Chapter 1
Introduction

What is physics?

Physics deals with
the behavior and composition
of *matter* and its interactions
at the most fundamental level.

Curiosity to understand and describe the nature

Key contents:

* Fundamentals
* Units
* Coordinate systems

Classical physics: (1600 - 1900)

Classical Mechanics

Thermodynamics

Electromagnetism

Modern physics: (1900 – now)

Special Relativity

Quantum Mechanics

(General Relativity)

The basic interactions

TABLE 1.1 THE BASIC INTERACTIONS

Interaction	Relative Strength	Range
Strong	1	10^{-15} m
Electromagnetic	10^{-2}	Infinite
Weak	10^{-6}	10^{-17} m
Gravitational	10^{-38}	Infinite

The elementary particles

$s = 0$ $\quad$ *Higgs boson* $\quad H^0$

fermions (half-integer spin)
bosons (integer spin)

$$s = \frac{1}{2} \quad \begin{array}{ll} lepton & \begin{array}{c} e, m, t \\ n_e, n_m, n_t \end{array} \\ quark & \begin{array}{c} u, s, t \\ d, c, b \end{array} \end{array} \quad \| \quad Þ \quad hadron \quad \begin{array}{l} baryon\,(q, q, q) \\ meson\,(q, \bar{q}) \end{array}$$

$$s = 1 \quad gauge\ boson \quad \begin{array}{c} g \\ W^{\pm}, Z^0 \\ gluons \end{array}$$

$$s = 2 \qquad graviton(?)$$

Concepts, Models, and Theories

- Concepts: A concept is an idea or a physical quantity that is used to analyze natural phenomena. (operational definitions)
- Laws and Principles: A law is a mathematical relationship among some physical quantities; a principle is a very general statement about how nature operates.
- Models: A model is a convenient analog or representation of a physical system and can be useful even if it is incomplete or incorrect.
- Theories: A theory uses combined principles, a model, and initial assumptions to deduce specific consequences or laws (always tentative).

Units: Système International

- The value of any physical quantity must be expressed in terms of some standard or **unit**.
- MKS (SI) unit system: All physical quantities can be expressed in terms of three fundamental quantities: Length (m), mass(kg), and time (s).
- The Gaussian (cgs) unit system is also often used.

Time

Repeated events can be used as a possible time interval standard, such as Earth rotation.

Atomic clocks give very precise time measurements.

In 1967 the standard second was defined to be the time taken by 9 192 631 770 oscillations of the light emitted (at a certain atomic transition) by cesium-133 atom.
(That is, the frequency of that specific electromagnetic wave is defined to be 9 192 631 770 Hz.)

Even more precise clocks are being developed.

Time

Table 1-4

Some Approximate Time Intervals

Measurement	Time Interval in Seconds
Lifetime of the proton (predicted)	3×10^{40}
Age of the universe	5×10^{17}
Age of the pyramid of Cheops	1×10^{11}
Human life expectancy	2×10^{9}
Length of a day	9×10^{4}
Time between human heartbeats	8×10^{-1}
Lifetime of the muon	2×10^{-6}
Shortest lab light pulse	1×10^{-16}
Lifetime of the most unstable particle	1×10^{-23}
The Planck time[a]	1×10^{-43}

[a]This is the earliest time after the big bang at which the laws of physics as we know them can be applied.

Length

Redefining the meter:

In 1792 the unit of length, the meter, was defined as one ten-millionth of the distance from the north pole to the equator.

Later, the meter was defined as the distance between two finely engraved lines near the ends of a standard platinum-iridium bar, the standard meter bar. This bar is placed in the International Bureau of Weights and Measures near Paris, France.

In 1960, the meter was defined to be 1 650 763.73 wavelengths of a particular orange-red light emitted by krypton-86 in a discharge tube that can be set anywhere in the world.

In 1983, the meter was defined as the length of the path traveled by light in a vacuum during the time interval of 1/299 792 458 of a second. The speed of light is then exactly 299 792 458 m/s.

Some examples of lengths

Table 1-3

Some Approximate Lengths

Measurement	Length in Meters
Distance to the first galaxies formed	2×10^{26}
Distance to the Andromeda galaxy	2×10^{22}
Distance to the nearby star Proxima Centauri	4×10^{16}
Distance to Pluto	6×10^{12}
Radius of Earth	6×10^{6}
Height of Mt. Everest	9×10^{3}
Thickness of this page	1×10^{-4}
Length of a typical virus	1×10^{-8}
Radius of a hydrogen atom	5×10^{-11}
Radius of a proton	1×10^{-15}

Mass

A platinum-iridium cylinder, kept at the International Bureau of Weights and Measures near Paris, France, has the standard mass of 1 kg.

(since 1889)

Another unit of mass is used for atomic mass measurements. Carbon-12 atom is defined to have a mass of 12 atomic mass units (amu, or simply u).

$1\ u = 1.660\ 539\ 040(20) \times 10^{-27}$ kg

The definition of the mass unit, the kilogram, looks 'out dated'.

