Chapter 1 Physical Quantities and Measurements

Curriculum Specification	**Remarks**		
	Before	**After**	**Revision**
1.1 Dimensions of physical quantities			
a) Define dimension (C1, C2)			
b) Determine the dimensions of derived quantities (C3, C4)			
c) Verify the homogeneity of equations using dimensional analysis (C3, C4)			
1.2 Scalars and vectors			
a) Define scalar and vector quantities (C1, C2)			
b) Resolve vector into two perpendicular components (*x* and *y* axes) (C3, C4)			
c) Illustrate unit vectors $(\hat{\imath}, \hat{\jmath}, \hat{k})$ in Cartesian coordinate (C3, C4)			
d) State the physical meaning of dot (scalar) product: $\vec{A} \bullet \vec{B} = AB\cos\theta$ (C1, C2)			
e) State the physical meaning of cross (vector) product: $\vec{A} \times \vec{B} = AB\sin\theta\,\hat{n}$ *Note*: Direction of cross product is determined by corkscrew method of right hand rule (C1, C2)			
1.3 Significant figures and uncertainties analysis			
a) State the significant figures of a given number (C1, C2)			
b) Use the rules for stating the significant figures at the end of a calculation (addition, subtraction, multiplication or division) (C3, C4)			
c) Determine the uncertainty for average value and derived quantities (C3, C4)			
d) Calculate basic combination (propagation) of uncertainties (C3, C4)			
e) State the sources of uncertainty in the results of an experiment (C1, C2)			
f) Draw a linear graph and determine its gradient, y-intercept and its respective uncertainties (C3, C4)			
g) Measure and determine the uncertainty of physical quantities (Experiment 1: Measurement and uncertainty) (C1, C2, C3, C4)			
h) Write a laboratory report (Experiment 1: Measurement and uncertainty) (C1, C2, C3, C4)			

Revision: Quantities and Unit Conversion

Physics Quantities

Physics experiments involve the measurement of a variety of quantities, and we generally use numbers to describe the results of measurements. Any number that is used to describe a physical phenomenon quantitatively is called a **physical quantity**. It consists of a precise numerical value and a unit. Physical quantity can be categorized into 2 types: **base quantity and derived quantity**

{Quantity} = {Numerical value × Unit}

Base quantities are the fundamental quantities which are distinct in nature and cannot be defined by other quantities. The corresponding units for these quantities are called **base quantities**. Scientist has recognised **seven** quantities as base quantities:

No.	Basic Quantity	Symbol	SI unit (with symbol)
1	Length	l	metre (m)
2	Mass	m	kilogram (kg)
3	Time	t	second (s)
4	Temperature	T / θ	kelvin (K)
5	Electric current	I	ampere (A)
6	Amount of substance	N	mole (mol)
7	Luminous Intensity		candela (cd)

All other quantities can be defined in terms of the above seven base quantities, and are referred to as **derived quantities**, since they are combinations of the base units. Derived units will be introduced from time to time, as they arise naturally along with the related physical laws.

Unit

When dealing with the law and equations of physics it is very important to use a consistent set of units. In this text, we emphasize the system of units known as **SI units**, which stands for the French phrase "Le **S**ystème **I**nternational d'Unités."

Since any quantity, such as length, can be measured in several different units, it is important to know how to convert from one unit to another. **Unit** is defined as a standard size of measurement of physical quantities. **Unit prefixes** is used for presenting larger and smaller values.

Prefix	Symbol	Multiple	Prefix	Symbol	Multiple
tera	T	$\times10^{12}$	**centi**	c	$\times10^{-2}$
giga	G	$\times10^{9}$	**milli**	m	$\times10^{-3}$
mega	M	$\times10^{6}$	**micro**	μ	$\times10^{-6}$
kilo	k	$\times10^{3}$	**nano**	n	$\times10^{-9}$
desi	d	$\times10^{-1}$	**pico**	p	$\times10^{-12}$

Physics problems frequently ask you to convert between different units of measurement. It is always more convenient to **convert all unit of measurements into SI unit** when solving physics problems

For example, you may measure the number of centimetres your toy car goes in three minutes and thus be able to calculate the speed of the car in centimetres per minute, but that's not a standard unit of measure, you cannot use it to calculate the work done or the power of the car, so you need to convert centimetres per minute to meters per second.

Example 1
If you wish to remove a unit prefix from the quantity, substitute the unit prefix with its value.

$$25\,\text{Mm} = 25\times10^{6}\ \text{m}$$

unit prefix (Mm) → value (10^6)

Example 2
If you wish to add a unit prefix into the quantity, divide the value of the unit prefix.

bring the numerator out to pair with **m** so that the unit becomes **km**

$$7\ \text{m} = 7\times\left(\frac{\text{k}}{\text{k}}\right)\text{m} = \left(\frac{7}{\text{k}}\right)\text{km} = \left(\frac{7}{10^{3}}\right)\text{km} = 7\times10^{-3}\ \text{km}$$

substitute the denominator with value then **divide the 7 by the denominator (unit prefix)**

Example 3a
If the quantity has squared or cubed unit, then you have to add a cube on the unit prefix.

$$2\ \text{cm}^3 = 2\ \text{c}^3\text{m}^3 = 2\times\left(10^{-2}\right)^3\ \text{m}^3 = 2\times10^{-6}\ \text{m}^3$$

The true form of $2\ \text{cm}^3$ is $2\,(\text{cm})^3$, therefore it can be written as $2\ \text{c}^3\text{m}^3$ in unit conversion

