Physical Quantities, Units and Measurements

What Are Physical Quantities?

All objects can be described by their **physical quantities**. A **physical quantity** is a *quantity* that can be measured. It typically consists of a numeral magnitude and a unit. E.g. 0.16 m.

There are 7 basic **physical quantities**, or **base quantities**. We use a system of standardised units called **SI units**.
Base quantities and their SI units

Base Quantity	SI Unit and Symbol
Length	Metre, *m*
Mass	Kilogram, *kg*
Time	Second, *s*
Electric current	Ampere, *A*
(Thermodynamic) temperature	Kelvin, *K*
Amount of substance	Mole, *mol*

For physical quantities with very big or very small magnitudes, we can write them in the **standard form** with the format: $A \times 10^n$, where $1 \leq A < 10$, where *n* is an integer. **NOTE:** The number of s.f. in the standard form varies in questions!

Example of standard forms

Example of Physical Quantity	Magnitude and Unit	Standard Form

Length of the F1 Singapore Grand Prix Circuit (hehe sanjay)	30 900 m	3.09×10^5 m
Speed of light in vacuum	300 000 000 m/s	3.0×10^8 m/s
Diameter of a hydrogen atom	0.000 000 000 05 m	5.0×10^{-11} m

We can also use common **prefixes** to represent <u>submultiples (smaller than 10) and multiples (bigger than 10) of 10</u> of the SI units.

Some common prefixes and their symbols

	Factor	Prefix	Symbol
Multiples	10^{12}	tera-	T
	10^9	giga-	G
	10^6	mega-	M
	10^3	kilo-	k
Submultiples	10^{-1}	deci-	d
	10^{-2}	centi-	c
	10^{-3}	milli-	m
	10^{-6}	micro-	μ
	10^{-9}	nano-	n

How Do We Measure Physical Quantities?

The objects in our physical world are in a range of sizes as indicated by their **orders of magnitude**.

- *Size of a typical atom = 1×10^{-10} m. Its order of magnitude is -10.
- *Size of Earth = 6.378×10^{6} m. Its order of magnitude is 6.

We can measure the physical quantity of length using various **measuring instruments**.

- The **measuring tape** is commonly used to measure objects up to one metre.
- The **metre rule** is commonly used to measure objects that are up to several centimetres to one metre.
- The **digital calipers** (i.e. Vernier calipers) are a useful instrument to measure objects' internal and external diameters and depths that are up to 15 cm.
- The **digital micrometer screw gauge** is used to measure objects that are up to 2.5 cm.

We choose the most suitable measuring instrument based on its precision and range.

- **Precision** is the smallest value that an instrument can measure.
- **Range** is the bracket of values that an instrument can measure.

Some common measuring instruments

Instrument	Precision	Range	Example of Usage
Measuring tape	0.1 cm or 1 mm	Up to several metres	Length of a room

Metre rule	0.1 cm or 1 mm	Up to one metre	Length of a book
Digital calipers	0.001 cm or 0.01 mm (record data to 0.01 cm)	Between 1 cm to 10 cm	Diameter of a test tube
Digital micrometer screw gauge	0.0001 cm or 0.001 mm (record data to 0.001 cm)	Less than 1 cm	Diameter of a wire

Errors can occur during experiments.

- **Parallax errors** are caused by the inaccurate positioning of the observer's eyes while taking readings. To avoid parallax errors, the eye should be positioned directly above the markings.
- **Zero error** is the non-zero reading when we expect a zero reading. For example, an end of a metre rule starts at 0.1 cm instead of 0 cm due to wear and tear. An accurate reading can be obtained by subtracting the zero error from the measured reading.

We can measure the physical quantity of time using a **stopwatch**. The SI unit for time is **second (s)**. The year, month, day, hour, minute are other units for measuring time.

The **simple pendulum** consists of a heavy object **(bob)** attached to a string. The bob swings back and forth, called an **oscillation**. The time taken for the pendulum to complete a full oscillation (from point A to B and back to A) is called its **period**.

We can use the stopwatch to measure the period *T* of the simple pendulum.

a) Let the bob swing back and forth at a small angle. Start the stopwatch when the pendulum is at the highest point and it is momentarily stationary to reduce random error.
b) Count the number of full oscillations. Stop the stopwatch when 20 full oscillations are complete.
c) Divide the time taken by the number of oscillations to obtain the average time taken for each oscillation, or the period.

Period T = $\frac{t_{20}}{20}$

NOTE: The period is not affected by the mass of the bob or the angle of the swing. It depends on the length of the string with *g* as a constant.

Most stopwatches can measure time to a precision of 0.01s. Digital stopwatches usually show readings up to two decimal places. However, we usually take readings to the nearest one decimal place. This is because, unlike the electronic sensors used in data loggers, stopwatches need to be started and stopped by hand. This manual operation introduces a random error called **human reaction time**. Human reaction time is about 0.3 - 0.5s.