Table 1-5

Some Approximate Masses

Object	Mass in Kilograms
Known universe	1×10^{53}
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}

ALL CHANGE

Under the revised SI system, every unit will be defined in relation to a constant, whose value will become fixed. Many of the units will be defined in relation to each other: for example, definition of the kilogram requires Planck's constant, and definitions of the second and metre.

→ Dependency

SECOND (s)

Measures: Time
Requires: Hyperfine-transition frequency of the caesium-133 atom
Definition: Duration of 9,192,631,770 cycles of the radiation corresponding to the transition between two hyperfine levels of caesium-133

That is, to define the Planck constant to be exactly
$6.626\ 070\ 15 \times 10^{-34}$ kg m^2 s^{-1} .

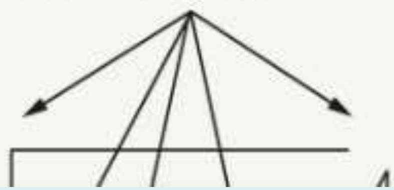
METRE (m)

Measures: Length
Requires: Speed of light
Definition: Length of the path travelled by light in a vacuum in 1/299,792,458 seconds

KILOGRAM (kg)

Measures: Mass
Requires: Planck's constant
Definition: One kilogram is Planck's constant divided by $6.626\,070\,15 \times 10^{-34}$ $\cancel{m^{-2}}s$

m^2 s^{-1}



Change of the SI unit definition:

Voted in General Conference on Weights and Measure in Versailles, France, on Nov 16, 2018;
Effective from May 20, 2019. (Nature, Nov 16, 2018; doi: 10.1038/d41586-018-07424-8)

Units: Derived Units

DERIVED UNITS WITH SPECIAL NAMES

Quantity	Derived Unit	Name
Activity	1 decay/s	Bequerel (Bq)
Capacitance	C/V	farad (F)
Charge	A.s	coulomb (C)
Electric Potential; EMF	J/C	volt (V)
Energy, work	N.m	joule (J)
Force	$kg.m/s^2$	newton (N)
Frequency	l/s	hertz (Hz)
Inductance	V.s/A	henry (H)
Magnetic flux density	Wb/m^2	tesla (T)
Magnetic flux	V.s	weber (Wb)
Power	J/s	watt (W)
Pressure	N/m^2	pascal (Pa)
Resistance	V/A	ohm (Ω)

Units: Conversion of Units

$$25\ \frac{km}{h} = \left(\frac{25\ km}{h}\right)\left(\frac{1000\ m}{1\ km}\right)\left(\frac{1\ h}{3600\ s}\right)$$

$$\left(= 6.9444\ldots\frac{m}{s}\right)$$

$$\approx 6.9\,\frac{m}{s}$$

Power of Ten Notation and Significant Figures

Scientific notation uses the power of 10.

Example:

3 560 000 000 m = 3.56×10^9 m.

Sometimes special names are used to describe very large or very small quantities.

For example,

2.35×10^{-9} s = 2.35 nanoseconds (ns)

Numerical values obtained from the measurement always have some uncertainty.

Significant figures indicate the precision of data.

Power of Ten Notation and Significant Figures

Table 1-2

Prefixes for SI Units

Factor	Prefix[a]	Symbol	Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y	10^{-1}	deci-	d
10^{21}	zetta-	Z	$\mathbf{10^{-2}}$	**centi-**	**c**
10^{18}	exa-	E	$\mathbf{10^{-3}}$	**milli-**	**m**
10^{15}	peta-	P	$\mathbf{10^{-6}}$	**micro-**	$\boldsymbol{\mu}$
10^{12}	tera-	T	$\mathbf{10^{-9}}$	**nano-**	**n**
$\mathbf{10^{9}}$	**giga-**	**G**	$\mathbf{10^{-12}}$	**pico-**	**p**
$\mathbf{10^{6}}$	**mega-**	**M**	10^{-15}	femto-	f
$\mathbf{10^{3}}$	**kilo-**	**k**	10^{-18}	atto-	a
10^{2}	hecto-	h	10^{-21}	zepto-	z
10^{1}	deka-	da	10^{-24}	yocto-	y

[a]The most frequently used prefixes are shown in bold type.

