference causes a lift force on the object.

E.g. the cross-sectional shape of an aircraft wing creates a lift force.

A **spinning ball** experiences a force due to the same effect, the force can be in any direction depending on **how the ball is made to spin**.