Lecture 1: Introduction into physics

Basic info:

1. Organisation of the term (semester) and evaluation of the subject, all lectures on the website www.kaeg.sk, with each lecture also a small vocabulary will be given (*like Mathematics*).
2. Evaluation of the subject – 100% final examination (few definitions and solution of exercises)

   (*like Mathematics*).
3. Basic literature + lectures + internet sources

   (Feynman lectures on physics,

   Physics - free and fun, wiki, …).

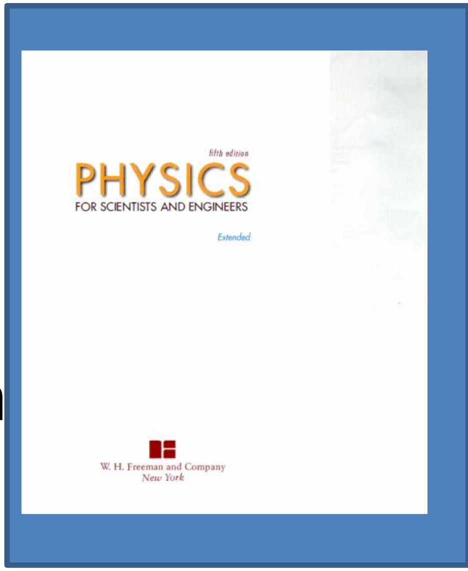
Lecture 1: Introduction into physics

Basic literature:

- "official sources":

Tipler P.A. and Mosca G., 2014 :

Physics for scientists and engineers. Freeman and Co, New York



Schiller Ch., 2016:

Motion Mountain, The adventure of physics – vol. I – VI.

(free download under „Physics - free and fun")

- lectures from this class (www.kaeg.sk)

We also recommend a Slovak text-book for terminology:

Zemanová A., 2014: Anglický jazyk pre študentov FMFI UK, Fyzika, UK v Bratislave

Lecture 1: Introduction into physics

Content:

- introduction into physics
- branches in physics
- basic forces in physics (nature)
- basic units (SI system)
- physical quantities vs. units
- formalism: calculus, scalars, vectors, tensors
- problem solving strategy
- something from the early history of physics (classical mechanics)

Introduction into physics

Physics is the natural science that involves the study of **matter and its motion through space and time**, along with related concepts such as energy and force.

It is one of the most fundamental scientific disciplines, the main goal of physics is to understand how the universe behaves.

The word physics has been derived from the from ancient Greek: φυσική = phusiké , which means the **knowledge of nature**.

Comment: But what is Biology? (Bios-life, logos- the study of). So biology is the knowledge of life.

Introduction into physics

Physics – two main branches:

Classical physics:

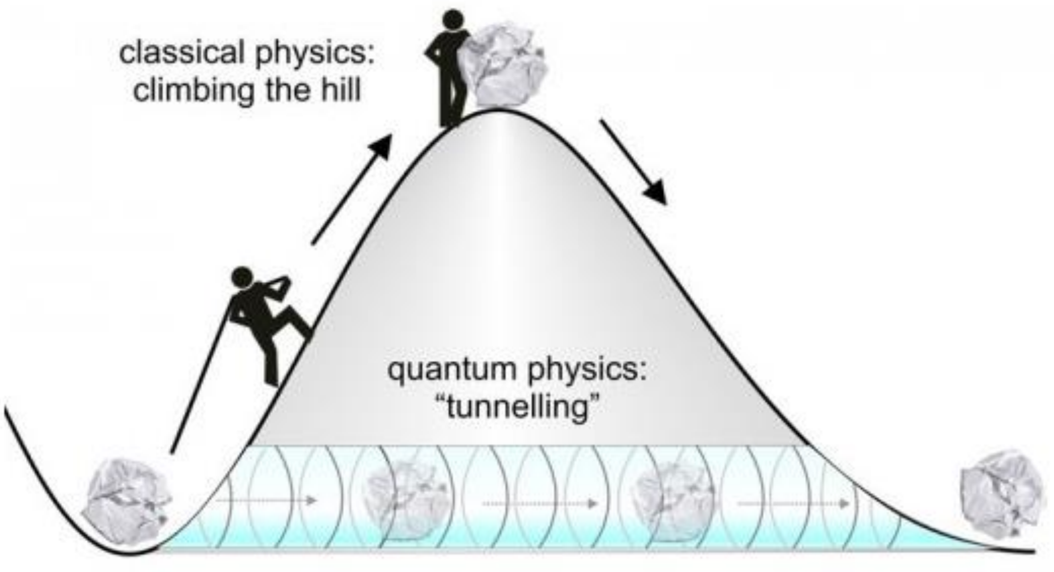
- is mainly concerned with the laws of motion and gravitation, kinetic theory, thermodynamics and classical electromagnetism,
- important contributors: I. Newton and J. C. Maxwell,
- **energy and matter** are **considered as separate entities,**
- **understands time as independent and stable entity,**

