MEASUREMENT AND UNCERTAINTY

AS Level Physics

Information

- Content
- Physical quantities
- Units
- Scalars and vectors
- Significant figures
- Errors
- Uncertainty
- Plotting the graph

- Assessments
- Lab work – Measuring the density of an object.
- Work sheet
- Go formative - http://goformative.com/teacher/#/assignments/WNCM796/edit?assign

Physical quantity

- Nature provides different experiences to the mankind , *Phenomena.*
- These experiences which are measurable scientifically termed as *Physical quantities.*
- we have two types of physical quantities.
  - Fundamental(SI) quantities
  - Derived quantities

Physical quantities

Fundamental

- They are the basic quantities using which we can derive all other quantities.
- These are independent.
- Eg: Mass, Length, Time

Derived

- They are dependent on fundamental quantities.
- Eg: area, volume, density, force,….

Units

- A quantity used as a standard of measurement

Example: Units of time are second, minute, hour, day, week, month, year and decade.

How many different units of length can you think of?

Units of length?

Light year, light second, parsec, AU, mile, furlong, fathom, yard, feet, inches, Angstroms, nautical miles, cubits, cm, mm, km, µm, nm, ?

The SI system of units

There are seven fundamental base units which are clearly defined and on which all other derived units are based:

You need to know these, but not their definitions.

The metre

This is the unit of distance. It is the distance traveled by light in a vacuum in a time of 1/299792458 seconds.

The second

This is the unit of time. A second is the duration of 9192631770 full oscillations of the electromagnetic radiation emitted in a transition between two hyperfine energy levels in the ground state of a caesium-133 atom.

- https://www.youtube.com/watch?annotation_id=annotation_2965246921&feature=iv&index=90&list=PLMrtJn-MOYmfqNgyPxx6NYMZnd25y4shc&src_vid=r7x-RGfd0Yk&v=NXRVtfCpLr4

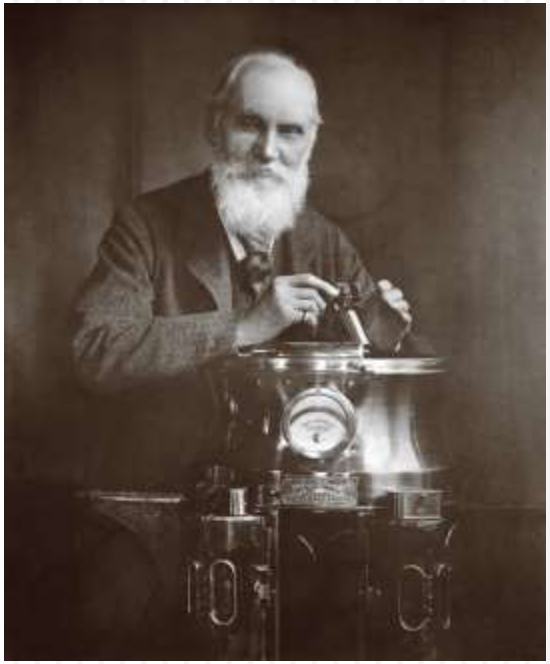
The ampere

This is the unit of electrical current. It is defined as that current which, when flowing in two parallel conductors 1 m apart, produces a force of 2×10^{-7} N on a length of 1 m of the conductors.

Note that the Coulomb is NOT a base unit.

The kelvin

This is the unit of temperature. It is 1/273.16 of the thermodynamic temperature of the triple point of water.



The mole

- One mole of a substance contains as many molecules as there are atoms in 12 g of carbon-12. This special number of molecules is called Avogadro's number and equals 6.02×10^{23}.

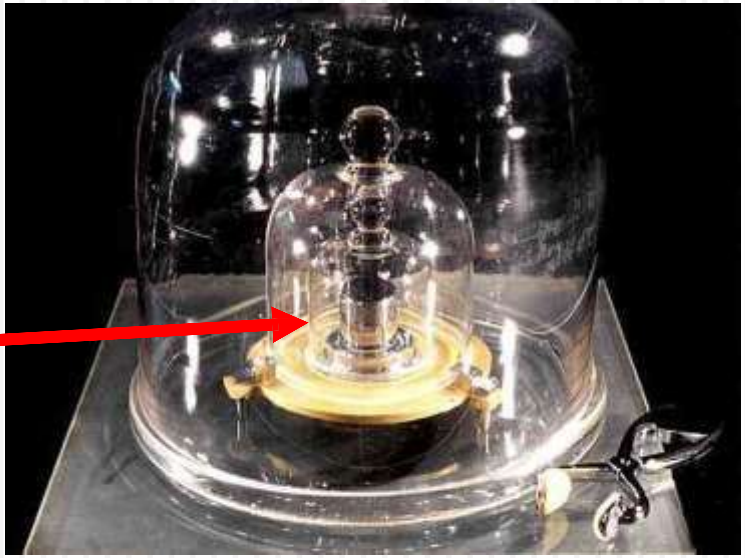
The candela (not used in IB)

This is the unit of luminous intensity. It is the intensity of a source of frequency 5.40×10^{14} Hz emitting 1/683 W per steradian.