Example 3b

$$2\ \text{m}^3 = 2\times\left(\frac{\text{c}^3}{\text{c}^3}\right)\text{m}^3 = \frac{2}{\text{c}^3}\text{c}^3\text{m}^3 = \frac{2}{\left(10^{-2}\right)^3}\text{c}^3\text{m}^3 = 2\times10^{6}\ \text{cm}^3$$

Law of Indices

- $x^0 = 1$
- $x^{-n} = \dfrac{1}{x^n}$
- $x^n \times x^m = x^{n+m}$
- $x^n \div x^m = x^{n-m}$
- $\left(x^n\right)^m = x^{n\times m}$
- $x^{\frac{n}{m}} = \sqrt[m]{x^n}$

Example 4
If the quantity has a derived unit, then convert the units separately.

$$3\ \text{km h}^{-1} = \frac{3\ \text{km}}{1\ \text{hour}} = \frac{3\times10^{3}\ \text{m}}{3600\text{s}} = 0.83\ \text{m s}^{-1}$$

Change it into fraction form to make it easier to convert

Note:

m and **s** with a space between them means **meter second**, **m** and **s** represent **two separate units** in this case

$$\text{ms} \neq \text{m s}$$

m and **s** without space in between means **millisecond**, **m** is acting as unit prefix in this case

1.1 Dimensions of Physical Quantities

- In physics, the term dimension is used to refer to the physical nature of a quantity and the type of unit used to specify it.
- The seven fundamental quantities are enclosed in square brackets [ ] to represent its dimensions: length [L], time [T], mass [M], electric current [A], amount of substance [mol], temperature [K] and luminous intensity [Cd].
- Dimensional analysis is used to check mathematical relations for the consistency of their dimensions.
- A dimensional check **can only tell you when a relationship is wrong**. It can't tell you if it is completely correct because the numerical factors do not affect dimensional check.
- Standard mathematical functions such as trigonometric functions (such as sine and cosine), logarithms, or exponential functions that appear in the equation must be dimensionless. These functions require pure numbers as inputs and give pure numbers as outputs.

Example 5

Given $v = u + \frac{1}{2}at^2$. Check if it's dimensionally homogeneous.

$$\left[\frac{L}{T}\right] \overset{?}{=} \left[\frac{L}{T}\right] + \left[\frac{L}{\cancel{T^2}}\right]\left[\cancel{T^2}\right] = \left[\frac{L}{T}\right] + [L]$$

Note: Dimensions cancel just like algebraic quantities and numerical factors, like ½ the here, do not affect dimensional checks.

The dimension on the left of the equals sign does not match those on the right, so the equation is incorrect.

Example 6

Given $s = ut - \frac{1}{2}at^2$. Check if it's dimensionally homogeneous.

$$[L] \overset{?}{=} \left[\frac{L}{\cancel{T}}\right]\left[\cancel{T}\right] - \left[\frac{L}{\cancel{T^2}}\right]\left[\cancel{T^2}\right] = [L] - [L] = [L]$$

Note: Addition and subtraction won't change the dimension and it can only be done if both quantities have same dimensions.

The dimension on the left of the equals sign matches that on the right, so this relation is dimensionally correct.

This is an example why dimensional analysis can't tell whether an equation is correct. Although the equation is dimensionally correct, this equation is in fact incorrect due to incorrect math operation. The correct equation should be $s = ut + \frac{1}{2}at^2$.

1.2 Scalars and Vectors

A **scalar quantity** is one that can be described with a single number (including any units) giving its size or **magnitude**. *Example*: mass, temperature, pressure, electric current, work, energy and etc.

A quantity that deals inherently with both **magnitude and direction** is called a **vector quantity**. Because direction is an important characteristic of vectors, arrows are used to represent them; the direction of the arrow gives the direction of the vector. By convention, the length of a vector arrow is proportional to the magnitude of the vector. *Example*: displacement, velocity, force and etc.

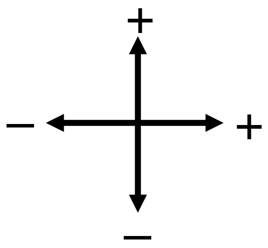
Magnitude of vector $\vec{A}$ can be written as $|A|$

Direction of vector can be represented by using:

- Direction of compass

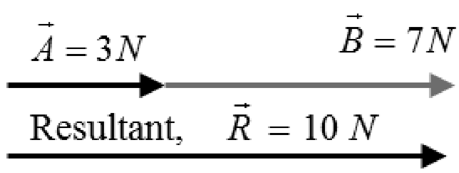
  Example: East, west, north, south, north-east, north-west, south-east and south-west
- Angle with a reference line.

  Example: A boy throws a stone at a velocity of 20 m s^{-1}, 50° above horizontal.
- Cartesian coordinates
- Polar coordinates
- Denotes with + or – signs



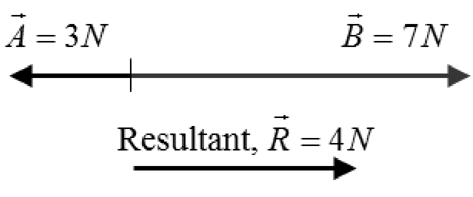
Adding **parallel** vectors:

- Vectors in the **same** directions



$\vec{A} + \vec{B} = (+3) + (+7) = +10$ N
To the right

- Vectors in the **opposite** directions

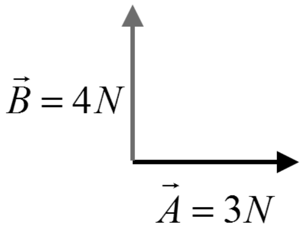


$\vec{A} + \vec{B} = (-3) + (+7) = +4$ N
To the right

The direction of resultant vector ***R*** is in the direction of the **bigger** vector

