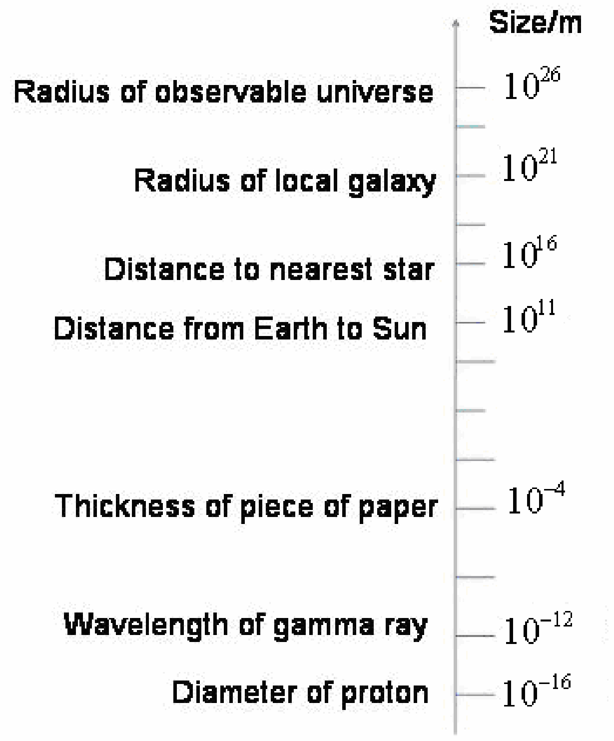
Chapter 1 Physical Measurement

1.1 The Realm of Physics

In order to get a feel of the size of objects, from the small, such as atoms, to the large, such as galaxies, it is helpful to use approximate values when comparing them. Physicists round sizes to the nearest power of ten and each factor of ten differences is known as an **order of magnitude**.

For example, it is known that the mass of the Earth is 10^{25} kg and the mass of a normal-sized car is 10^{3} kg.
Therefore, the mass of the Earth is 22 orders of magnitude larger than a car.
(Ratios of quantities are stated as a difference of their orders of magnitude.)