The kilogram

This is the unit of mass. It is the mass of a certain quantity of a platinum-iridium alloy kept at the Bureau International des Poids et Mesures in France.

THE kilogram!



SI Base Units

Can you copy this please?

Quantity	Unit
distance	metre
time	second
current	ampere
temperature	kelvin
quantity of substance	mole
luminous intensity	candela
mass	kilogram

Note: No Newton or Coulomb

Derived units

Other physical quantities have units that are combinations of the fundamental units.

Speed = distance/time = $m\ s^{-1}$

Acceleration = $m\ s^{-2}$

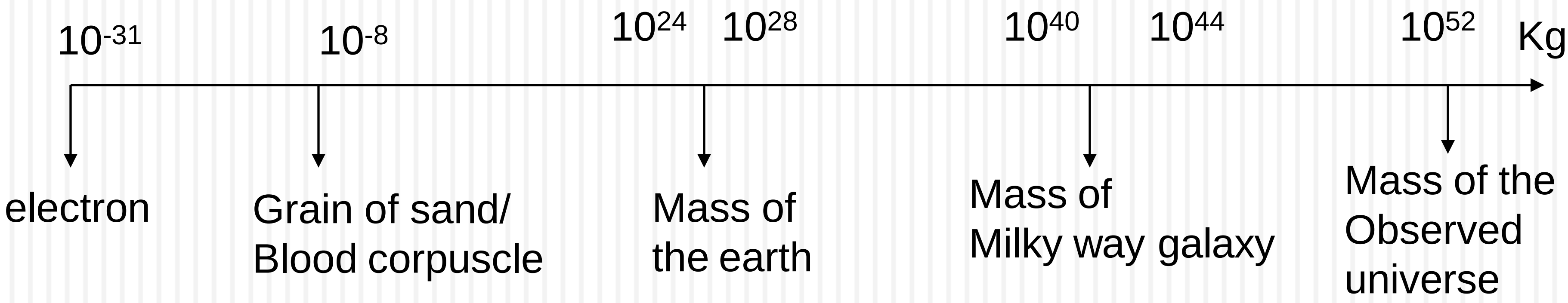
Force = mass x acceleration = $kg\ m\ s^{-2}$ (called a Newton)

Order of magnitude

- This is power of 10
- It is helpful to avoid *getting lost* among the numbers
- Eg. The diameter of an atom, 10^{-10}m does not sound much larger than diameter of proton in its nucleus, 10^{-15}m.
- But the ratio between them is 10^{5} or 100000 times bigger. This is we say *a difference of 5 orders of magnitude'*

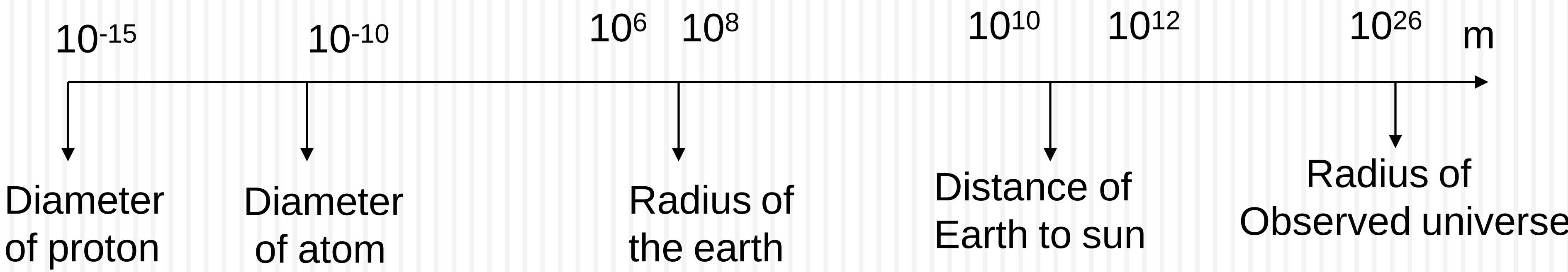
https://www.youtube.com/watch?v=bhofN1xX6u0
https://www.youtube.com/watch?v=UDAtFVsZXTc
http://joemonster.org/gry/41805 Interactive for order of magnitude.