Adding **perpendicular** vectors:

The magnitude of the resultant vector can be determined by using Pythagorean Theorem



Magnitude:

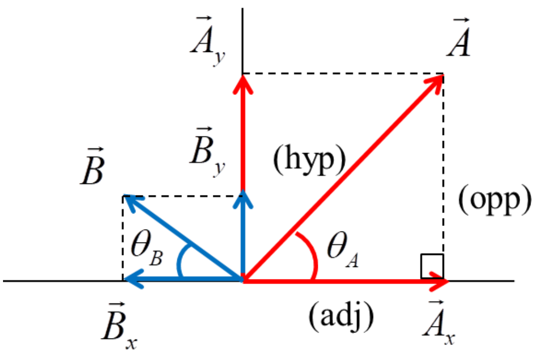
$$\vec{R} = \sqrt{(+3)^2 + (+4)^2} = +5\text{ N}$$

Direction:

$$\theta = \tan^{-1}\left(\frac{4}{3}\right) = 53.1^\circ \text{ above} + \text{ve } x\text{-axis}$$

Adding vectors **at other angles**:

When $\vec{A}$ and $\vec{B}$ are neither perpendicular nor parallel to each other, then you had to resolve the vectors into 2 perpendicular vector components with the aid of trigonometry.



Step 1: Resolve $\vec{A}$ and $\vec{B}$ into $\vec{A}_x$, $\vec{A}_y$, $\vec{B}_x$ and $\vec{B}_y$

$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{A_x}{\vec{A}} \quad \rightarrow A_x = A\cos\theta$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{A_y}{\vec{A}} \quad \rightarrow A_y = A\sin\theta$$

**Repeat the same step for* $\vec{B}$

Step 2: Calculate the sum for each axis

$$R_x = A_x + (-B_x) \qquad R_y = A_y + B_y$$

–ve because pointing to the left

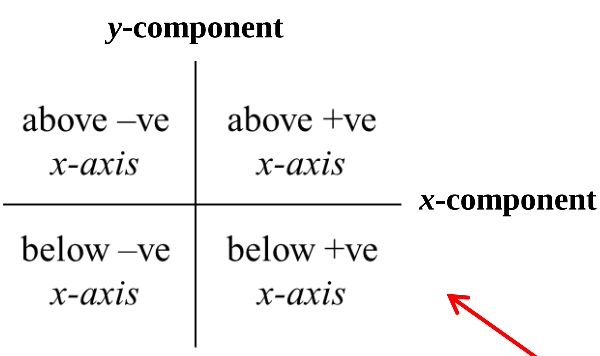
Step 3: Determine the **magnitude (resultant)**

$$\text{Resultant, } R = \sqrt{(R_x)^2 + (R_y)^2}$$

Step 4: Determine the **direction**

$$\theta = \tan^{-1}\left|\frac{R_y}{R_x}\right|$$

Remember to describe the position



Alternative for **Step 2**: Make a table

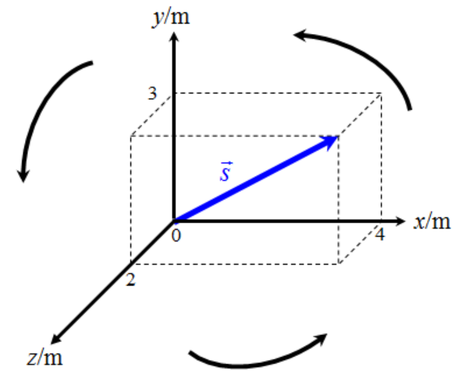
Vector	x-component	y-component
A	$A_x = A\cos\theta_A$	$A_y = A\sin\theta_A$
B	$-B_x = -B\cos\theta_B$	$-B_y = B\sin\theta_B$
Resultant, *R*	$R_x = A_x - B_x$	$R_y = A_y + B_y$

Unit vector

A **unit vector** is a vector that **has a magnitude of 1 with no units**. The purpose of unit vector is only to **describe the direction of vectors**.

In the Cartesian coordinate system, the unit vectors along the x, y and z axes are represented by $\hat{i}, \hat{j}$ and $\hat{k}$ respectively.

For example:



$\vec{s} = x\hat{i} + y\hat{j} + z\hat{k}$
$= (4\hat{i} + 3\hat{j} + 2\hat{k})$ m — Vector ***s*** in terms of unit vector

$|s| = \sqrt{x^2 + y^2 + z^2}$
$= \sqrt{29}$ m — Magnitude

$\hat{s} = \dfrac{\vec{s}}{|s|} = \dfrac{x\hat{i} + y\hat{j} + z\hat{k}}{\sqrt{x^2 + y^2 + z^2}}$ — Unit vector in the direction of vector ***s***

Additional Knowledge: Vector Multiplication

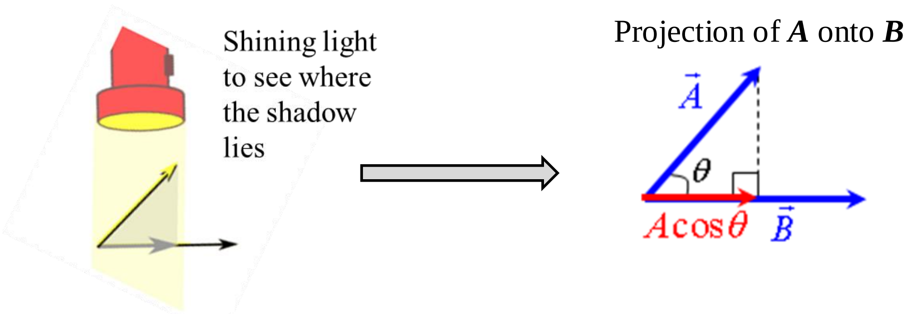
Since vector has direction as well as magnitude, they cannot be multiplied in the same way the scalars are. There are three ways to define how to multiply vectors that we find useful in physics:

- multiplication of a vector by a scalar
- multiplication of one vector by a second vector to produce a scalar – **scalar product**
- multiplication of one vector by a second vector to produce another vector – **vector product**

Dot (scalar) product

Scalar (or dot) product is defined as the product of the magnitude of one vector (say B) and the component (or projection) of the other vector along the direction of the first ($A \cos \theta$).

