



PHYS 111 PHYSICS I (MECHANICS)

5(4-2)

Chapter 1 *Introduction, Measurement, and Estimation*



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Course Book

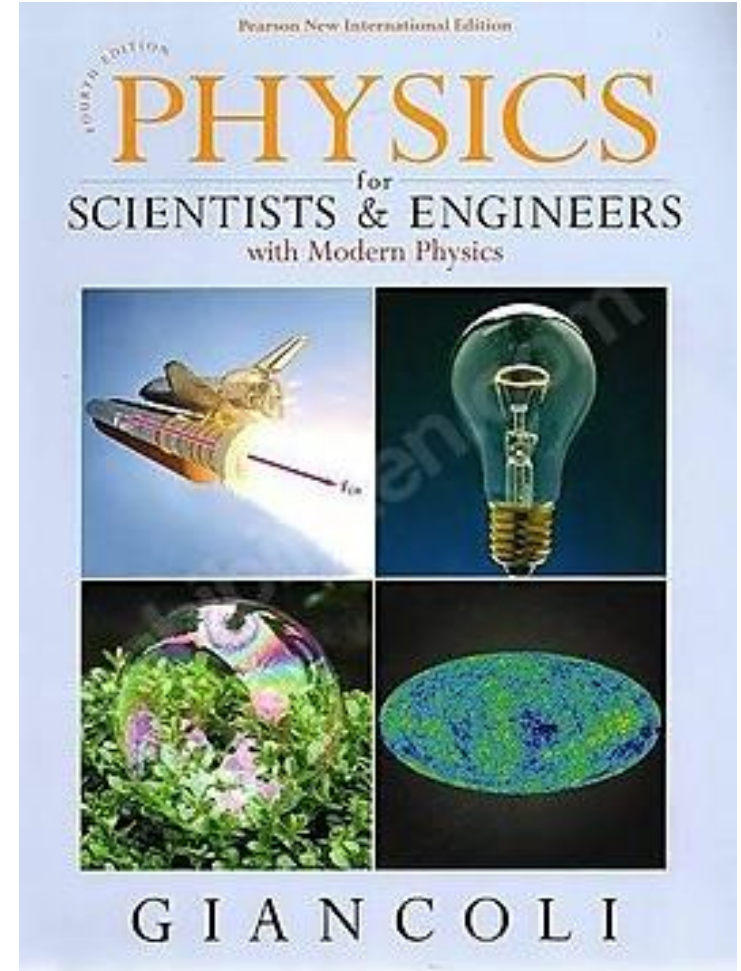
5th Ed.

PHYS111 (Mechanics)

Covers Chapter 1-14

PHYS112 (Electricity and Magnetizm)