Range of masses



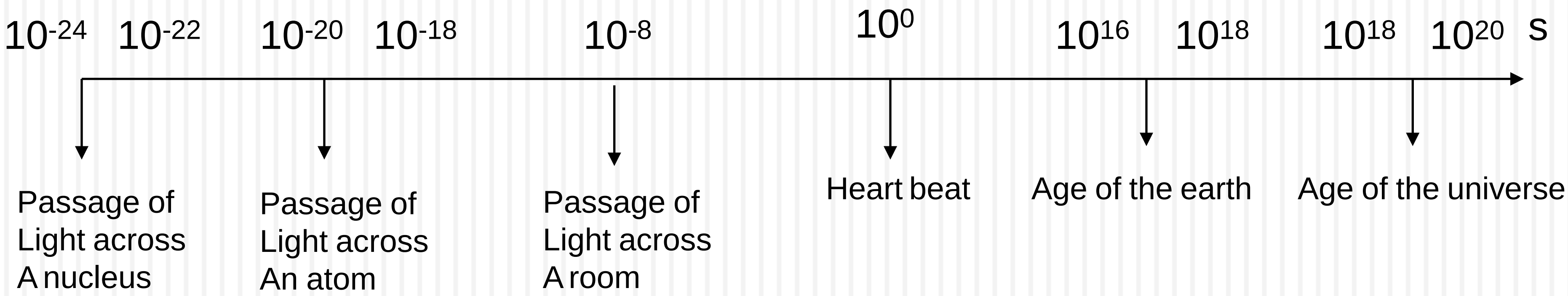
Most fundamental particle is quark and it hides inside proton and neutron.
the lightest quark is *up quark* , whose mass is about 10^{-30} kg.

Range of lengths



There is a much smaller fundamental unit of length, Planck length, which is around 10^{-35} m.

Range of Time



What is theoretical lower limit of time?

Estimation – what is ratio of rest mass of proton to rest mass of electron?

Estimate the following:

(to the nearest order of magnitude)

1. The mass of an apple
2. The number of times a human heart beats in a lifetime.
3. The speed a cockroach can run.
4. The number of times the earth will fit into the sun ($R_s = 6.96 \times 10^8$ m, $R_e = 6.35 \times 10^6$ m)

Estimate the following:

(to the nearest order of magnitude)

1. The mass of an apple 10^{-1} kg
2. The number of times a human heart beats in a lifetime.
3. The speed a cockroach can run.
4. The number of times the earth will fit into the sun ($R_s = 6.96 \times 10^8$, $R_e = 6.35 \times 10^6$)

Estimate the following:

(to the nearest order of magnitude)

1. The mass of an apple 10^{-1} kg
2. The number of times a human heart beats in a lifetime. 70x60x24x365x70=10^{9}
3. The speed a cockroach can run.
4. The number of times the earth will fit into the sun ($R_s = 6.96 \times 10^8$, $R_e = 6.35 \times 10^6$)

Estimate the following:

(to the nearest order of magnitude)

1. The mass of an apple 10^{-1} kg
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Estimate the following:

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2. The number of times a human heart beats in a lifetime. 70x60x24x365x70=10^{9}
3. The speed a cockroach can run. 10^{0} m/s
4. The number of times the earth will fit into the sun $(6.96 \times 10^{8})^{3}/(6.35 \times 10^{6})^{3} = 10^{6}$

Significant figures

- These are number of digits up to which we are sure about their accuracy.
- Significant figures do not change if we measure a physical quantity in different units.
- E.g. 14.5 cm = 0.145 m = 14.5 X 10^{-2} m