For example:



$$\vec{A} \bullet \vec{B} = B(A\cos\theta)$$

$\vec{A} \bullet \vec{B}$ = zero (**minimum**) when $\boldsymbol{\theta}$ **= 90°** because cos 90˚ = 0

$\vec{A} \bullet \vec{B}$ = **maximum** value when $\boldsymbol{\theta}$ **= 0°** because cos 0˚ = 1

The angle range from 0° to 180°:

- $0° < \theta < 90°$ scalar product is **positive**
- $\theta = 90°$ scalar product is **zero**
- $90° < \theta < 180°$ scalar product is **negative**

Commutative law applied to dot product:

$$\vec{B} \bullet \vec{A} = B(A\cos\theta) \xleftrightarrow{\text{equal}} \vec{A} \bullet \vec{B} = A(B\cos\theta)$$

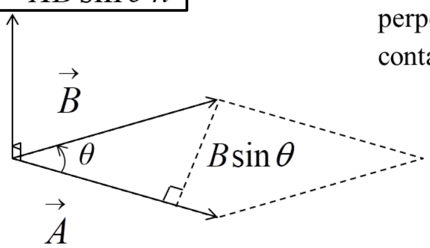
Example of physical quantity: $W = F \bullet s = Fs\cos\theta$

<u>**Cross (vector) product**</u>

The vector (or cross) product of two vectors $\vec{A}$ and $\vec{B}$ is defined as a vector that is perpendicular to both $\vec{A}$ and $\vec{B}$ with a direction given by the right-hand rule, and whose magnitude is equal to the area of the parallelogram that the vectors span.

$$\vec{A} \times \vec{B} = AB\sin\theta\,\hat{n}$$

$\hat{n}$ is the unit vector perpendicular to the plane containing $\vec{A}$ and $\vec{B}$



$\vec{A} \times \vec{B}$ = zero (**minimum**) when $\boldsymbol{\theta = 0°}$ because $\sin 0° = 0$

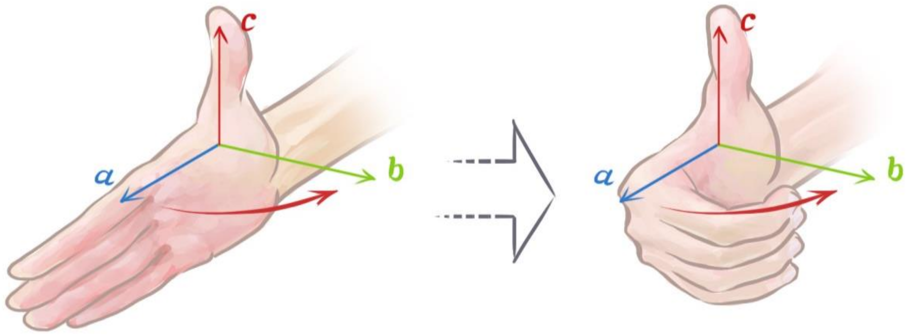
$\vec{A} \times \vec{B}$ = **maximum** value when $\boldsymbol{\theta = 90°}$ because $\sin 90° = 1$

The angle range from 0° to 180°, therefore the vector product is **always positive**.

Vector product is **not commutative**.

$$\vec{A} \times \vec{B} \neq \vec{B} \times \vec{A} \qquad \text{but} \qquad \vec{A} \times \vec{B} = -(\vec{B} \times \vec{A})$$

Direction of vector product is determined by the right-hand rule.



1.3 Significant Figures and Uncertainties Analysis

Significant Figures

The number of significant figures in a number is the number of digits whose values are known with certainty.

For example:

- If we say it is roughly 80 km between two cities, then there is only **one** significant figure (the 8) since the zero is merely a place holder.
- If we say it is 80 km within an accuracy of 1 to 2 km, then 80 has **two** significant figures.
- If it is precisely 80 km, to within ±0.1 km, then we write 80.0 km (**three** significant figures).

Rules for identifying significant figures:

1. Nonzero digits are always significant.

   55 → 2 s.f.

2. Final or ending zeros written to the right of the decimal point are significant.

   5.0 → 2 s.f.

3. Zeros written on either side of the decimal for the purpose of spacing the decimal point are not significant.

   0.0**50** → 2 s.f.

4. Zeroes written between significant figures are significant.

   505 → 3 s.f.

When two or more numbers are used in a calculation, the number of significant figures in the answer is limited by the number of significant figures in the original data.

For example:

- **Multiplication or division**: No more than in the number with fewest significant figures.

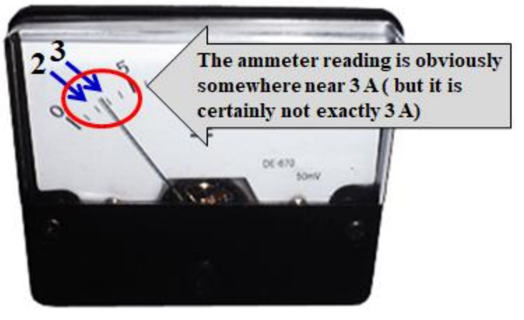
  (0.745×**2.2**) /3.885 = 0.**42** (2 s.f.)