Covers Chapter 21-31

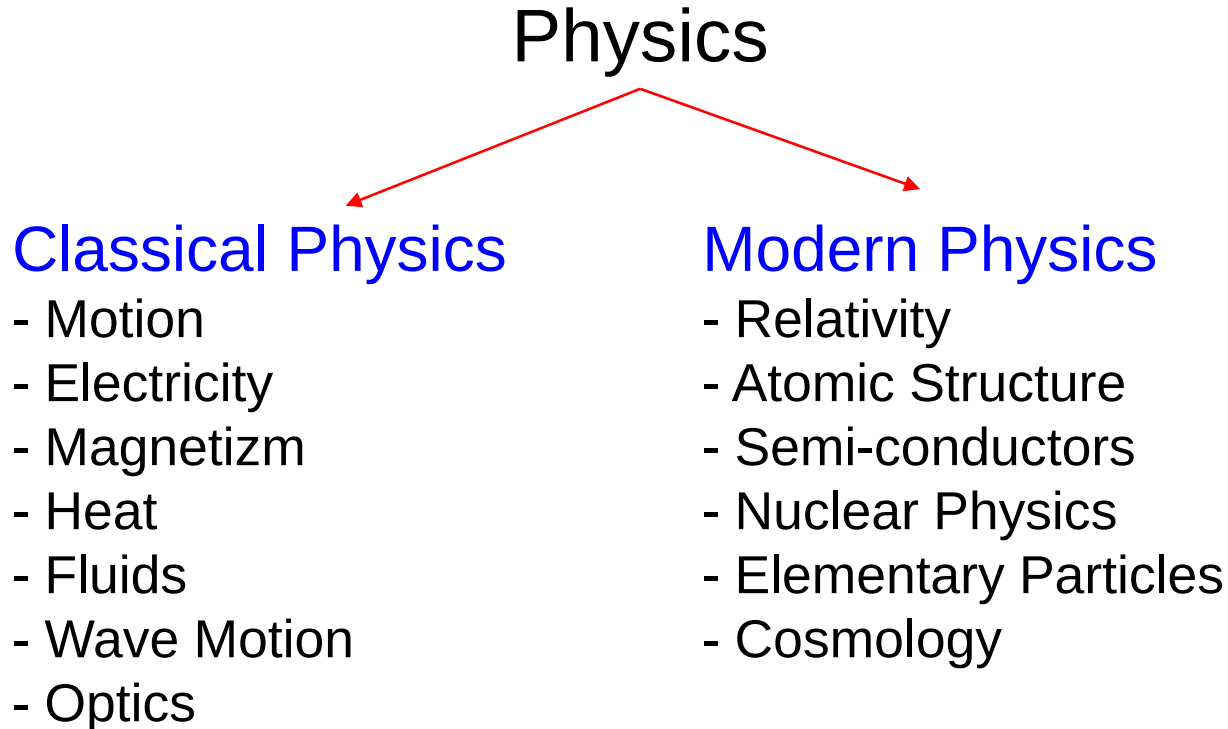


Chapter 1

Introduction, Measurement and Estimation

Physics

Physics is the most basic of the sciences.
It deals with the behavior and structure of matter.

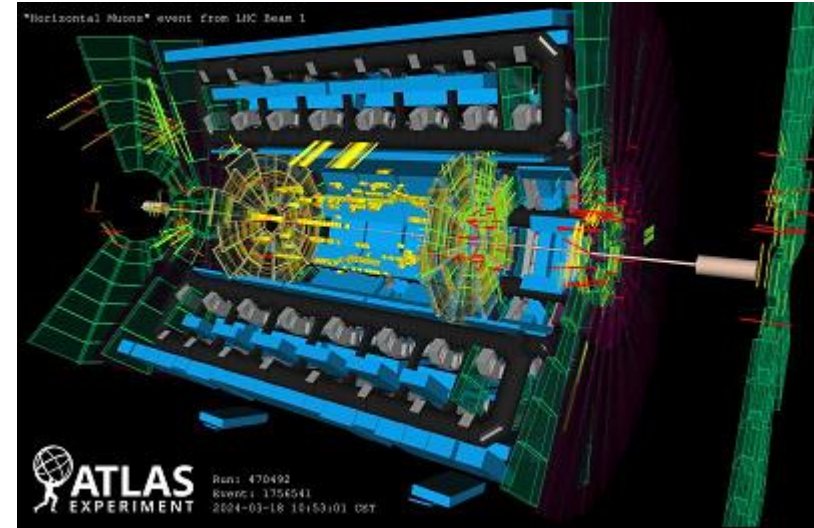


Nature of Science

The principal aim of all sciences is generally considered to be:

the search for order in our observations of the world around us.

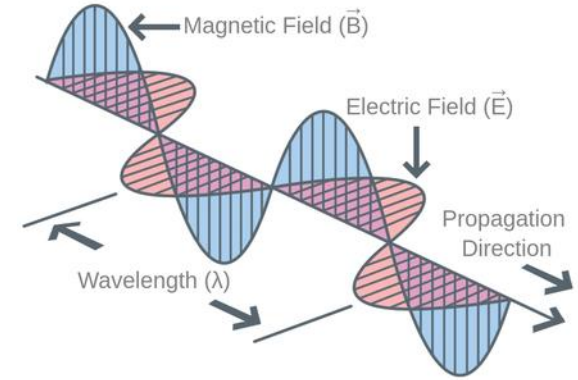
One important aspect of science is observation of events, which includes the design and carrying out of experiments.



Model, Theory and Law

- A **model**, is a kind of analogy or mental image of the phenomena in terms of something we are familiar with.

e.g. Wave model of light



- A **theory** can give quantitatively testable predictions.

e.g. Theory of Special Relativity

$$E = mc^2$$

- A **law** is related to how nature behaves which is not based on theory.

e.g. Conservation of energy

$$F = ma$$

Dimension

- All physical and engineering quantities can be described by a combination of basic quantities such as

Length, Time, Mass, etc.