  Here three values have same

  significant figures i.e. 3

Rules for significant figures

1. All non zero digits are significant figures.
   - 17 - 2
   - 178 - 3

2. All zeros occurring between non zero digits are significant figures.
   - 401 - 3
   - 40056 - 5

3. All zeros to the right of the last non zero digit are not significant figures.
   - 20 - 1
   - 20350 - 4

4. All zeros to the right of a decimal point and to the left of a non zero digit are not significant figures.

- 0.04 - 1
- 0.0045 - 2

5. All zeros to the right of a decimal point and to the right of a non zero digit are significant figures.

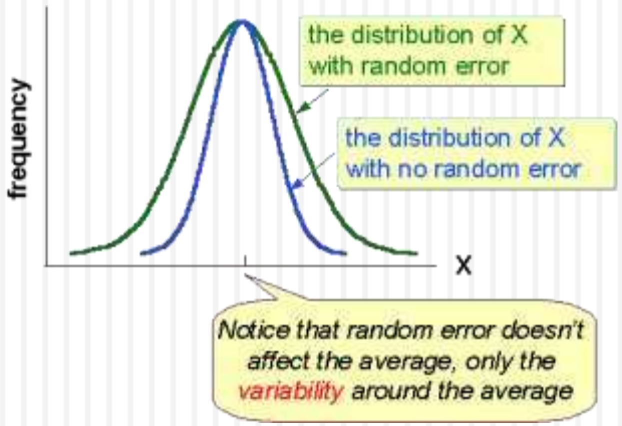
- 0.20 - 2
- 0.2370 - 4

Uncertainty or error in measurement

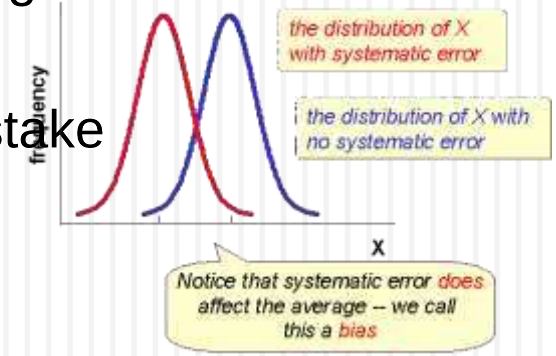
- The difference in the true value and measured value is called error.
- Types of error
  - Random error
  - Systematic error

Random error

- usually random errors are caused by the person doing the experiment.
- Causes –
  - changes in the experimental conditions like temp, pressure or humidity etc..
  - A different person reading the instrument
  - Malfunction of a piece of apparatus



- Systematic error
- This error is due to the system or apparatus being used.
- Causes –
  - An observer consistently making the same mistake
  - An instrument with zero error
  - Apparatus calibrated incorrectly



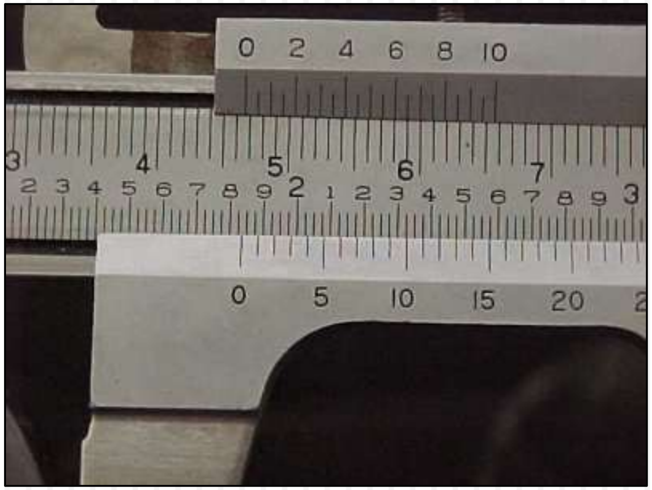
- **How to avoid the errors?**

  Random errors can be reduced by repeating the measurement many times and taking the average, but this process will not effect systematic errors.
- An accurate experiment is one that has a small systematic error, where as a precise experiment is one that has a small random error.

Precision and Accuracy in Measurements

- **Precision**

  How reproducible are measurements?

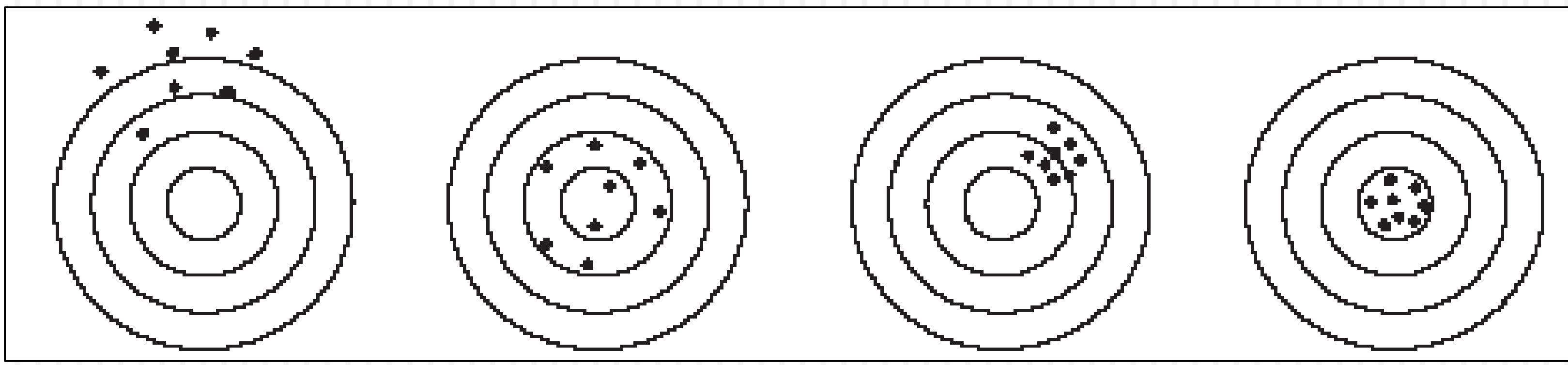


- **Accuracy**

  How close are the measurements to the true value.

Dartboard analogy to Precision and accuracy

- A person throwing darts, trying to hit the bulls-eye, his results may be....