- **Addition or subtraction**: Determined by the number with the largest uncertainty (location of the decimal point that matter).

  27.153 + 138.**2** – 11.74 = 153.**6** (1 d.p.)

Uncertainties

No measurement is absolutely precise. There is an uncertainty associated with every measurement. Among the most important sources of uncertainty, other than blunders, are **the limited accuracy of every measuring instrument** and **the inability to read an instrument beyond some fraction of the smallest division shown**.



The uncertainty of a measurement depends on **its type** and **how it is done**. The usual way to express the error in a measurement is to **write down the result** of the measurement, **followed by a plus minus symbol and uncertainty** in the measurement: $(x \pm \Delta x)$

Example:
If a measurement of length is found to be 3.24 cm with an uncertainty of 0.02 cm. It should be written as:

Measured value **Unit**

Length = (3.24 ± 0.02) cm

Uncertainty

*****Decimal points must be consistent***

Percentage of uncertainty is given by: $\dfrac{\Delta x}{x} \times 100\%$

A measurement with a **smaller % uncertainty** is **more accurate** than a measurement with a higher % uncertainty.

<u>Method to determine the uncertainty for **single reading**</u>

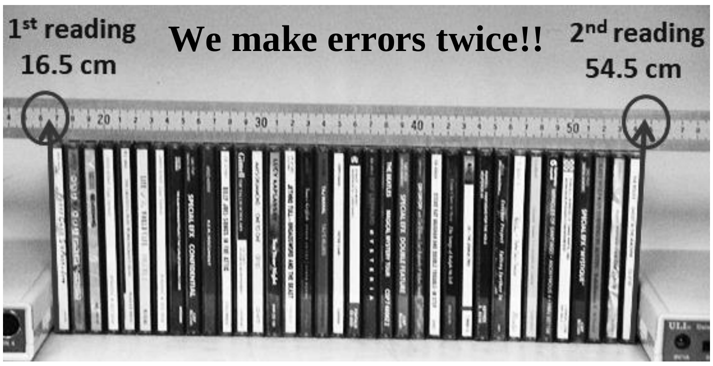
i) If the reading is taken from a **single point** or at the end of the scale:

$$\Delta x = \frac{1}{2} \times (\text{the smallest division of the scale})$$

ii) If the readings are taken from **two points** on the scale:

$$\Delta x = 2 \times \frac{1}{2} \times (\text{the smallest division of the scale})$$

$$\Delta x = \text{the smallest division of the scale}$$



iii) If the apparatus has a **vernier scale**:

$$\Delta x = \text{the smallest division of the vernier scale}$$

Method to determine the uncertainty for **repeated reading**

For a set of n repeated measurements, the best value is the **average** value.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

The uncertainty is given by:

$$x = \frac{\sum_{i=1}^{n} \left| \bar{x} - x_i \right|}{n}$$

Example: ***Refer experiment one*.**

Uncertainties of gradient and *y*-intercept for a straight line graph

Gradient: $\Delta m = \frac{m_{\max} - m_{\min}}{2}$

***y*-intercept**: $\Delta c = \frac{c_{\max} - c_{\min}}{2}$

Example: ***Lab manual – Guidance for students*.**

Combination of uncertainties

1. **Addition or subtraction**

   $x = a + b - c \quad \rightarrow \quad \Delta x = \Delta a + \Delta b + \Delta c$

2. **Multiplication with constant *k***

   $x = ka \quad \rightarrow \quad \Delta x = k\Delta a$

3. **Multiplication or division**

   $x = \frac{ab}{c} \quad \rightarrow \quad \frac{\Delta x}{x} = \left(\frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} \right)$

4. **Index**

   $x = a^n \quad \rightarrow \quad \frac{\Delta x}{x} = n\left(\frac{\Delta a}{a} \right)$

Example: ***Lab manual – Guidance for students*.**

Percent Uncertainty vs. Significant Figures

The significant figures rule is only approximate, and in some cases may underestimate the accuracy (or uncertainty) of the answer. Suppose for example we divide 97 by 92:

$$\frac{97}{92} = 1.05 \approx 1.1$$

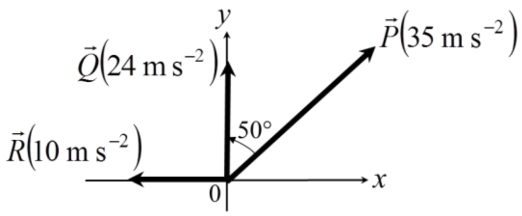
Both 97 and 92 have two significant figures, so the rule says to give the answer as 1.1. Yet the numbers 97 and 92 both imply an uncertainty of ±1 if no other uncertainty is stated. Both 92 ± 1 and 97 ± 1 imply an uncertainty of about 1%. But the final result to two significant figures is 1.1, with an implied uncertainty of ±0.1, which is an uncertainty of about 10%. It is better in this case to give the answer as 1.05 (which is three significant figures). Because 1.05 implies an uncertainty of ±0.01 which is 1%, just like the uncertainty in the original numbers 92 and 97.

