# HL IB Physics

## Scalars & Vectors

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# Scalar & Vector Quantities

## Scalar & Vector Quantities

- A **scalar** is a quantity which **only** has a magnitude (size)
- A **vector** is a quantity which has **both** a **magnitude** and a **direction**
- For example, if a person goes on a hike in the woods to a location which is a couple of miles from their starting point
  - As the crow flies, their **displacement** will only be a few miles but the **distance** they walked will be much longer
- **Distance** is a **scalar** quantity
  - This is because it describes how an object has travelled overall, but not the direction it has travelled in
- **Displacement** is a **vector** quantity
  - This is because it describes how far an object is from where it started and in what direction
- Some common scalar and vector quantities are shown in the table below:

**Scalars and Vectors Table**

| Quantity | Type | Has Magnitude? | Has Direction? | Example Units | Examples |
|---|---|---|---|---|---|
| Distance | Scalar | ✅ Yes | ❌ No | meters (m) | 5 m |
| Displacement | Vector | ✅ Yes | ✅ Yes | meters (m) | 5 m east |
| Speed | Scalar | ✅ Yes | ❌ No | meters per second (m/s) | 20 m/s |
| Velocity | Vector | ✅ Yes | ✅ Yes | meters per second (m/s) | 20 m/s north |
| Mass | Scalar | ✅ Yes | ❌ No | kilograms (kg) | 10 kg |
| Force | Vector | ✅ Yes | ✅ Yes | newtons (N) | 50 N downwards |
| Time | Scalar | ✅ Yes | ❌ No | seconds (s) | 10 s |
| Acceleration | Vector | ✅ Yes | ✅ Yes | meters per second² (m/s²) | 3 m/s² to the left |
| Energy | Scalar | ✅ Yes | ❌ No | joules (J) | 100 J |
| Momentum | Vector | ✅ Yes | ✅ Yes | kg·m/s | 15 kg·m/s forward |
| Temperature | Scalar | ✅ Yes | ❌ No | degrees Celsius (°C), kelvin (K) | 25°C |

## Representing Vectors

- **Vectors** are represented by an arrow
  - The **arrowhead** indicates the **direction** of the vector
  - The **length** of the arrow represents the **magnitude**

- **Component** vectors are sometimes drawn with a dotted line and a **subscript** indicating horizontal or vertical
  - For example, $F_x$ is the horizontal component and $F_y$ is the vertical component of the force $F$

# Combining & Resolving Vectors

## Combining & Resolving Vectors

- Vectors can be changed in a variety of ways, such as
  - Combining through vector **addition** or **subtraction**
  - Combining through vector **multiplication**
  - Resolving into **components** through trigonometry

### Combining Vectors

- Vectors can be combined by **adding** or **subtracting** them to produce the **resultant vector**
  - The **resultant vector** is sometimes known as the 'net' vector (e.g. the net force)
- There are two methods that can be used to combine vectors: the **triangle method** and the **parallelogram method**

#### Triangle method

- To combine vectors using the triangle method:
  - **Step 1:** link the vectors head-to-tail
  - **Step 2:** the resultant vector is formed by connecting the tail of the first vector to the head of the second vector

#### Parallelogram method

- To combine vectors using the parallelogram method:
  - **Step 1:** link the vectors tail-to-tail
  - **Step 2:** complete the resulting parallelogram
  - **Step 3:** the resultant vector is the diagonal of the parallelogram

## Vector Multiplication

- The product of a scalar and a vector is **always** a vector
- For example, consider the scalar quantity **mass** $m$ and the vector quantity **acceleration** $\vec{a}$
- The product of mass $m$ and acceleration $\vec{a}$ gives rise to a vector quantity **force** $\vec{F}$

$$\vec{F} = m \times \vec{a}$$

- For another example, consider the scalar quantity **mass** $m$ and the vector quantity **velocity** $\vec{v}$
- The product of mass $m$ and velocity $\vec{v}$ gives rise to a vector quantity **momentum** $\vec{p}$

$$\vec{p} = m \times \vec{v}$$

## Resolving Vectors

- Two vectors can be represented by a single **resultant vector**
  - Resolving a vector is the opposite of adding vectors
- A single resultant vector can be resolved
  - This means it can be represented by **two** vectors, which in combination have the same effect as the original one

## Force as a Vector

- In physics, vectors appear in many different topic areas
  - Specifically, vectors are often **combined** and **resolved** to solve problems when considering motion, forces, and momentum
- Forces vector diagrams are often represented by free-body force diagrams
- The rules for drawing a free-body diagram are the following:
  - **Rule 1:** Draw a point in the centre of mass of the body
  - **Rule 2:** Draw the body free from contact with any other object
  - **Rule 3:** Draw the forces acting on that body using vectors with length in proportion to its magnitude
  - **Rule 4:** Draw the tail of the vector from the centre of mass and use the tip to indicate the direction

## Forces on an Inclined Plane

- A common scenario is an object on an inclined plane
- An inclined plane, or a slope, is a flat surface tilted at an angle, θ
- Inclined slope problems can be simplified by considering the components of the forces as **parallel** or **perpendicular** to the slope
- The **weight** ($W = mg$) of the object is always directed **vertically downwards**
- On the inclined slope, weight can be split into the following components:

**Perpendicular** to the slope: $\swarrow W = mg\cos\theta$

**Parallel** to the slope: $\searrow W = mg\sin\theta$

- The **normal** (or reaction) force $R$ is always **vertically upwards**, or perpendicular to the surface
- If there is **no friction**, the parallel component of weight, $mg\sin\theta$, causes the object to move down the slope
- If the object is **not moving** perpendicular to the slope, the normal force is $R = mg\cos\theta$

## Equilibrium

- Coplanar forces can be represented by vector triangles
- Forces are in equilibrium if an object is either
  - At rest
  - Moving at **constant** velocity
- In equilibrium, coplanar forces are represented by **closed** vector triangles
  - The vectors, when joined together, form a closed path
- The most common forces on objects are
  - Weight
  - Normal reaction force
  - Tension (from cords and strings)
  - Friction
- The forces on a body in equilibrium are demonstrated below:

## Scale Diagrams

### Scale Diagrams

- There are two methods that can be used to combine or resolve vectors
  - **Calculation** – if the vectors are perpendicular
  - **Scale drawing** – if the vectors are not perpendicular
- Calculating vectors using a scale drawing involves drawings the lengths and angles of the vectors accurately using a sharp **pencil**, **ruler** and **protractor**

- When two vectors are **not** at right angles, the resultant vector can be calculated using a scale drawing
  - **Step 1:** Link the vectors head-to-tail if they aren't already
  - **Step 2:** Draw the resultant vector using the triangle or parallelogram method
  - **Step 3:** Measure the length of the resultant vector using a ruler
  - **Step 4:** Measure the angle of the resultant vector (from North if it is a bearing) using a protractor