General Physics 1

for Sciences and Engineering Faculties

Chapter 1 – Physics and Measurements

Physics

Fundamental Science

- Concerned with the fundamental principles of the Universe
- Foundation of other physical sciences
- Has simplicity of fundamental concepts

Divided into six major areas:

- Classical Mechanics
- Relativity
- Thermodynamics
- Electromagnetism
- Optics
- Quantum Mechanics

Objectives of Physics

To find the limited number of fundamental laws that govern natural phenomena

To use these laws to develop theories that can predict the results of future experiments

Express the laws in the language of mathematics

- Mathematics provides the bridge between theory and experiment.

Theory and Experiments

Should complement each other

When a discrepancy occurs, theory may be modified or new theories formulated.

- A theory may apply to limited conditions.
  - Example: Newtonian Mechanics is confined to objects traveling slowly with respect to the speed of light.
- Try to develop a more general theory

Measurements

Used to describe natural phenomena

Each measurement is associated with a physical quantity

Need defined standards

Characteristics of standards for measurements

- Readily accessible
- Possess some property that can be measured reliably
- Must yield the same results when used by anyone anywhere
- Cannot change with time

Standards of Fundamental Quantities

Standardized systems

- Agreed upon by some authority, usually a governmental body

SI – Systéme International (Main system used in this text)

- Agreed to in 1960 by an international committee

Fundamental Quantities and Their Units

Quantity	SI Unit
Length	meter
Mass	kilogram
Time	second
Temperature	Kelvin
Electric Current	Ampere
Luminous Intensity	Candela
Amount of Substance	mole

- In mechanics, three fundamental quantities are used: Length, Mass, Time
- All other quantities in mechanics can be expressed in terms of the three fundamental quantities.

Derived quantities can be expressed as a mathematical combination of fundamental quantities.

Examples:

- Area
  - A product of two lengths
- Speed
  - A ratio of a length to a time interval
- Density
  - A ratio of mass to volume

Prefixes

Prefixes correspond to powers of 10.

Each prefix has a specific name and has a specific abbreviation.

The prefixes can be used with any basic units.

They are multipliers of the basic unit.

Examples: 1 mm = 10^{-3} m 1 mg = 10^{-3} g

TABLE 1.4 *Prefixes for Powers of Ten*

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{3}	kilo	k
10^{-21}	zepto	z	10^{6}	mega	M
10^{-18}	atto	a	10^{9}	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

Models of Matter

Some Greeks thought matter is made of atoms.
No additional structure

JJ Thomson (1897) found electrons and showed atoms had structure.

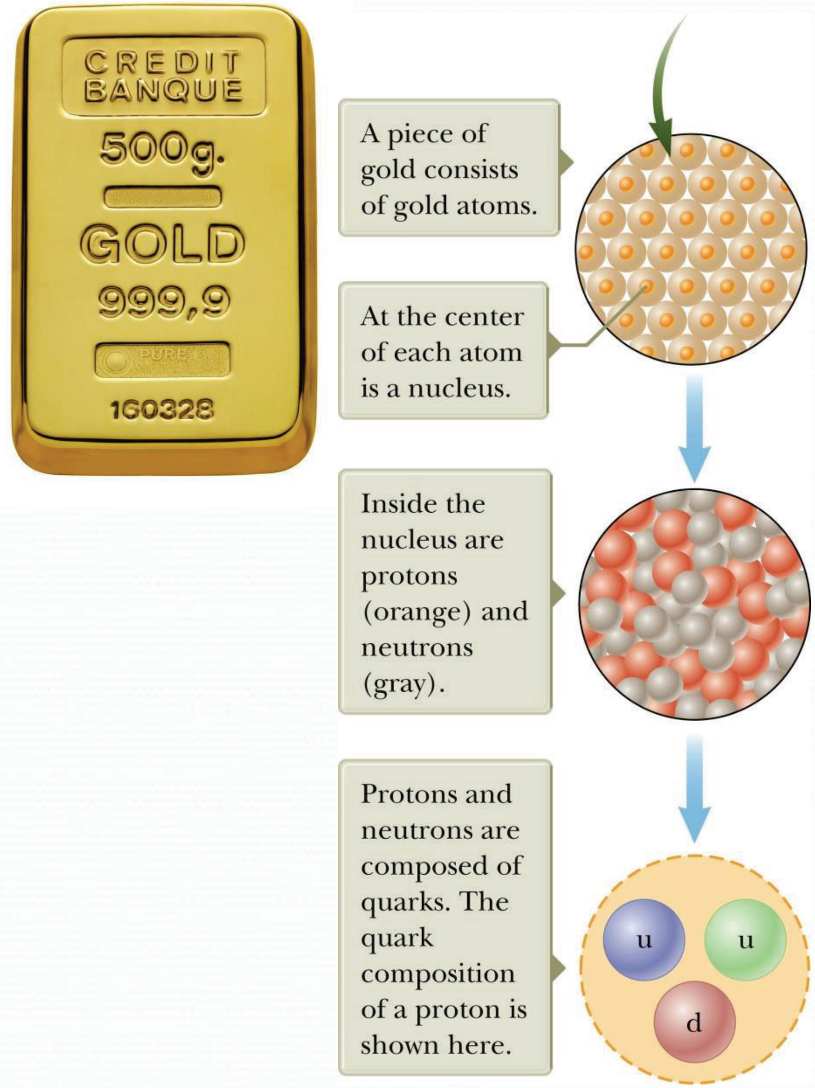
Rutherford (1911) determined a central nucleus surrounded by electrons.