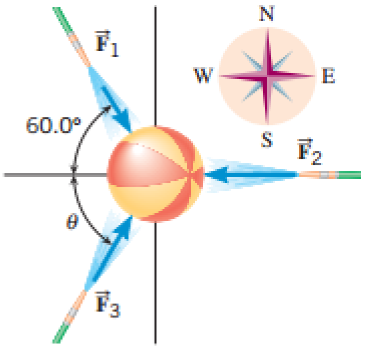
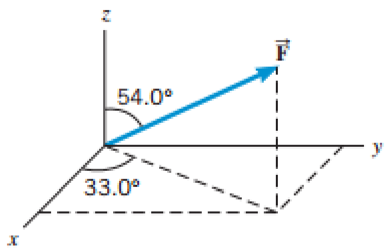
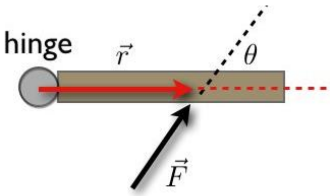
SUGGESTION: Use the significant figures rule, but consider the % uncertainty too, and add an extra digit if it gives a more realistic estimate of uncertainty.

Exercise

Revision	
1.	The unit of impulse is **N s**. Express **N s** in terms of the base SI units.
2.	The highest waterfall in the world is Angel Falls in Venezuela, with a total drop of 979.0 m. Express this drop in kilometre.
3.	A light-year is the distance light travels in one year (at speed = 3.00×10^{8} m s^{-1}). a) How many meters are there in 1.00 light-year? b) An astronomical unit (AU) is the average distance from the Sun to Earth, 1.50×10^{8} km. How many AU are there in 1.00 light-year?
4.	Suppose a man's scalp hair grows at a rate of 0.35 mm per day. What is this growth rate in meter per second?
5.	The density of blood is 13.6 g cm^{-3}. Expressed this density in kg m^{-3}.

Dimensions of Physical Quantities	
1.	What are the dimensions of density, which is mass per volume?
2.	The speed of an object is given by the equation $v = At^3 - Bt$ where t refers to time. a) What are the dimensions of A and B? b) What are the SI units for the constants A and B?
3.	Consider the equation $v = \frac{1}{2}zxt^2$. The dimension of the variables v, x, and t are [L]/[T], [L], and [T], respectively. The numerical factor ½ is dimensionless. What must be the dimensions of the variable z, such that both sides of the equation have the same dimensions?
4.	A spring is hanging down from the ceiling, and an object of mass m is attached to the free end. The object is pulled down, thereby stretching the spring, and then released. The object oscillates up and down, and the time T required for one complete up-and-down oscillation is given by the equation $T = 2\pi\sqrt{\frac{m}{k}}$, where k is known as the spring constant. What must be the dimension of k for this equation to be dimensionally correct?

Scalars and Vectors	
1.	A car moves at a velocity of 50 m s^{-1} in a direction north 30° east. Calculate the component of the velocity due north **and** due east.
2.	Given three vectors *P*, *Q* and *R* as shown in Figure  Calculate the resultant vector of *P*, *Q* and *R*.

3.	At a picnic, there is a contest in which hoses are used to shoot water at a beach ball from three directions. As a result, three forces act on the ball, $\vec{F}_1$, $\vec{F}_2$, and $\vec{F}_3$. The magnitudes of $\vec{F}_1$ and $\vec{F}_2$ are F_1 = 50.0 N and F_2 = 90.0 N. Determine the magnitude of $\vec{F}_3$ and the angle θ such that the resultant force acting on the ball is zero. 
4.	Given that $\boldsymbol{P} = 2\boldsymbol{i} + \boldsymbol{j} - 5\boldsymbol{k}$ and $= 3\boldsymbol{i} + 6\boldsymbol{j} + 2\boldsymbol{k}$, find the resultant $(\boldsymbol{P} + \boldsymbol{Q})$ and the unit vector in the direction of the resultant.
5.	The drawing shows a force vector that has a magnitude of 475 N. Determine the *x*, *y* and *z* components of the vector. Expressed the answer in unit vector form. 
6.	Given $\vec{\tau} = \vec{r} \times \vec{F}$, determine the direction of torque $\vec{\tau}$ in the Figure. 

Significant Figures and Uncertainties Analysis	
1.	Multiply 3.079×10^{2} m by 0.068×10^{-1} m, taking into account significant figures.
2.	Add (9.2×10^{3} s) + (8.3×10^{4} s) + (0.008×10^{6} s), taking into account significant figures.
3.	What is the percent uncertainty in the volume of a spherical beach ball of radius $r = 0.84 \pm 0.04\,\text{m}$?
4.	What is the area, and its approximate uncertainty, of a circle of radius 3.1×10^{4} cm?
5.	A friend asks to borrow your precious diamond for a day to show her family. You are a bit worried, so you carefully have your diamond weighed on a scale which reads 8.17 grams. The scale's accuracy is claimed to be ±0.05 grams. The next day you weigh the returned diamond again, getting 8.09 grams. Is this your diamond?

Additional Knowledge: Errors in Measurement

The **difference** between the **actual value** of a quantity and the **value** obtained in measurement is the **error**. There are two main types of errors: **systematic errors** and **random errors**.