Not accurate Not precise	Accurate Not precise	Not accurate Precise	Accurate Precise

Mathematical representation of uncertainties

- ***Absolute error (Absolute uncertainty)* –**
  It is the magnitude of difference between true value of quantity and the measurement value.
  If p is the measured quantity then absolute error expressed as
  $\pm \Delta p$

- ***Relative error (Fractional uncertainty)*–**
  The ratio of absolute error to the true value of the physical quantity is called relative error.
  Here $\pm \frac{\Delta p}{P}$ is the relative error.

- ***Percentage error (Percentage Uncertainty)* –**
  relative error X 100% = $\pm \frac{\Delta p}{P} \times 100\ \%$

- **Uncertainty in Addition and Subtraction**
  A, B are two quantities and Z = A + B or Z = A - B
  ΔA, ΔB, ΔZ are uncertainties in A, B, Z respectively
  then $\Delta Z = \Delta A + \Delta B$

- **Uncertainty in Multiplication and Division**
  A, B are two quantities and Z = A X B or Z = A / B
  ΔA, ΔB, ΔZ are uncertainties in A, B, Z respectively
  then $\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$

- **Uncertainty in powers**
  A is quantity and $Z = A^n$ then
  $\frac{\Delta Z}{Z} = \frac{n\,\Delta A}{A}$

Graphs introduction

Graphs are the visible representation of collected data

- The graph should have a title.
- The scales of the axes should be suitable – there should not be any sudden or uneven jumps in the numbers.
- The inclusion of the origin has been thought about. You can always draw a second graph without it if necessary.
- The final graph should cover more than half the paper in either direction.
- The axes are labeled with both the quantity and units
- The points are clear. Vertical and horizontal lines to make crosses are better than 45 degrees crosses or dots.

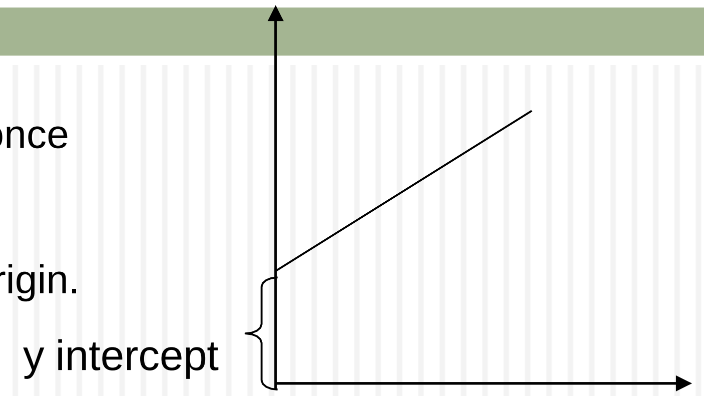
A best plotted graph have…

- All the points been plotted correctly.
- Error bars are included if necessary.
- A best fit line is added. (It is there to show overall trend.)
- If best fit line is a curve, this has been drawn as a single smooth line.
- As a general rule, there should be roughly the same number of points above the line as below the line.
- Any points that do not agree with the best fit line have been identified.

Gradient and intercept

- Intercept
  - A straight line graph can only intercept (cut) either axis once and often it is

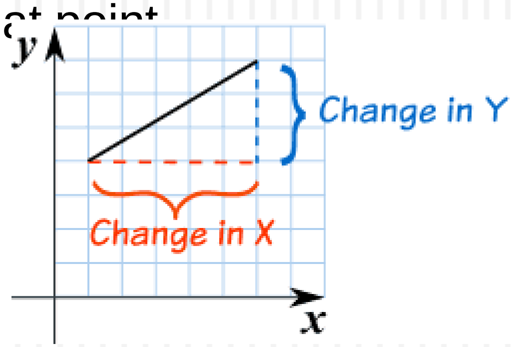
  y – intercept.
  - if a graph has an intercept of zero it goes through the origin. (proportional)

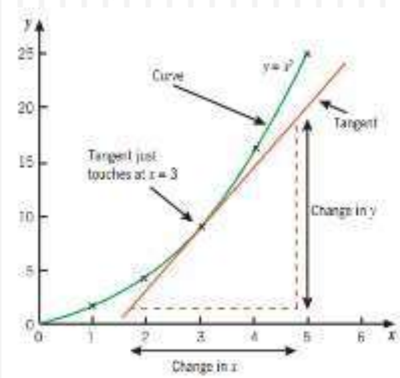


Gradient or slope

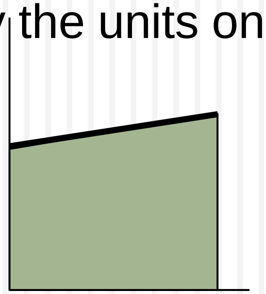
It is the ratio of change in y – axis to the change in x – axis. i.e. $m = \frac{\Delta y}{\Delta x}$

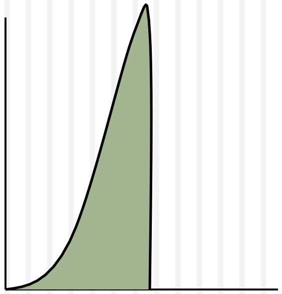
A straight line graph has a constant gradient.
The triangle used to calculate the gradient should be as large as possible.
The gradient has units.
The gradient of a curve at any particular point is gradient of the tangent to the curve at that point.





