Physics and Medicine

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DIMES

Introduction

Physics & Medicine

- The functioning of biological systems is based on the principles of Physics and Chemistry.

$$\text{Physics} \Leftrightarrow \text{Physiology.}$$

- Physics enters clinical practice through several **technologies** and **devices**:

Diagnosis and Therapy

- Physics is a basic discipline, propaedeutic to any other scientific discipline;
- It is useful for training, as it is the reference model for the **scientific method**.

Physics $\Leftrightarrow$ Physiology

Kinematics-Mechanics	Musculoskeletal System
	Molecular Engines
	Molecular Switches
Gas/Fluid Physics	Breathing
Diffusion laws	semipermeable membranes
Surface tension	respiratory system
Fluid Mechanics	Blood Circulation
Osmotic pressure	renal function, filtration
Thermodynamics	Metabolism
Electricity Electricity	Nerve Conduction
	Muscle Contraction
Optics (eye) Acoustics (ear)	sense organs
Atomic Physics, Biophysics	Biochemical and Molecular Processes

Physics in clinics, diagnostics and therapy

- Laboratory analysis (sedimentation, centrifugation, electrophoresis)
- Radiological techniques: X-ray, Computerized Axial Tomography (CT), Positron emission tomography (PET), Single photon computed tomography (SPECT).
- Diagnostic and therapeutic techniques based on electromagnetic fields: electroencephalography (EEG), electrocardiography (ECG), defibrillator.
- Therapeutic applications of non-ionizing radiation: Laser, ultraviolet rays, magnetotherapy.

Physics in clinics, diagnostics and therapy

- “Imaging” techniques: microscopy, fluoroscopy, mammography, absorbimetry and angiography.
- Diagnostic techniques based on magnetic resonance imaging: Nuclear magnetic resonance (NMR), functional magnetic resonance imaging (FMRi).
- Ultrasound: Ultrasound Techniques for Imaging and Fluximetry (Eco-Doppler)
- Radiotherapy: X, Gamma, and hadrontal sources

Many of the latest diagnostic techniques (brain MRi, molecular-level microscopy, lab-on-chip) have entered common medical practice (or at least in medical research) despite being based on very advanced physics (Quantum Mechanics, Microfluidics).

Interaction between Physics, Biology and Medicine is not a negligible aspect, in the next few years there will be a strengthening of this union in various fields. (personalized medicine, transcriptomics, nanomedicine, bacterial and viral ecology, immunology, neuroscience, evolutionary biology).

Physical quantities

Physical quantity

- *physical quantities*: measurable, objective and repeatable quantities, to link the abstract concepts with the observed reality.
- This link is given by the operational definition which indicates how the quantity in question should be measured.
- The operational definition must necessarily indicate a practical or experimental method by which the result is achieved (for example, comparison with an appropriate standard).
- Some definitions, such as length, could be given in a completely theoretical way (spatial extension), but this does not constitute an operative definition.

Physical quantity

- *fundamental*: (e.g. space, time, mass, temperature)
- *derived*, obtained as a function of fundamental quantities (speed, energy, magnetic field flux).

Every physical quantity is characterized by a specific *dimensionality*, given by the combination of fundamental quantities that compose it.

Only two physical quantities of the same species (homogeneous) can be compared to each other and therefore measured

Fundamental Quantities of the I.S.

Systems that assume certain quantities as fundamental and which express, compared to those, the others as derivatives. International System (IS, or M.K.S.):

Physical size	Symbol	SI unit name	SI symbol
Length	L	meter	m
Mass	M	kilogram	kg
Time	t	second	s
Electricity	I	ampere	A
Temperature	T	kelvin	K
Quantity of substance	n	mole	mol
Luminous intensity	I_v	candela	cd

Powers: intervals of 10^3

Power	Prefix	Symbol
10^{15}	Peta	P
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

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Measure

- Direct measurement: comparison with another quantity of the same species (unit of measure) and obtain the number (integer or decimal) which expresses how many times the unit of measure (or a part of it) is contained in the given size (es length).
- Indirect measurement: the magnitude of interest is in mathematical relation with that actually measured
  (eg pressure, temperature, metabolism)

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Measurement error

- Each measure is affected by a **error**, related to the sensitivity of the instrument, random errors and systematic errors.
- For example, a length is expressed by a number that expresses its relation to another socket as a unit of measurement (meters or centimeters) ± an error (absolute or relative)
- Absolute error: deviation from the "true measure" $\Delta x = x - x_m$
- Relative error: ratio between absolute error and "true measure" $E_{rel} = \frac{\Delta x}{x_m}$, possibly expressed as a percentage

es. l = 34.5m ± 0.2 m   l = 34.5m ± 0.2 %

Fundamental quantities IS

- **meter**: distance traveled by light in vacuum over a period of 1/299 792 458 s.
- **kilogram** mass of a cylinder with a height and diameter of 0.039 m of a platinum-iridium alloy deposited at the International Bureau of Weights and Measures
- **second** duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels, from (F = 4, MF = 0) to (F = 3, MF = 0), of the fundamental state of the cesium-133 atom.
- **ampere** intensity of electrical current that, if maintained in two parallel linear conductors, of infinite length and negligible cross section, placed one meter away from each other in the vacuum, produces between them a force equal to 2×10^{-7} newton per meter of length.