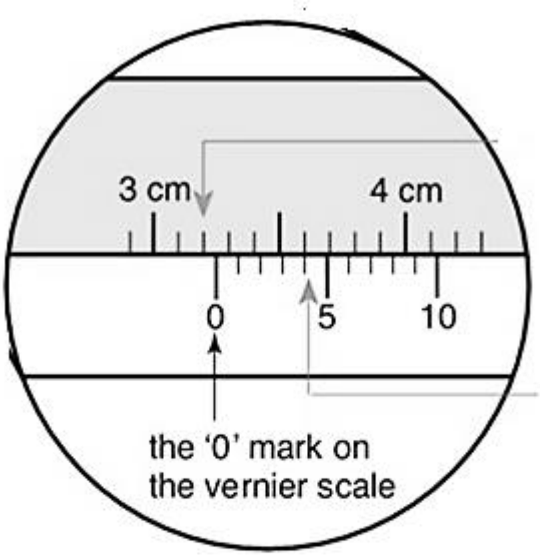
Systematic errors are **cumulative errors** that can be corrected, if the errors are known. It results from:

- an **incorrect** position of the zero point, known as **zero error**
- an **incorrect calibration** of the measuring instrument

Random errors may occur for a **variety of reasons**. They may be due to

- personal errors such as **parallax error** (due to wrong position of the eye when reading a scale)
- **natural error** such as changes in wind, temperature, humidity, refraction, magnetic field or gravity while the experiment is in progress
- the use of a **wrong technique** of measurement such as applying excessive pressure when turning a micrometer screw gauge

Vernier Calliper



Note:
Since the vernier callipers has an accuracy of **0.01 cm**, it means any readings taken from the vernier callipers has to be written to two decimal places even it is a whole number, e.g. 1.00 cm.

How to take reading:
Main scale reading:

- Read the mark on the main scale preceding the '0' mark on the vernier scale. The '0' mark on the vernier scale acts as pointer for the main scale reading.
- The '0' mark on the vernier scale in this example lies between 3.2 cm and 3.3 cm. Therefore, the reading on the main scale is 3.2 cm.

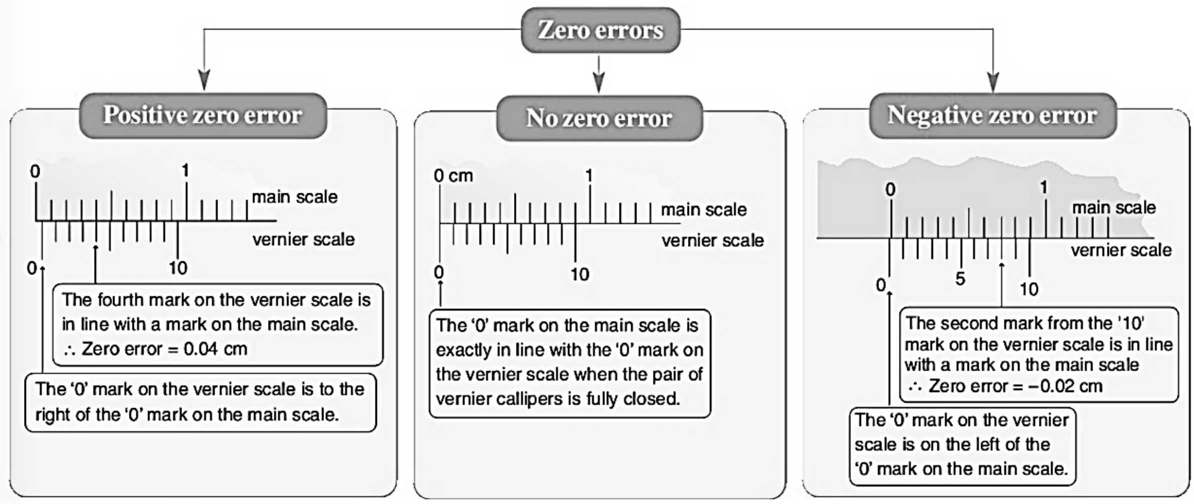
Vernier scale:

- Read the mark on the vernier scale that is exactly in line or coincides with any mark on the main scale.
- In this example, the fourth mark on the vernier scale exactly in line with a mark on the main scale. Therefore, the vernier scale reading is 0.04 cm.

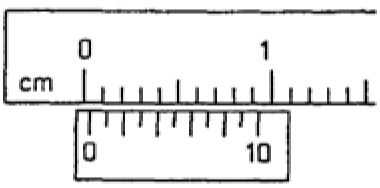
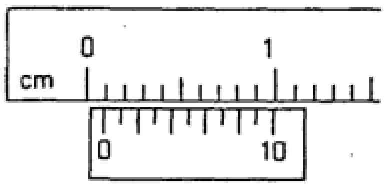
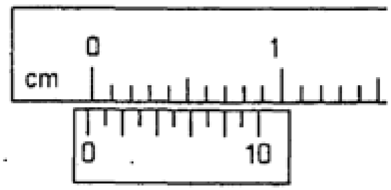
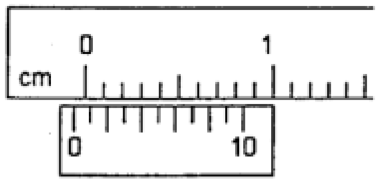
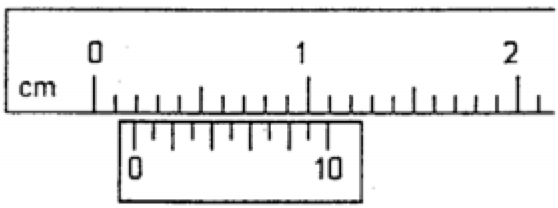
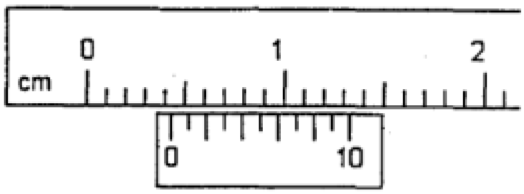
Vernier callipers reading
= Main scale reading + Vernier scale reading
= 3.24 cm