- Area under a graph
  - it is the product of quantity on y axis and by the quantity on x axis.
  - i.e. Area = quantity on y **X** quantity on x
  - If the graph is a curve, the area can be calculated by counting the squares and working out what one square represents.
  - The units for the area under graph are the units on the y axis multiplied by the units on the x axis.





Uncertainties in graphs

- Uncertainties in graphs can be shown as error bars

- Uncertainties are many types.
  - With analog instruments, such as rulers, you would add onto the end of a value a plus or minus half the value of the last digit, eg. on a ruler with 1mm precision, you would put +/- .5mm.
  - Digital instruments use a different system, where it is plus or minus the value of the last digit, eg. with an electronic scale that reads 291g, the uncertainty would be +/- 1g.
  - We take a time of 8.06 s with a stopwatch that measures 1/100 seconds, so half the limit of reading would be 0.005 s. But we know from experience that our reaction time is longer than that, so we estimate it to for example 0.10 s, and have the result 8.06±0.1s.

- If we have several (at least about 5) measurements of the same thing, we can use the **highest residual** as an absolute uncertainty. A residual = the absolute value of the difference between a reading and the average of the readings.

- Ex. Five people measure the mass of an object. The results are 0.56 g, 0.58 g, 0.58 g, 0.55 g, 0.59g.

The average is (0.56g + 0.58g + 0.58g + 0.55g + 0.59g)/5 = 0.572g

- The residuals are 0.56g - 0.572g = (-) <u>0.012g</u>, 0.58g - 0.572g = <u>0.008g</u>, 0.58g - 0.572g = <u>0.008g</u>, 0.55g - 0.572 g = (-)<u>**0.022 g**</u>, 0.59g - 0.572g = <u>0.018g</u>

- Then the measurement is m = 0.572g±0.022g or sometimes 0.57±0.02g (uncertainties are usually approximated to one significant digit).

Scalars and Vectors

- Scalar quantities are those which have magnitude(or size) alone. They can be expressed as number (albeit with unit) and use the rule of algebra when dealing with them.
- Vector quantities are those which have both magnitude and direction. They follow the vector algebra while doing various mathematical operations.

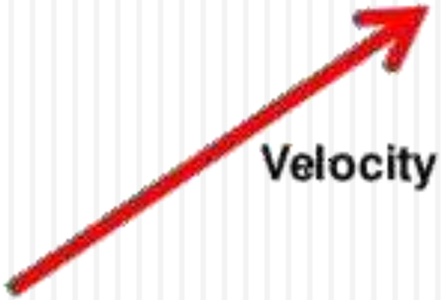
Scalars and Vectors

Scalar quantities

Length, Area, Volume,
Speed,
Mass, Density
Temperature, Pressure
Energy, Entropy
Work, Power

Vector quantities

Displacement, Direction,
Velocity, Acceleration,
Momentum, Force,
Electric field, Magnetic field