Range of Distances, Masses and Times



Length Range

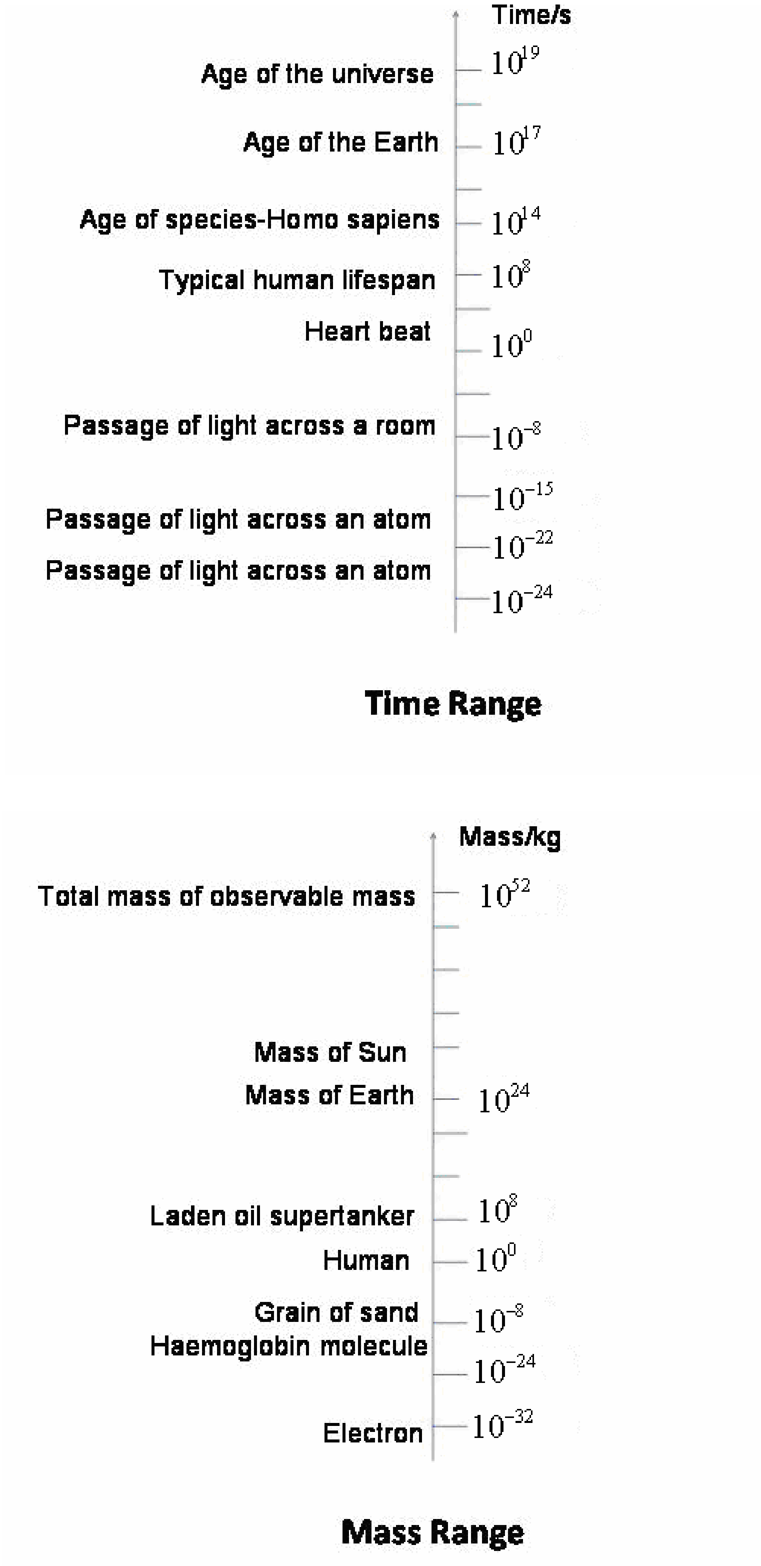


Fig. 1.1.1 Range of time, length and mass

1.2 Measurement and Uncertainties

Fundamental Units

A unit is an important part of a quantity. A quantity on its own, e.g. "The mass is 6", is meaningless and writing this would lose you marks in the exam. Unless the quantity is dimensionless, we need to quote numbers with an appropriately defined unit. In modern day science, we use the **SI unit system** and the fundamental units are as follows:

Quantity	SI Unit	Symbol
Mass	Kilogram	kg
Length	Meter	m
Time	Second	s
Electric Current	Ampere	A
Substance Amount	Mole	mol
Temperature	Kelvin	K

Derived Units

Combinations of the fundamental units are known as **derived units**. For example, acceleration is not included in the fundamental list of units and a derived unit is required. This can be obtained from the definition of acceleration = velocity divided by time. Since velocity is not a fundamental unit either, we can again use the definition of velocity = displacement divided by time and end up with the unit of meter per second per second for acceleration [or ms^{-2}].

Some derived units are so common that a new name is used instead. For example, "Newton" is used as a unit for force. From the equation force equals the product of mass and acceleration, 1 Newton is equal to 1kg ms^{-2}
As the scale of a quantity can span many magnitudes, it is sometimes necessary to use **standard notation** (also called **scientific notation**) or to use a **prefix** in order to express them.

Example: Which one of the following units is a unit of energy?

(a) Nms^{-1} (b) Ws^{-1} (c) eV (d) ms^{-1}

Answer: (c)

Uncertainties - Error in Measurement

There are two types of errors encountered when dealing with experimental data. This difference from the perfect value is either **random** or **systematic**.

A random error can be caused by external means or the device is far from precise.

For example, a change in room temperature can affect readings of some measurements. The way the readings are taken by an observer can also give random errors.

A systematic error is one that consistently gives inaccurate value. An example is a device having a wrong calibration or a zero offset.

Repeated measurements may reduce random errors but not systematic ones.

When calculating quantities, a rule of thumb is that for multiplication and division, the number of significant figures should not exceed that of the least precise value that is used.

Uncertainties – Calculated Results

Uncertainties can be quoted as an absolute value (size of an error), fractional (ratio of the absolute value to the actual reading) or a percentage uncertainty (multiplying the fractional uncertainty by 100).

When calculating results, the uncertainties depend on the functions used. For addition or subtraction, the absolute errors are added. For multiplication, division or powers, the percentage uncertainties are added.

<u>Example:</u>

Peter measures the mass and speed of a car. The percentage uncertainty in the mass and speed is 3% and 10% respectively. The calculated value of the kinetic energy for the car will have an uncertainty of: (a) 3% (b) 13% (c) 23% (d) 33%

Answer: (c)

Uncertainties – Graphs

All measured values have an uncertainty range. For example, measuring an object with an exact length of 12.4102425cm with a standard 30cm ruler may fall closer to 12.4cm than to 12.5cm. The uncertainty of such a measurement will be $+/-$ half the smallest scale division. i.e. 0.05cm.

On a graph, this uncertainty is shown as an error bar.