- These *primary dimensions* can be written as
 $[L]$, $[T]$, $[M]$, etc.

e.g: the speed has the dimension:

$$speed \equiv \frac{length}{time} = \frac{[L]}{[T]} = [LT^{-1}]$$

e.g: the mass density has the dimension:

$$density \equiv \frac{mass}{volume} = \frac{[M]}{[L]^3} = [ML^{-3}]$$

System of Units

- Each primary dimension has a unit.
- There are several systems of units in use today.
 1. **International System (SI) or MKS units**
 2. **CGS units**
 3. **British Gravitational (BG)**
 4. **U.S. Customary units**

e.g: Length can be measured in

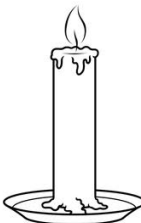
meters, centimeters, yards, inches, etc.

SI Base Units

The International System of Units (SI) defines seven units of measure as a basic set.

TABLE 1–5 SI Base Quantities and Units		
Quantity	Unit	Unit Abbreviation
Length	meter	m
Time	second	s
Mass	kilogram	kg
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

A candle has luminous intensity of approx. 1 candela



Name	Symbol	Definition
Meter	m	<i>The length</i> of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
Kilogram	kg	<i>The mass</i> of the international prototype of the kilogram
Second	s	<i>The duration</i> of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
Ampere	A	The constant <i>electric current</i> which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
Kelvin	K	The fraction 1/273.16 of the <i>thermodynamic temperature</i> of the triple point of water.
Mole	mol	<i>The amount of substance</i> of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12 atom.
Candela	cd	<i>The luminous intensity</i> in a given direction, of a light source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian.

Time

For many years, the second was defined as 1/86 400 of a mean solar day.

The standard second is now defined more precisely in terms of the frequency of radiation emitted by cesium atoms when they pass between two particular states.

One second is defined as the time required for 9,192,631,770 oscillations of this radiation.



TABLE 1–2 Some Typical Time Intervals
(order of magnitude)

Time Interval	Seconds (approximate)
Lifetime of very unstable subatomic particle	10^{-23} s
Lifetime of radioactive elements	10^{-22} s to 10^{28} s
Lifetime of muon	10^{-6} s
Time between human heartbeats	10^0 s (= 1 s)
One day	10^5 s
One year	3×10^7 s
Human life span	2×10^9 s
Length of recorded history	10^{11} s
Humans on Earth	10^{13} s
Age of Earth	10^{17} s
Age of Universe	4×10^{17} s

Length

Original Definition (1790)

The meter was chosen to be one ten-millionth of the distance from the Earth’s equator to either pole.

Latest Definition (1983)

The meter is the length of path traveled by light in vacuum during a time interval 1/299 792 458 of a second.

TABLE 1–1 Some Typical Lengths or Distances
(order of magnitude)

Length (or Distance)	Meters (approximate)
Neutron or proton (diameter)	10^{-15} m
Atom (diameter)	10^{-10} m
Virus [see Fig. 1–8a]	10^{-7} m
Sheet of paper (thickness)	10^{-4} m
Finger width	10^{-2} m
Football field length	10^2 m
Height of Mt. Everest [see Fig. 1–8b]	10^4 m
Earth diameter	10^7 m
Earth to Sun	10^{11} m
Earth to nearest star	10^{16} m
Earth to nearest galaxy	10^{22} m
Earth to farthest galaxy visible	10^{26} m

Mass

The kilogram is the unit of mass in SI; it is equal to the mass of the international prototype of the kilogram. (90% Pt & 10% Ir)



TABLE 1-3 Some Masses

Object	Kilograms (approximate)
Electron	10^{-30} kg
Proton, neutron	10^{-27} kg
DNA molecule	10^{-17} kg
Bacterium	10^{-15} kg
Mosquito	10^{-5} kg
Plum	10^{-1} kg
Human	10^2 kg
Ship	10^8 kg
Earth	6×10^{24} kg
Sun	2×10^{30} kg
Galaxy	10^{41} kg

Derived SI Units

- Relying on the base units, all other units of measurement can be formed.
- For example,
 - the SI derived unit of area is square meter (m^2)
 - density is kilograms per cubic meter (kg/m^3)

Some *named* derived units:

<u>Quantity</u>	<u>Symbol</u>	<u>Dimen.</u>	<u>SI</u>	<u>Deriv.SI</u>
Force	<i>F</i>	$[\text{MLT}^{-2}]$	kg.m/s^2	Newton, N
Energy	<i>E</i>	$[\text{ML}^2\text{T}^{-2}]$	$\text{kg.m}^2/\text{s}^2$	Joule, J
Pressure	<i>P</i>	$[\text{ML}^{-1}\text{T}^{-2}]$	$\text{kg}/\text{m.s}^2$	Pascal, Pa

Name	Symbol	Quantity	Expression in terms of other units	Expression in terms of SI base units
hertz	Hz	frequency	1/s	s^{-1}
radian	rad	angle	m/m	dimensionless
steradian	sr	solid angle	m^2/m^2	dimensionless
newton	N	force, weight	$kg \cdot m/s^2$	$kg \cdot m \cdot s^{-2}$
pascal	Pa	pressure, stress	N/m^2	$kg \cdot m^{-1} \cdot s^{-2}$
joule	J	energy, work, heat	$N \cdot m = C \cdot V = W \cdot s$	$kg \cdot m^2 \cdot s^{-2}$
watt	W	power, radiant flux	$J/s = V \cdot A$	$kg \cdot m^2 \cdot s^{-3}$
coulomb	C	electric charge or quantity of electricity	$s \cdot A$	$s \cdot A$
volt	V	voltage, electrical potential difference, electromotive force	$W/A = J/C$	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
farad	F	electric capacitance	C/V	$kg^{-1} \cdot m^{-2} \cdot s^4 \cdot A^2$
ohm	Ω	electric resistance, impedance, reactance	V/A	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-2}$
siemens	S	electrical conductance	$1/\Omega = A/V$	$kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2$
weber	Wb	magnetic flux	J/A	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-1}$
tesla	T	magnetic field strength, magnetic flux density	$V \cdot s/m^2 = Wb/m^2 = N/(A \cdot m)$	$kg \cdot s^{-2} \cdot A^{-1}$
henry	H	inductance	$V \cdot s/A = Wb/A$	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-2}$
degree Celsius	$^{\circ}C$	temperature relative to 273.15 K	K	K
lumen	lm	luminous flux	$cd \cdot sr$	cd
lux	lx	illuminance	lm/m^2	$m^{-2} \cdot cd$
becquerel	Bq	radioactivity (decays per unit time)	1/s	s^{-1}
gray	Gy	absorbed dose (of ionizing radiation)	J/kg	$m^2 \cdot s^{-2}$
sievert	Sv	equivalent dose (of ionizing radiation)	J/kg	$m^2 \cdot s^{-2}$
katal	kat	catalytic activity	mol/s	$s^{-1} \cdot mol$

Scaling Prefixes of SI Units

<u>Multiplication Factor</u>	<u>Prefix</u>	<u>SI symbol</u>
1,000,000,000,000,000,000,000,000 = 10^{24}	yotta	Y
1,000,000,000,000,000,000,000 = 10^{21}	zetta	Z
1,000,000,000,000,000,000 = 10^{18}	exa	E
1,000,000,000,000,000 = 10^{15}	peta	P
1,000,000,000,000 = 10^{12}	tera	T
1,000,000,000 = 10^9	giga	G
1,000,000 = 10^6	mega	M
1000 = 10^3	kilo	k
100 = 10^2	hecto	h
10 = 10^1	deka	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000,001 = 10^{-6}	micro	μ
0.000,000,001 = 10^{-9}	nano	n
0.000,000,000,001 = 10^{-12}	pico	p
0.000,000,000,000,001 = 10^{-15}	femto	f
0.000,000,000,000,000,001 = 10^{-18}	atto	a
0.000,000,000,000,000,000,001 = 10^{-21}	zepto	z
0.000,000,000,000,000,000,000,001 = 10^{-24}	yocto	y

Examples:

$$1 \text{ GHz} = 10^9 \text{ Hz}$$

$$1 \text{ MW} = 10^6 \text{ W}$$

$$1 \text{ kPa} = 10^3 \text{ Pa}$$

$$1 \text{ mm} = 10^{-3} \text{ m}$$

$$1 \text{ }\mu\text{F} = 10^{-6} \text{ F}$$

Measurement

Measurement is the assignment of numbers to objects or events.