Nucleus has structure, containing protons and neutrons

- Number of protons gives atomic number
- Number of protons and neutrons gives mass number

Protons and neutrons are made up of quarks.
Six Quarks: Up, down, strange, charmed, bottom, top

- Fractional electric charges
  - $+\frac{2}{3}$ of Up, charmed, top
  - $\frac{1}{3}$ of Down, strange, bottom



Basic Quantities and Their Dimension

Dimension has a specific meaning – it denotes the physical nature of a quantity.

Dimensions are often denoted with square brackets.

- Length [L]
- Mass [M]
- Time [T]

Dimensions and Units

Each dimension can have many actual units.

Table 1.5 for the dimensions and units of some derived quantities

TABLE 1.5 *Dimensions and Units of Four Derived Quantities*

Quantity	Area (A)	Volume (V)	Speed (v)	Acceleration (a)
Dimensions	L^2	L^3	L/T	L/T^2
SI units	m^2	m^3	m/s	m/s^2
U.S. customary units	ft^2	ft^3	ft/s	ft/s^2

Dimensions and Units

Quantity	SI Unit		Dimension
velocity	m/s	ms^{-1}	LT^{-1}
acceleration	m/s^2	ms^{-2}	LT^{-2}
force	N $kg\ m/s^2$	$kg\ ms^{-2}$	$M\ LT^{-2}$
energy (or work)	Joule J N m, $kg\ m^2/s^2$	$kg\ m^2s^{-2}$	ML^2T^{-2}
power	Watt W N m/s $kg\ m^2/s^3$	Nms^{-1} $kg\ m^2s^{-3}$	ML^2T^{-3}
pressure (or stress)	Pascal P, N/m^2, $kg/m/s^2$	Nm^{-2} $kg\ m^{-1}s^{-2}$	$ML^{-1}T^{-2}$
density	kg/m^3	$kg\ m^{-3}$	ML^{-3}

Dimensional Analysis

Technique to check the correctness of an equation or to assist in deriving an equation

Dimensions (length, mass, time, combinations) can be treated as algebraic quantities.

- Add, subtract, multiply, divide

Both sides of equation must have the same dimensions.

Any relationship can be correct only if the dimensions on both sides of the equation are the same.

Cannot give numerical factors: this is its limitation

Example: Given the equation: $x = ½\, a t^2$ Check dimensions on each side:

$$L = \frac{L}{\cancel{T^2}} \cdot \cancel{T^2} = L$$

The T^2's cancel, leaving L for the dimensions of each side.

- The equation is dimensionally correct.
- There are no dimensions for the constant.

Dimensional Analysis to Determine a Power Law

Determine powers in a proportionality

- Example: find the exponents in the expression

$$x \propto a^m t^n$$

  - You must have lengths on both sides.
  - Acceleration has dimensions of L/T^2
  - Time has dimensions of T.
  - Analysis gives $x \propto at^2$

Example

Suppose that the acceleration of a particle moving in circle of radius *r* with uniform velocity *v* is proportional to the r^n and v^m. Use the dimensional analysis to determine the power n and m.

Solution

Let us assume *a* is represented in this expression $a = k\, r^n v^m$

Where *k* is the proportionality constant of dimensionless unit.

The right hand side $[a] = \quad = \frac{L}{T^2}$

The left hand side

$$[k\, r^n\, v^m] = L^n \left(\frac{L}{T}\right)^m = \frac{L^{n+m}}{T^m}$$

Therefore

$$\frac{L}{T^2} = \frac{L^{n+m}}{T^m}$$

hence

n+m=1 and m=2

Therefore. n =-1 and the acceleration a is $a = k\, r^{-1}\, v^2$

k=1 $a = \dfrac{v^2}{r}$

Conversion of Units

When units are not consistent, you may need to convert to appropriate ones.

See Appendix A for an extensive list of conversion factors.

Units can be treated like algebraic quantities that can cancel each other out.