A common error occurs when the bob of the pendulum moves in a circular path rather than back and forth. This is called a **conical pendulum** which has a different period from a simple pendulum. A conical pendulum traces the shape of a cone with an angle θ (about the string) and a radius *r*.

What Are Scalars and Vectors?

Scalar quantities are physical quantities that have only magnitude.

Vector quantities are physical quantities that have both magnitude and direction.

Common scalar and vector quantities

Scalar	Vector
distance	displacement
speed	velocity/ acceleration
mass	weight
energy	force
time	weight
power	moment (momentum)
work done	-
pressure	-

Differences between Distance and Displacement:

1. **Distance**
- The total length covered by a moving object regardless of the direction of motion
- A scalar quantity
- SI unit: metre (m)
2. **Displacement**
- The distance measured in a straight line in a specified direction
- A vector quantity
- SI unit: metre

Speed is the distance moved per unit time. **Velocity** is the rate of change of displacement. Both quantities have the same SI unit of **metre per second (m/s)**. You can think of velocity as speed with a direction.

Formulae for speed and velocity:

Speed = $\frac{distance}{time\ taken}$

Velocity = $\frac{displacement}{time\ taken}$

When we talk about the velocity of an object, we have to state the speed of the object and the direction in which it is travelling.

Area under displacement-time graph = Distance travelled
Area under velocity-time graph = Displacement
Area under acceleration-time graph = Rate of change of velocity

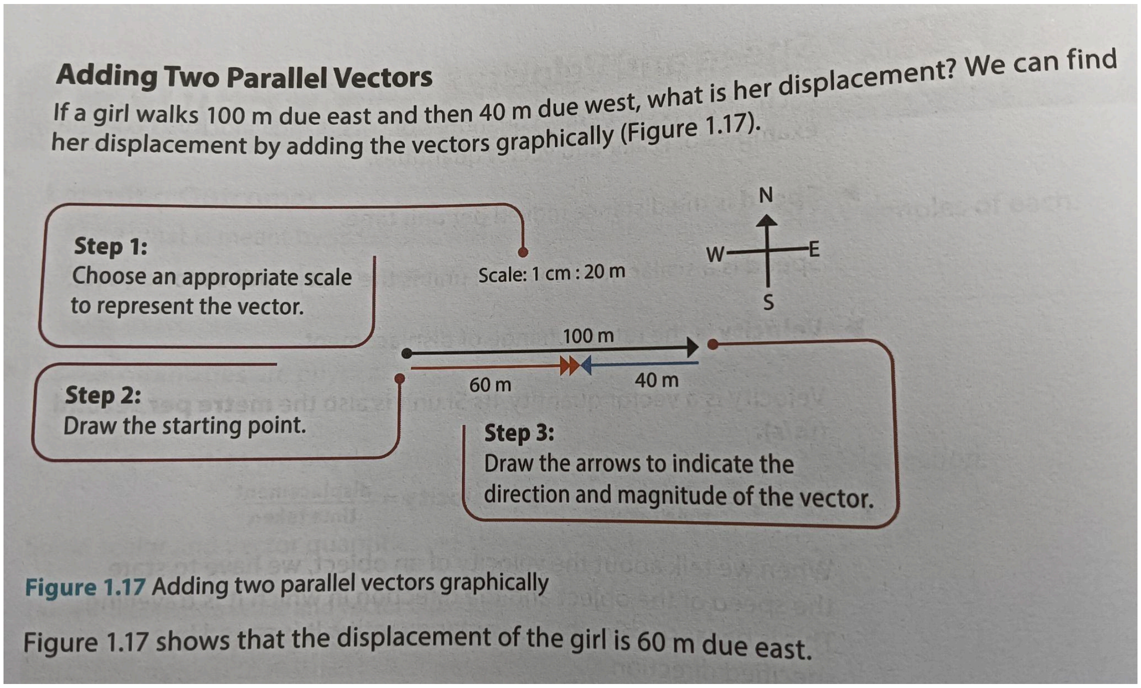
We can use a **vector diagram** to add up two vectors. In a vector diagram, a vector quantity is represented by an arrow.

- The length of the arrow is proportional to the magnitude of the vector.
- The direction of the arrow indicates the direction of the vector.

When we add two or more vectors, we cannot add their magnitudes only. We need to find a single vector that produces the same effect as the vectors combined. This single vector is called the **resultant vector**.

Adding parallel two vectors:

Two parallel vectors acting against each other. (Eg, a force eastward and a force westward.)


Adding Two Parallel Vectors

If a girl walks 100 m due east and then 40 m due west, what is her displacement? We can find her displacement by adding the vectors graphically (Figure 1.17).