Correct reading: (3.24 ± 0.01) cm

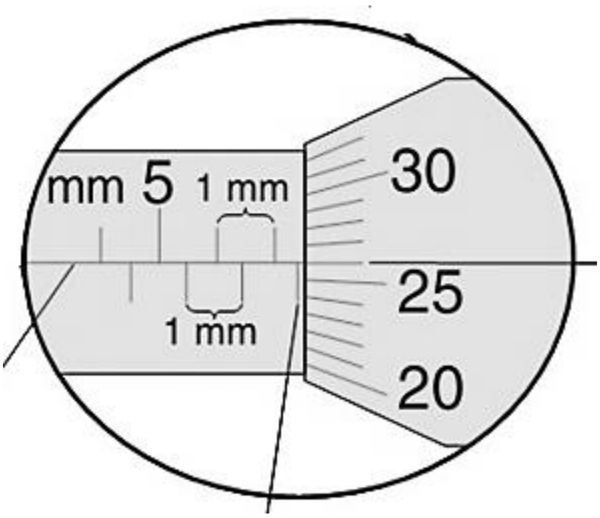
To eliminate the zero error: Correct reading = Callipers reading – Zero error



Exercise

Question
Determine the zero error:  Zero Error = __________cm  Zero Error = __________cm  Zero Error = __________cm  Zero Error = __________cm
Determine the actual reading:  Zero Error = - 0.08 cm Actual Reading = ______________  Zero Error = +0.05 cm Actual Reading = ______________

<u>Micrometer Screw Gauge</u>



How to take reading:
Main scale reading:
- Read the main scale reading at the edge of the thimble. Take note that an additional half scale division (0.5 mm) must be included if the mark below the horizontal reference line is visible. Therefore, the reading on the main scale is 7.5 mm.

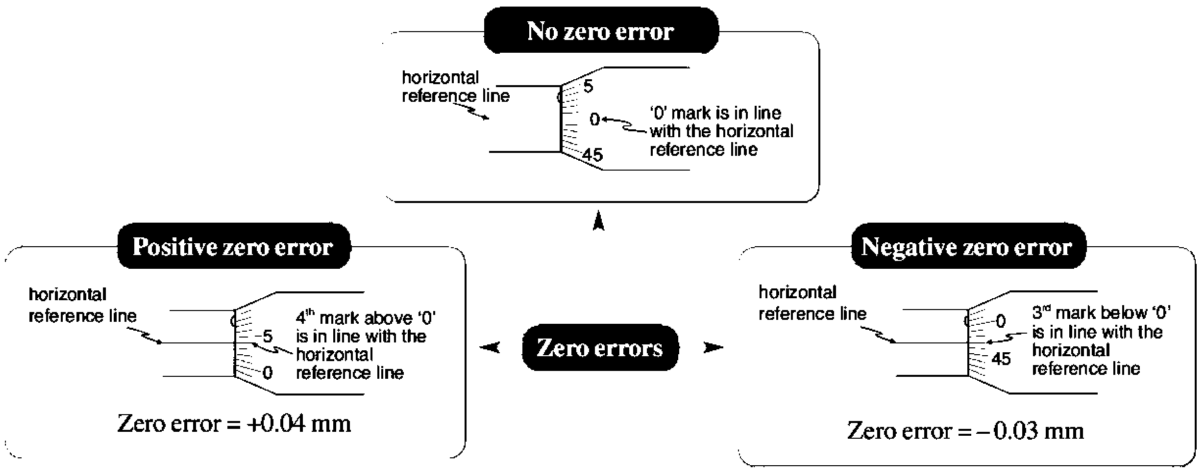
Vernier scale:
- Read the thimble scale reading at the point where the horizontal reference line of the main scale is in line with the graduation mark on the thimble scale. Therefore, the vernier scale reading is 0.26 mm.

Micrometer screw gauge reading
= Main scale reading + Thimble scale reading
= 7.76 cm

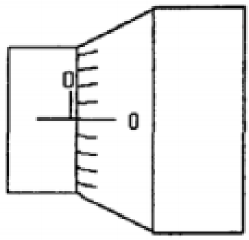
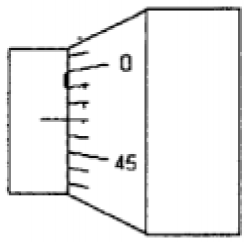
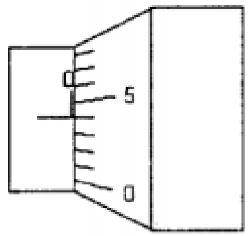
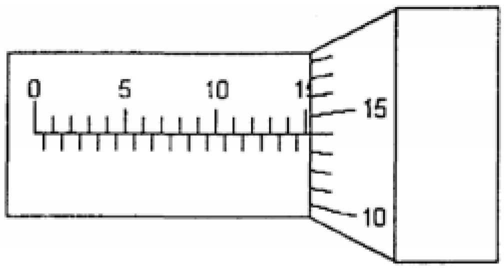
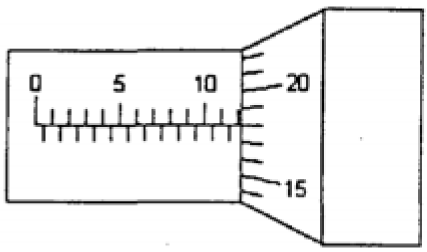
Correct reading: (7.76 ± 0.01) mm

Note:
The accuracy of a micrometer screw gauge is **0.01 mm**.

Correct reading = Reading obtained – Zero error



Exercise

Question
Determine the zero error:    Zero Error = __________mm Zero Error = __________mm Zero Error = __________mm
Determine the actual reading:  Zero Error = +0.23 mm Actual Reading = ______________  Zero Error = - 0.21 mm Actual Reading = ______________