Always include units for every quantity, you can carry the units through the entire calculation.

Multiply original value by a ratio equal to one.

Example:

$$15.0\,in = ?\,cm$$

$$15.0\,\cancel{in}\left(\frac{2.54\,cm}{1\,\cancel{in}}\right) = 38.1\,cm$$

- Note the value inside the parentheses is equal to 1, since 1 inch is defined as 2.54 cm.

conversions

Length

$1 \text{ in.} = 2.54 \text{ cm (exact)}$

$1 \text{ m} = 39.37 \text{ in.} = 3.281 \text{ ft}$

$1 \text{ ft} = 0.304\,8 \text{ m}$

$12 \text{ in.} = 1 \text{ ft}$

$3 \text{ ft} = 1 \text{ yd}$

$1 \text{ yd} = 0.914\,4 \text{ m}$

$1 \text{ km} = 0.621 \text{ mi}$

$1 \text{ mi} = 1.609 \text{ km}$

$1 \text{ mi} = 5\,280 \text{ ft}$

$1\ \mu\text{m} = 10^{-6} \text{ m} = 10^{3} \text{ nm}$

$1 \text{ lightyear} = 9.461 \times 10^{15} \text{ m}$

Area

$1 \text{ m}^2 = 10^4 \text{ cm}^2 = 10.76 \text{ ft}^2$

$1 \text{ ft}^2 = 0.092\,9 \text{ m}^2 = 144 \text{ in.}^2$

$1 \text{ in.}^2 = 6.452 \text{ cm}^2$

Volume

$1 \text{ m}^3 = 10^6 \text{ cm}^3 = 6.102 \times 10^4 \text{ in.}^3$

$1 \text{ ft}^3 = 1\,728 \text{ in.}^3 = 2.83 \times 10^{-2} \text{ m}^3$

$1 \text{ L} = 1\,000 \text{ cm}^3 = 1.057\,6 \text{ qt} = 0.035\,3 \text{ ft}^3$

$1 \text{ ft}^3 = 7.481 \text{ gal} = 28.32 \text{ L} = 2.832 \times 10^{-2} \text{ m}^3$

$1 \text{ gal} = 3.786 \text{ L} = 231 \text{ in.}^3$

Mass

$1\,000 \text{ kg} = 1 \text{ t (metric ton)}$

$1 \text{ slug} = 14.59 \text{ kg}$

$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931.5 \text{ MeV}/c^2$

conversions

Force

$1\ \text{N} = 0.224\,8\ \text{lb}$

$1\ \text{lb} = 4.448\ \text{N}$

Velocity

$1\ \text{mi/h} = 1.47\ \text{ft/s} = 0.447\ \text{m/s} = 1.61\ \text{km/h}$

$1\ \text{m/s} = 100\ \text{cm/s} = 3.281\ \text{ft/s}$

$1\ \text{mi/min} = 60\ \text{mi/h} = 88\ \text{ft/s}$

Acceleration

$1\ \text{m/s}^2 = 3.28\ \text{ft/s}^2 = 100\ \text{cm/s}^2$

$1\ \text{ft/s}^2 = 0.304\,8\ \text{m/s}^2 = 30.48\ \text{cm/s}^2$

Pressure

$1\ \text{bar} = 10^5\ \text{N/m}^2 = 14.50\ \text{lb/in.}^2$

$1\ \text{atm} = 760\ \text{mm Hg} = 76.0\ \text{cm Hg}$

$1\ \text{atm} = 14.7\ \text{lb/in.}^2 = 1.013 \times 10^5\ \text{N/m}^2$

$1\ \text{Pa} = 1\ \text{N/m}^2 = 1.45 \times 10^{-4}\ \text{lb/in.}^2$

Time

$1\ \text{yr} = 365\ \text{days} = 3.16 \times 10^7\ \text{s}$

$1\ \text{day} = 24\ \text{h} = 1.44 \times 10^3\ \text{min} = 8.64 \times 10^4\ \text{s}$

Energy

$1\ \text{J} = 0.738\ \text{ft} \cdot \text{lb}$

$1\ \text{cal} = 4.186\ \text{J}$

$1\ \text{Btu} = 252\ \text{cal} = 1.054 \times 10^3\ \text{J}$

$1\ \text{eV} = 1.602 \times 10^{-19}\ \text{J}$

$1\ \text{kWh} = 3.60 \times 10^6\ \text{J}$

Power

$1\ \text{hp} = 550\ \text{ft} \cdot \text{lb/s} = 0.746\ \text{kW}$

$1\ \text{W} = 1\ \text{J/s} = 0.738\ \text{ft} \cdot \text{lb/s}$

$1\ \text{Btu/h} = 0.293\ \text{W}$