Figure 1.17 Adding two parallel vectors graphically

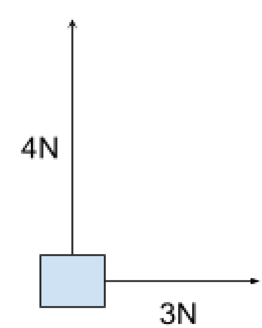
Figure 1.17 shows that the displacement of the girl is 60 m due east.

The orange arrow is the resultant vector, which has the same effect as the black arrow and blue arrow combined.

Adding non - parallel vectors:

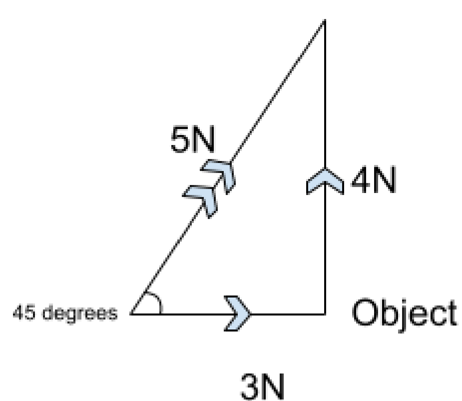
There are **two methods** of adding non - parallel vectors. Head to tail method and parallelogram method.

Visualise the two forces acting on a block. We need to connect the two heads of the forces to complete the "head and tail".



Scale: 1 cm = 1 Newton

Magnitude of the resultant vector (line with 2 arrows) = 5N



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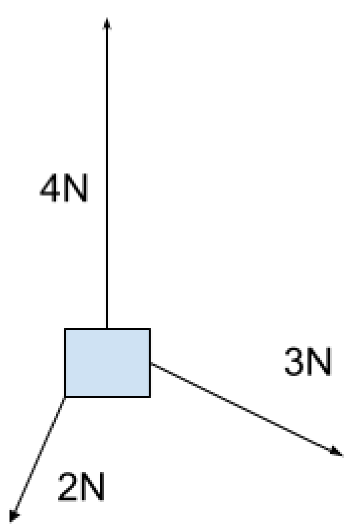
Direction: 45 degrees to the left
From force of 3N

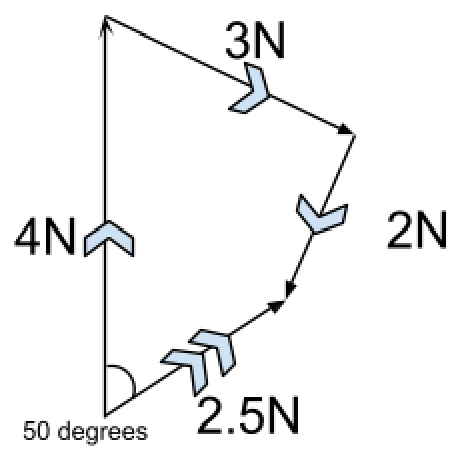
Sometimes, there can be two or more forces acting on a block. This means that we must use the <u>head to tail method</u>, and <u>move a vector</u> to the respective position.

Scale: 1 cm = 5 Newton

Magnitude = 2.5N

Direction: 50 degrees left from force
of 4N





Measurement Guide

Length measurements:

Metre ruler:

- Precision is 0.1 cm (1 mm)
- Used to measure straight lengths up to one metre
- Every measurement should be rounded to 1 mm
- Example: 14.78 cm = 14.8 cm (To 1 mm)

Measuring tape:

- Precision is 0.1 cm (1 mm)
- Used to measure lengths of up to several metres and measured straight distances or curved surfaces
- Every measurement should be rounded to 1 mm
- Example: 102.42 cm = 102.4 cm (To 1 mm)

Digital calliper:

- Precision is 0.01 cm (0.1 mm)
- Used to measure lengths from 2 - 15 centimetres
- Every measurement should be rounded to 0.1 mm
- Example: 601.256 mm = 601.27 mm (To 0.1 mm)

Digital micrometre screw gauge:

- Precision is 0.001 cm (0.01 mm)
- Used to measure lengths below 2 centimetres
- Every measurement should be rounded to 0.01 mm
- Example: 10.8734 mm = 10.873 (To 0.01 mm)

Time measurements:

Stopwatch:

- Precision is 0.01s (2 d.p.)

- Used to measure time (Example: Period of a pendulum)
- Readings are usually recorded to 0.1s.
- This is to avoid human reaction time error of 0.3s - 0.5s.
- Example of a reading: 10.82s = 10.8s (To 1 d.p.)

Theory papers: Always <u>round to 2 d.p or 3 d.p</u> (For example: Stopwatch to 0.01s in theory).

Practical papers: Follow the <u>rules of rounding</u> of each instrument (For example: Stopwatch to 0.1s in practical).

For addition/subtraction of quantities, the <u>s.f. of the final result</u> follows the <u>least no. of s.f.</u> of the quantities.

For multiplication/division, the <u>s.f. of the final result</u> follows the <u>least no. of s.f</u> of the quantities.

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