Phy 211: General Physics I

Chapter 1 Measurement
Lecture Notes

Observations

- The sciences are ultimately based on observations of the natural (& unnatural) world
- There are 2 types of observations:
- Qualitative
  - Subjective, touchy-feely

  Example: the outside temperature is <u>hot</u> today
- Quantitative
  - Objective, based on a number and a reference scale
  - Quantitative observations are referred to as **<u>measurements</u>**

  Example: the outside temperature is 80^{o}F today
- ***Notes:***
  - *Quantitative observations are only as reliable as the measurement device and the individual(s) performing the measurements*
  - *The accuracy associated with a measurement (or set of measurements) is the often specified as the % Error:*

$$\% \text{ Error} = \frac{|\text{accepted value - measured value}|}{\text{accepted value}} \times 100\%$$

  - *The precision associated with a set of measurements is the often specified as the % Range:*

$$\% \text{ Range} = \frac{\text{Range}}{\text{average value}} \times 100\ \% = \frac{|\text{highest value - lowest value}|}{\text{average value}} \times 100\%$$

  - The standard deviation is similar to ½ the range value for a set of measurements

Errors in Measurement

The error associated with calculated physical quantities, such as the area of a circle, can be estimated by the application of a little calculus:

For a quantity f dependent on measured variables x, y, …, i.e. f(x, y, …):

Error (or uncertainty) = $$df = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial y}dy + \ldots$$

where dx is ½ the range of x, dy is ½ the range of y, etc…

Example 1: Consider a circle with a measured radius(r) of 0.10 m +/- 0.01m

$A_{circle} = \pi(0.10\text{ m})^2 = 0.031\text{ m}^2$

$$\text{Error} \sim dA = \frac{\partial A}{\partial r}dr = \frac{\partial}{\partial r}\left(\pi r^2\right)dr = 2\pi r dr = 0.0063\text{ m}^2$$

$$\text{Relative Error } = \frac{dA}{A} = \frac{2\pi r dr}{\pi r^2} = \frac{2(0.01\text{ m})}{(0.10\text{ m})} = 0.20 \text{ or } 20\%$$

Example 2: Consider a sphere with a measured radius(r) of 0.10 m +/- 0.01m

$V_{sphere} = (4/3)\pi(0.10\text{ m})^3 = 0.0043\text{ m}^2$

$$\text{Error} \sim dV = \frac{\partial V}{\partial r}dr = \frac{\partial}{\partial r}\left(\frac{4}{3}\pi r^3\right)dr = 4\pi r^2 dr = 0.0013\text{ m}^3$$

$$\text{Relative Error } = \frac{dV}{V} = \frac{4\pi r^2 dr}{\frac{4}{3}\pi r^3} = \frac{3(0.01\text{ m})}{(0.10\text{ m})} = 0.30 \text{ or } 30\%$$

Systems of Measurement

- There are several units systems for measurement of physical quantities
- The most common unit systems are the metric and the USCS systems
- For consistency, the l'Systeme Internationale (or SI) was adopted
  - The SI system is a special set of metric units
- International System (SI) base units:

Mass	*Kilogram*	*kg*
Length	*meter*	*m*
Time	*second*	*s*
Temperature	*Kelvin*	*K*
Current	*Ampere*	*A*
Luminous Intensity	*candela*	*cd*
Amount of substance	*mole*	*mol*

- All of the other SI units are derived from these base units

Examples of derived units:

1 Newton = 1 N = 1 kg·m/s² ($1\text{ kg}\cdot\text{m/s}^2$)

1 Joule = 1 J = 1 kg·m²/s² ($1\text{ kg}\cdot\text{m}^2/\text{s}^2$)

1 Coulomb = 1 C = 1 A·s

Common Metric Prefixes

Prefix	Symbol	Meaning	Power of 10
Giga	G	1,000,000,000	10^9
Mega	M	1,000,000	10^6
kilo	k	1,000	10^3
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000,001	10^{-6}
nano	n	0.000,000,001	10^{-9}

Using Metric prefixes:

1 mm = $1\text{x}10^{-3}$ m $\rightarrow$ 35 mm = 35 x 10^{-3} m or 3.5 x 10^{-2} m

1 kg = $1\text{x}10^{3}$ g $\rightarrow$ 12 kg = 12 x 10^{3} g or 1.2 x 10^{4} g

Unit Conversion

In physics, converting units from one unit system to another (especially within the Metric system) can appear daunting at first glance. However, with a little guidance, and a lot of practice, you can develop the necessary skill set to master this process

Example: How is 25.2 miles/hour expressed in m/s?

1. **Eliminate:** *{assign mi units to the denominator and hr units to the numerator of the conversion factor}*

$$25.2\frac{mi}{hr} = \left(\frac{25.2\text{ mi}}{1\text{ hr}}\right)\left(\frac{??}{??\text{ mi}}\right)\left(\frac{??\text{ hr}}{??}\right) = ??\ \frac{\text{m}}{\text{s}}$$

2. **Replace:** *{assign m units to the numerator and s units to the denominator of the conversion factor}*

$$25.2\frac{mi}{hr} = \left(\frac{25.2\text{ mi}}{1\text{ hr}}\right)\left(\frac{??\text{ m}}{??\text{ mi}}\right)\left(\frac{??\text{ hr}}{??\text{ s}}\right) = ??\ \frac{\text{m}}{\text{s}}$$

3. **Relate:** *{assign the corresponding value to its unit, 1 mi = 1609 m & 1 hr = 3600 s}*

$$25.2\frac{mi}{hr} = \left(\frac{25.2\text{ mi}}{1\text{ hr}}\right)\left(\frac{1609\text{ m}}{1\text{ mi}}\right)\left(\frac{1\text{ hr}}{3600\text{ s}}\right) = 11.3\ \frac{\text{m}}{\text{s}}$$

Length, Time & Mass

Length is the 1-D measure of distance.

- Quantities such as area and volume, and their associated units, are ultimately derived from measures of length

  Definition of SI Unit: *The meter is the length of the path traveled by light (in vacuum) during a time interval of 1/299,792,458 s (or roughly 3.33564 ns)*

Examples of units derived from length (in this case radius, r):

1. Area of a circle = $A_{circle} = \pi r^2$ {units are m^2}
2. Volume of a sphere = $V_{sphere} = \frac{4}{3}\pi r^3$ {units are m^3}

Time is the physical quantity that measures either:

1. when did an event take place
2. the duration of the event

Definition of the SI Unit: *The second is the time taken by 9,192,631,770 oscillations of the light emitted by a cesium-133 atom*

Mass is the measure of inertia for a body (or loosely speaking the amount of matter present)

Definition of the SI Unit: *The kilogram is the amount of mass in a platinum-iridium cylinder of 3.9 cm height and diameter.*