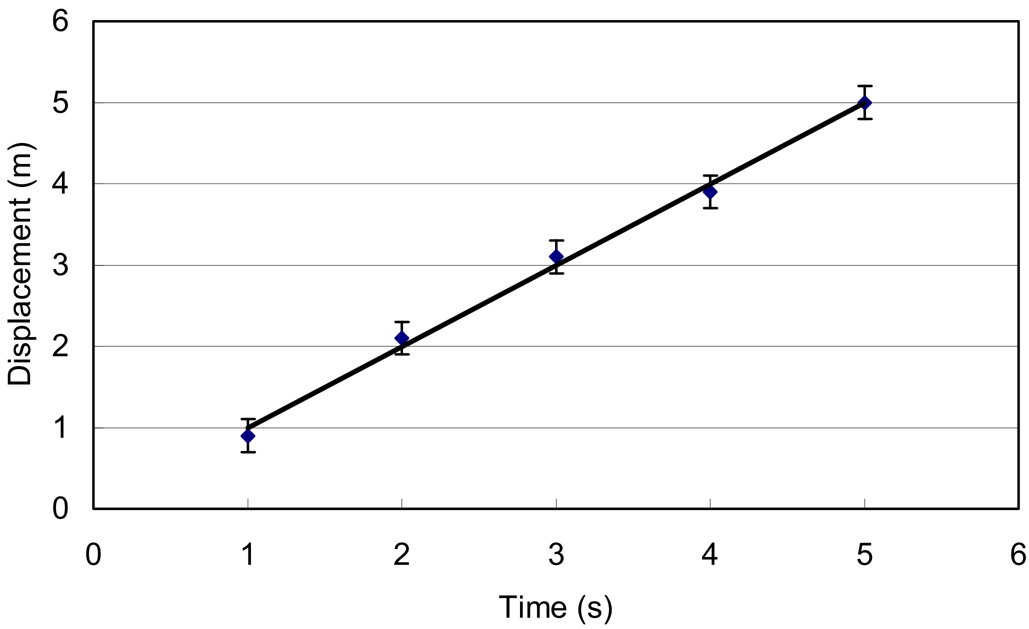


Fig. 1.2.1 Graph with error bars

In order to determine the uncertainty in the intercept of a straight line graph, two lines can be drawn passing through the error bars as maximum and minimum lines. A line of best fit lies between the two lines with the uncertainty being the **difference** between the line of best fit and the maximum and minimum lines.

The uncertainty of the gradient is found in a similar fashion but since division is required, the percentage errors will need to be added.

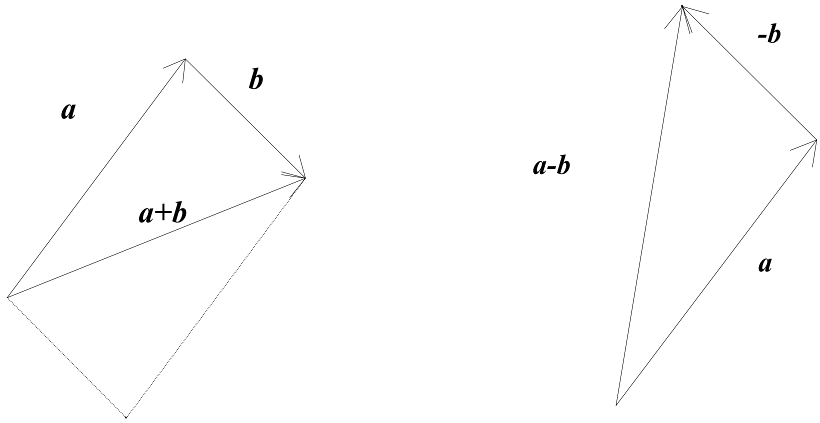
1.3 Scalar and Vectors

A measured quantity has a number and a unit. This combination is called a **magnitude**. In some cases, the quantity will also have a direction associated with it. Such a quantity that has both a magnitude and direction is known as a **vector**. Without the direction, it is considered to be a **scalar** only.

Common examples of scalar quantities include distance, mass and temperature. Vector quantities include displacement, velocity and force.

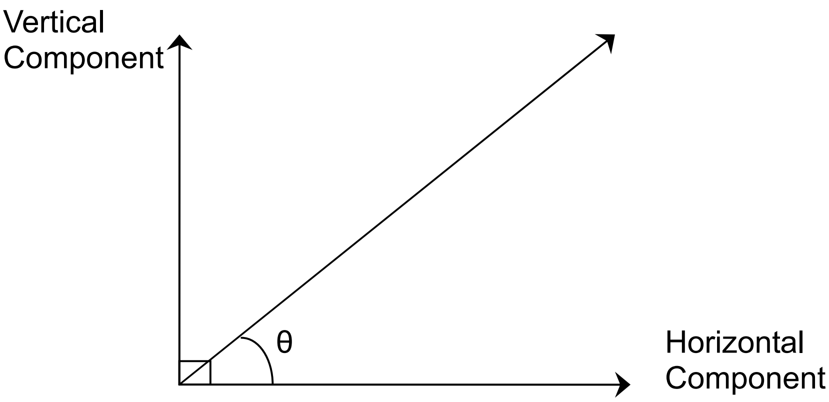
In texts, a vector is represented in bold whilst a scalar is represented in normal type.

Vectors can be added or subtracted graphically by the **parallelogram law**.



When solving vector problems, it is sometimes necessary to split vectors into **components** that are **perpendicular** to each other in order to analyse a problem.

For problems involving an inclined plane for example, resolving parallel and perpendicular to the plane via trigonometry will render each component independent of each other and thus enable them to be analysed separately.



Example:

Which of the following represents a vector quantity?

(a) Distance (b) Kinetic Energy (c) Force (d) Speed

Answer: (c)