Fundamental quantities IS

- I **kelvin** 1/273.16 of the thermodynamic temperature of the triple point of water.
- **mole** amount of substance of a system that contains a number of interacting units equal to the number of atoms present in 12 grams of carbon 12 ($N_A = 6.02 \cdot 10^{23}$).
- **candle** light intensity, in a given direction, of a source emitting a monochromatic radiation of frequency equal to 540×10^{12} hertz and of radiant intensity in that direction $w/$ 683 watt per steradian.

Some lengths

Length	Equivalence in meters
Distance Earth - Andromeda M31	2×10^{22}
Diameter of the milky way	8×10^{20}
Distance Earth - Proxima Centauri	4×10^{16}
Distance Earth - Sun	1.5×10^{11}
Earth radius (average)	6.37×10^{6}
Thickness of paper	1×10^{-4}
Diameter of a red blood cell	8×10^{-6}
Diameter of a virus	1×10^{-7}
Diameter of a ionic channel	1×10^{-9}
Diameter of an oxygen atom	1×10^{-10}
Diameter of a proton	2×10^{-15}
Classical radius of the electron	2×10^{-22}

Times

Time interval	seconds
Average life of an unstable particle	10^{-23}
Average life of a radioactive particle	$10^{-22} - 10^{28}$
Time for light to travel $1m$	0.3×10^{-8}
Cellular action potential propagation	3×10^{-3}
Hearth beat	1×10^{0}
One day	1×10^{5}
One year	3×10^{7}
Average human lifespan	2×10^{9}
Humans on the planet	1×10^{14}
Age of Earth	1×10^{17}
Age of Universe	1×10^{18}

Masses

Object	kilograms
Electron	10^{-30}
Proton, Neutron	10^{-27}
Molecole di DNA	10^{-17}
Bacteria	10^{-15}
Fly	10^{-5}
Human being	10^{2}
Earth	6×10^{24}
Sun	2×10^{30}
Galaxy	1×10^{41}

Derived quantities

- Volume=$L \times L \times L = m^3$
- Speed = space/time $\Rightarrow v = m/sec$
- Density =mass/volume $\Rightarrow \rho = kg/m^3$

Homogenetity principle of physical equations

- Physical laws are in general algebraic relationships between a quantity and a combination of other quantities.
- example: direct or inverse proportionality relationships. Equality is introduced through a proportionality constant that depends on the measurement system adopted.

$$y = \frac{h}{x} \qquad\qquad y = h \cdot x$$

- **Principle of homogeneity**: the terms of an equation must have the same units of measurement.

$$F = G\frac{m_1 m_2}{r^2} \Rightarrow G = \frac{Fr^2}{m_1 m_2} \Rightarrow [G] = \frac{Nm^2}{kg^2}$$

Physical constants

Constants	Symbol	Value	Unit
Light speed in vacuum	c	3×10^8	ms^{-1}
Electron charge	e	1.6×10^{-19}	C
Electron mass	m	9.1×10^{-31}	Kg
Proton mass	M	1.67×10^{-27}	Kg
Planck's constant	h	6.6×10^{-34}	J·s
Avogadro number	N_0	6.02×10^{23}	$mole^{-1}$
Perfect gas	R	8.3	$J \cdot K^{-1} mole^{-1}$
Boltzmann	k=R/N_0	1.38×10^{-23}	JK^{-1}
Faraday	F=$N_0 e$	96487	$C \cdot mole^{-1}$
Dielectric constant in vacuum	ε_0	8.86×10^{-12}	$C^2 N^{-1} m^{-2}$
Gravivational	G	6.67×10^{-11}	$N \cdot m^2 kg^{-2}$
Magnetic permeability in vacuum	μ_0	1.25×10^{-6}	$kg \cdot m\ C^{-2}$
Stefan-Boltzmann	σ	5.67×10^{-8}	$W \cdot m^{-2} \cdot K^{-4}$
Wien	k_w	2.897×10^{-3}	m· K
Mechanical equivalent	J	4.18	joule· $caloria^{-1}$