Scalar quantities

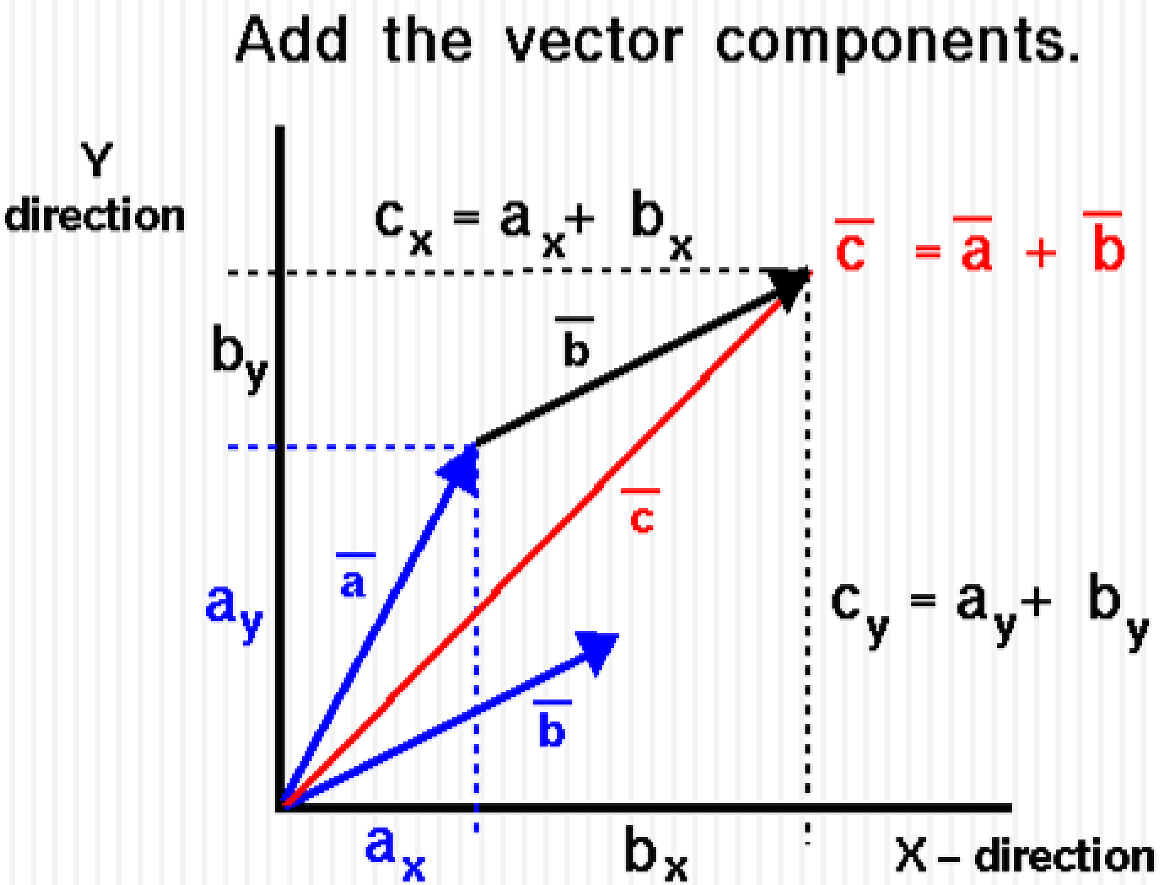
- distance (m)
- speed (m/s)
- time (s)
- mass (kg)
- temperature (K)
- pressure (Pa or N/m²)
- kinetic energy (J)
- gravitational potential energy (J)
- work done (J)
- power (P or J/s)
- current (A)
- potential difference (V)
- resistance (Ω)

Vector quantities

- displacement (m)
- velocity (m/s)
- acceleration (m/s²)
- force (N)
- weight (N)
- moment (Nm)