Dimensional Analysis

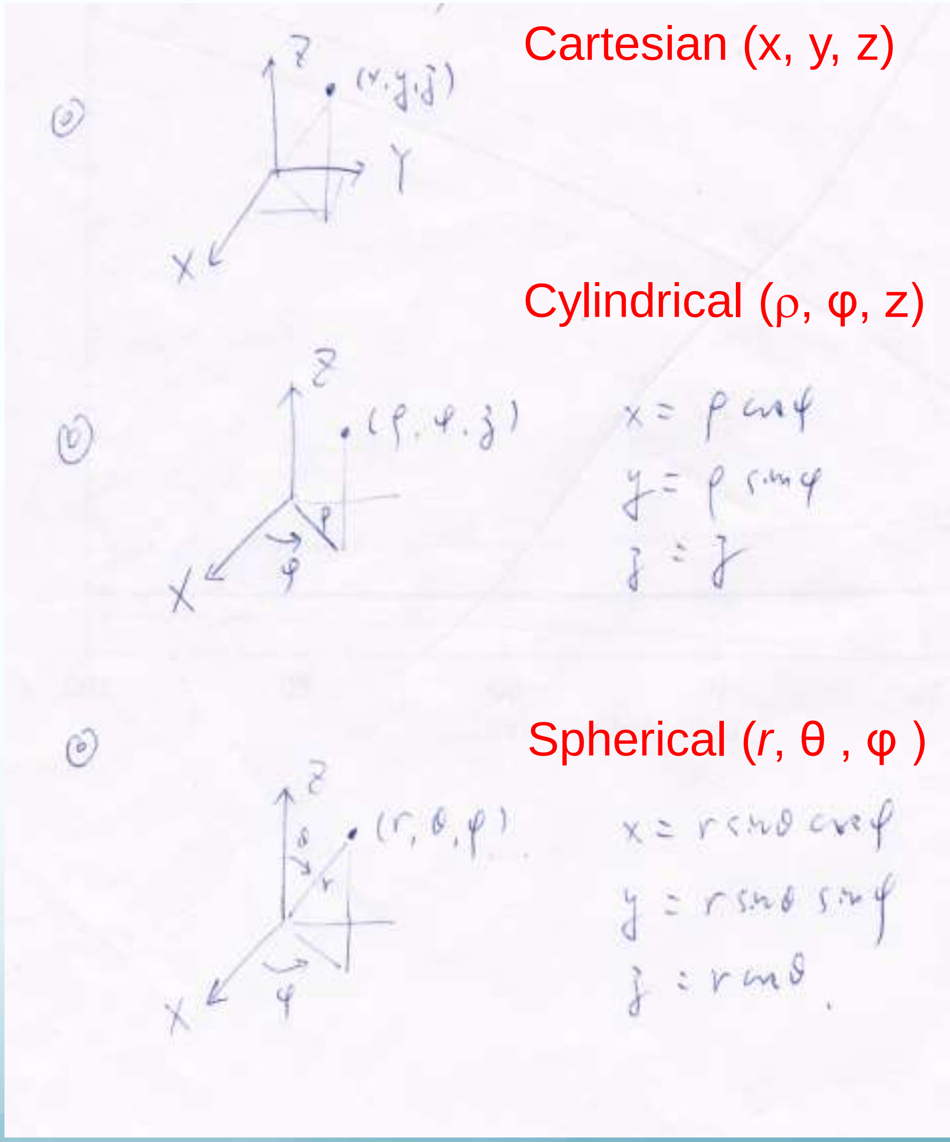
- Each derived unit in mechanics can be reduced to factors of the base units mass (M), length (L), and time (T).
- If one ignores the unit system, that is, whether it is SI or British, then the factors are called **dimension**.
- An equation must be dimensionally consistent. It provides a quick check. One can also use that to infer possible relations.
- One example: the period of a pendulum

$$P = k\, m^x\, l^y\, g^z \longrightarrow T = M^x\, L^y \left(\frac{L}{T^2}\right)^z \longrightarrow x = 0, y = +\frac{1}{2}, z = -\frac{1}{2}$$

$$P = k\sqrt{\frac{l}{g}}$$

Reference Frames and Coordinate System

- The position of a body has meaning only in relation to a frame of reference, which is something physical, such as a tabletop, a room, a ship, or the earth itself.
- The position is specified with respected to a coordinate system that consists of a set of axes, each of which specifies a direction in space.
- Three commonly employed coordinate systems are shown in the right.



Key contents:

* Fundamentals
* Units
* Coordinate systems

Standard Abbreviations for Units

STANDARD ABBREVIATIONS FOR UNITS

Ampere	A	Inch	in.
Angstrom	Å	Joule	J
Atomic mass unit	u	Kelvin	K
Atmosphere	atm	Kilocalorie	kcal (Cal)
British thermal unit	Btu	kilogram	kg
Coulomb	C	Pound	lb
Degree Celsius	°C	Meter	m
Electronvolt	eV	Minute	min
Degree Fahrenheit	°F	Mole	mol
Farad	F	Newton	N
Foot	ft	Ohm	Ω
Gauss	G	Pascal	Pa
Gram	g	Second	s
Henry	H	Tesla	T
Hour	h	Volt	V
Horsepower	hp	Watt	W
Hertz	Hz	Weber	Wb

The Greek Alphabet

THE GREEK ALPHABET

Alpha	Α	α	Iota	Ι	ι	Rho	Ρ	ρ
Beta	Β	β	Kappa	Κ	κ	Sigma	Σ	σ
Gamma	Γ	γ	Lambda	Λ	λ	Tau	Τ	τ
Delta	Δ	δ	Mu	Μ	μ	Upsilon	Υ	υ
Epsilon	Ε	ε	Nu	Ν	ν	Phi	Φ	ϕ
Zeta	Ζ	ζ	Xi	Ξ	ξ	Chi	Χ	χ
Eta	Η	η	Omicron	Ο	ο	Psi	Ψ	ψ
Theta	Θ	θ	Pi	Π	π	Omega	Ω	ω