All measurements consist of three parts:

- Magnitude (numerical value)
- Uncertainty (measurement error)
- Dimension (SI units)

For example electron mass:

$$m = 9.1093837015 \pm 0.0000000028 \times 10^{-31} \text{ kg}$$

Uncertainty

When performing experiments, we should be concerned not only with the measured value but also with its uncertainty (error).

We can never measure anything absolutely accurately!
any measured quantity has an associated error

For example, consider a measurement of the gravitational acceleration due to the gravity is obtained as:

$$g = 9.77 \pm 0.14 \text{ m/s}^2$$

Suppose we are asked to measure the length of a match. Our experimental error depends on the method of measurement.

<u>Method</u>	<u>Typical error</u>
Cheap ruler	0.5 mm
Calipers	0.05 mm
Travelling microscope	0.005 mm
Interferometer	0.00001 mm



Converting Units

Often, we are given a quantity in one set of units, but we want it expressed in another set of units.

Ex1: we measure that a shelf is 21.5 inches wide

$$1 \text{ in} = 2.54 \text{ cm} \rightarrow 1 = 2.54 \text{ cm} / \text{in}$$

$$21.5 \text{ inches} = (21.5 \cancel{\text{ in.}}) \times \left(2.54 \frac{\text{cm}}{\cancel{\text{ in.}}} \right) = 54.6 \text{ cm.}$$

Ex2: We measure speed of a car as $v = 108 \text{ km/h}$

$$v = (108 \text{ km/h})(1 \text{ h} / 3600 \text{ s})(1000 \text{ m} / 1 \text{ km}) = 30 \text{ m} / \text{s}$$

Significant Figures

The number of reliably known digits in a number is called the number of significant figures.

23.21 cm (4 significant figures)

0.062 cm (2 significant figures)

Calculations:

$$10.22 + 11.30 = 21.42 \quad 4 \text{ s.f.}$$

$$10.22 + 11.3 = 21.4 \quad 3 \text{ s.f.}$$

$$11.3 * 6.8 = 77 \quad 2 \text{ s.f.} \quad (\text{normally } 76.84)$$

$$97 / 92 = 1.1 \quad 2 \text{ s.f.} \quad (\text{normally } 1.05)$$

Significant Figures

Number	Number of s.f.	Reason	Scientific notation
504	3	in an integer all digits count (if last digit is not zero)	5.04×10^2
608 000	3	zeros at the end of an integer do not count	6.08×10^5
200	1	zeros at the end of an integer do not count	2×10^2
0.000 305	3	zeros in front do not count	3.05×10^{-4}
0.005 900	4	zeros at the end of a decimal count, those in front do not	5.900×10^{-3}

Order of Magnitude: Rapid Estimating

We are sometimes interested only in an approximate value for a quantity. This might be because an accurate calculation would take long time.

Ex: Estimate the thickness of a page of a book.

$$\frac{1.5 \text{ cm}}{250 \text{ sheets}} \approx 6 \times 10^{-3} \text{ cm} = 6 \times 10^{-2} \text{ mm} = 60 \text{ } \mu\text{m}$$

Solved Problems

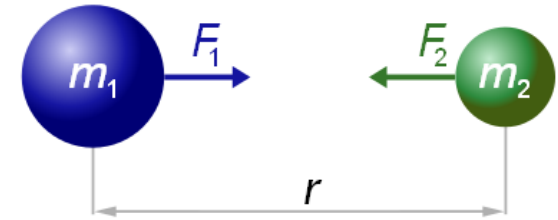
P1

How many seconds are in a year?

P2

Universal gravitational says that every particle in the universe attracts every other particle with a force

$$F = G \frac{m_1 m_2}{r^2}$$



$$F_1 = F_2 = F$$

Determine the SI unit of Gravitational constant G .

m_1, m_2 are masses of particles

r is distance between them

G is Universal Gravitational Constant

$$G = 6.673 \times 10^{-11} \text{ N.m}^2/\text{kg}^2$$

P3

The smallest meaningful measure of length is called the **Planck Length**.

$$\lambda_p = \sqrt{\frac{Gh}{c}}$$

Show that the dimension of λ_p is [L].

P4

Deriving an equation for a period of a pendulum. Find x , y and z .

$$T = km^x g^y L^z$$