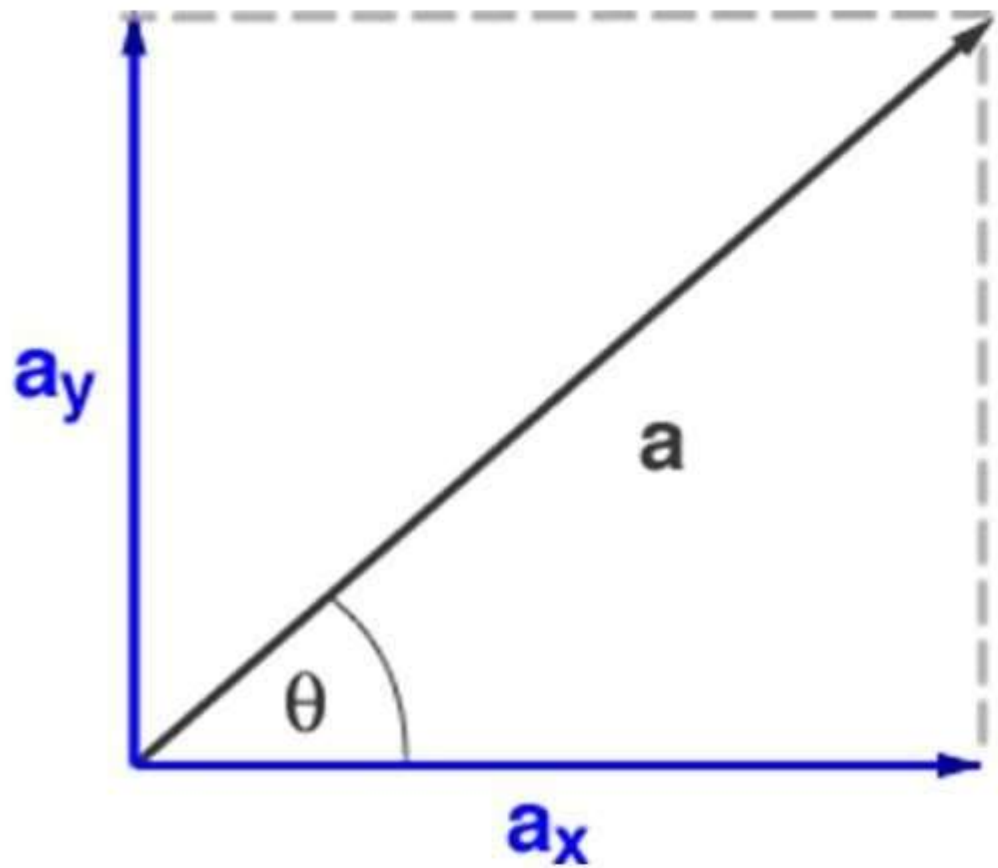
evan.toh

VECTOR ADDITION



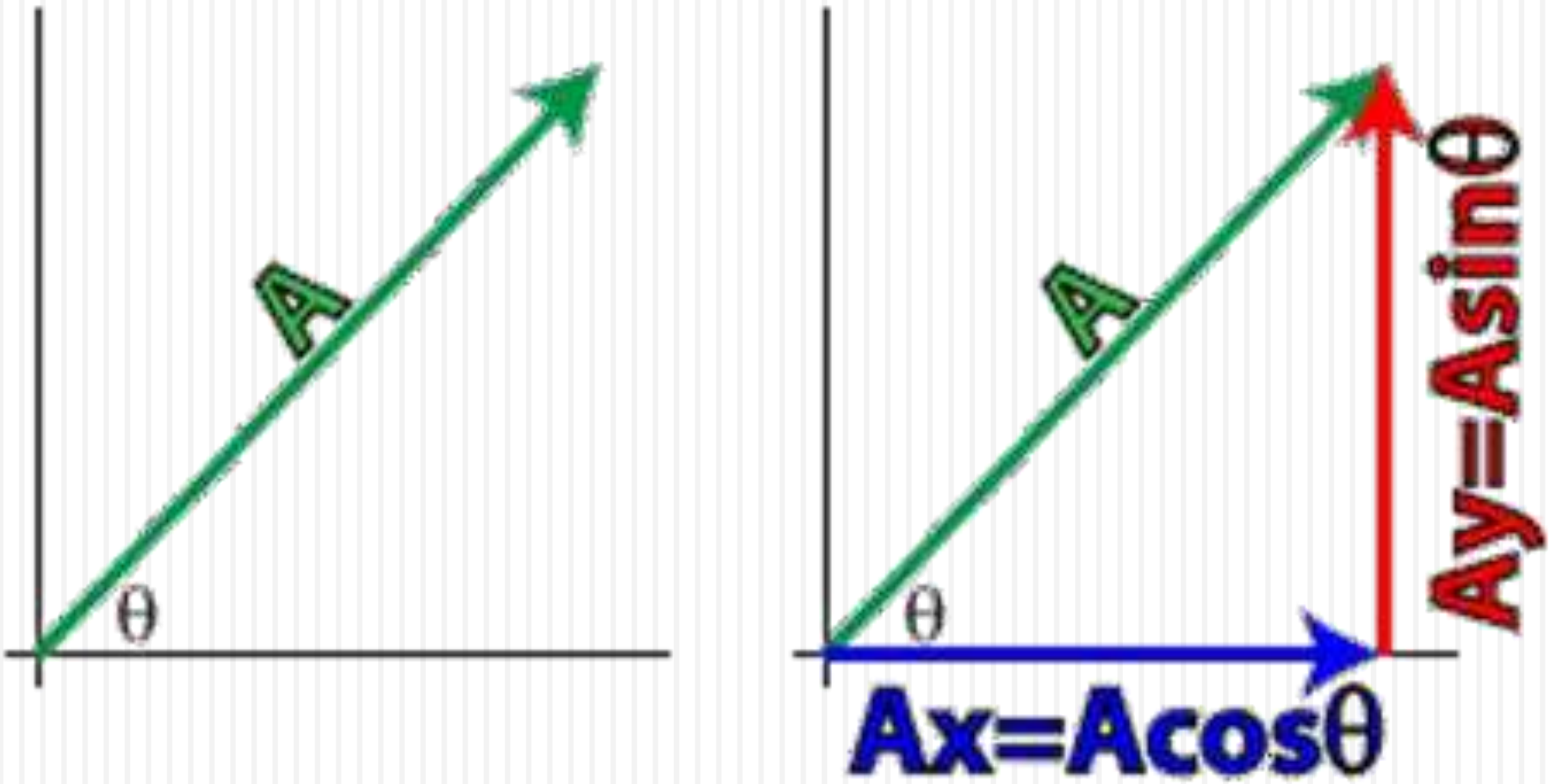
Vector Resolution: Graphical Method

- Sketch projection lines to x & y axis
- Draw component vectors along axes



Hepburn, Carl Jason. (n.d.) Scalars and Vectors. *Splung.com*. Retrieved from http://www.splung.com/content/sid/1/page/vectors

VECTOR RESOLUTION



Questions/Discussions

Work sheet uploaded in Edmodo.

ToK question: How far you are certain about the fundamentality of the fundamental units chosen by the S.I system ?

Assessment : Prepare a report of various units of time used by different people in different regions and different era. Discuss about the validity compared to the system that we are following now.