Modern physics:

- is mainly concerned with the theory of relativity and quantum mechanics,
- important pioneers: Albert Einstein and Max Plank,
- energy and matter are not considered as separate entities; rather **they are considered as different forms of each other.**
- **time is a more complicated topic, often part of the time-space,**

Physics – main topics in this term:

- mechanics,
- thermodynamics,
- acoustics,
- optics,
- electromagnetism,
- theory of relativity,
- atomic and nuclear physics,
- quantum physics.



Fundamental forces (interactions) in physics:

1. Gravitational: interaction of mass objects.
2. Electromagnetic: acting of electrically charged objects and influence of electric/magnetic fields.
3. Strong nuclear: binds protons and neutrons (nucleons) together to form the nucleus of an atom.
4. Week nuclear: acting of light elementary particles (leptons) among each other.

Discussed is also the so called 5th force (kind of gravitational force, which could be dependent on the kind of matter).

Which one is the strongest? (at very small distances)

strong	el-mag.	week	gravit.
1	10^{-4}	10^{-13}	10^{-40}

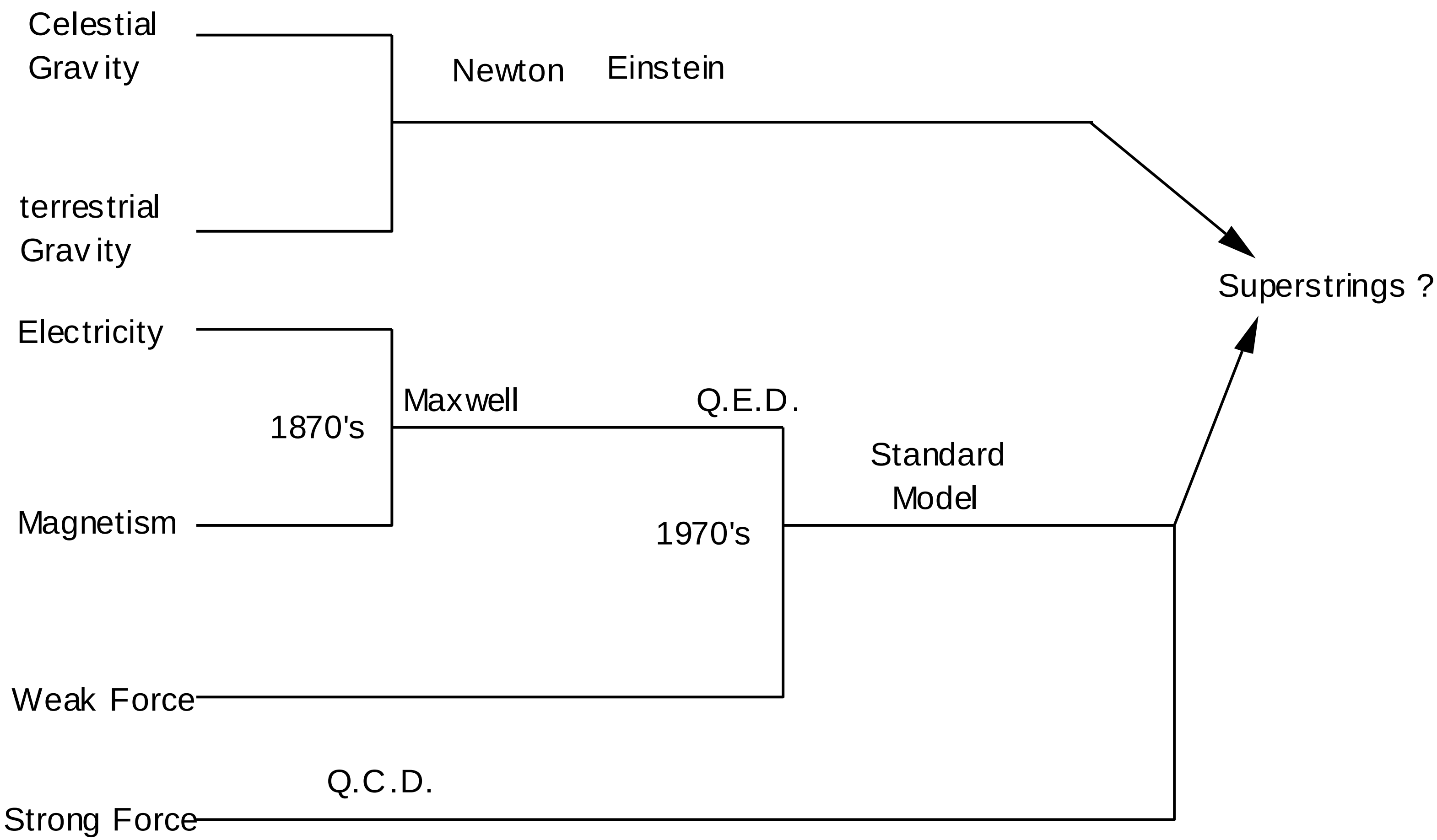
Fundamental forces (interactions) in physics:

The four fundamental interactions of nature

Property/Interaction	Gravitation	Weak	Electromagnetic	Strong	
		(Electroweak)		Fundamental	Residual
Acts on:	Mass - Energy	Flavor	Electric charge	Color charge	Atomic nuclei
Particles experiencing:	All	Quarks, leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Not yet observed (Graviton hypothesised)	$W^+ W^- Z^0$	γ (photon)	Gluons	Mesons
Strength at the scale of quarks:	10^{-41}	10^{-4}	1	60	Not applicable to quarks
Strength at the scale of protons/neutrons:	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Some theoretical physicists seek to quantize the gravitational field – theory of **quantum gravity** (QG).
Other theorists seek to unite the electroweak and strong fields within a **Grand Unified Theory** (GUT).
Trials to put everything together - so called **Theory of Everything** (ToE).

Fundamental forces (interactions) in physics:

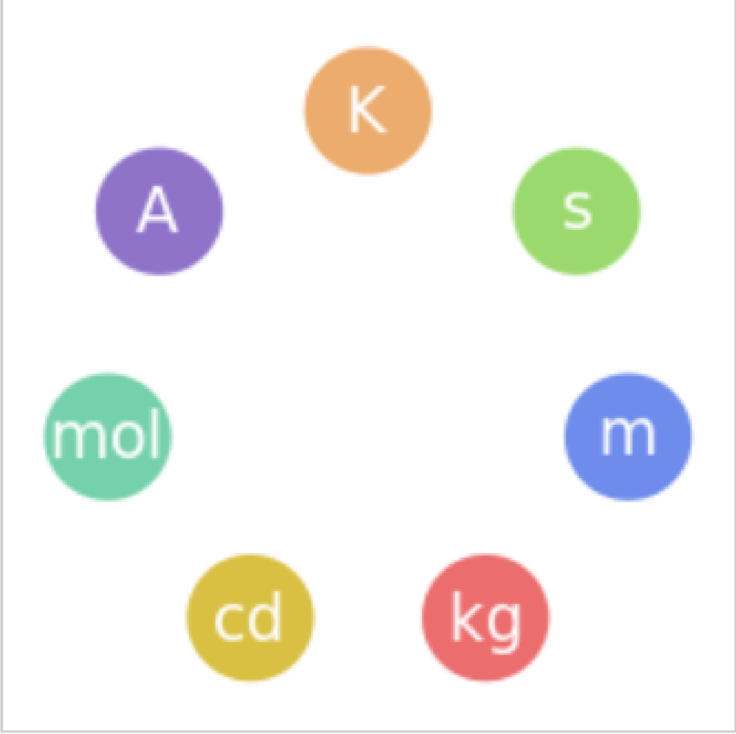


Comment: Q.E.D. - Quantum Electrodynamics, Q.C.D. - Quantum Chromodynamics,

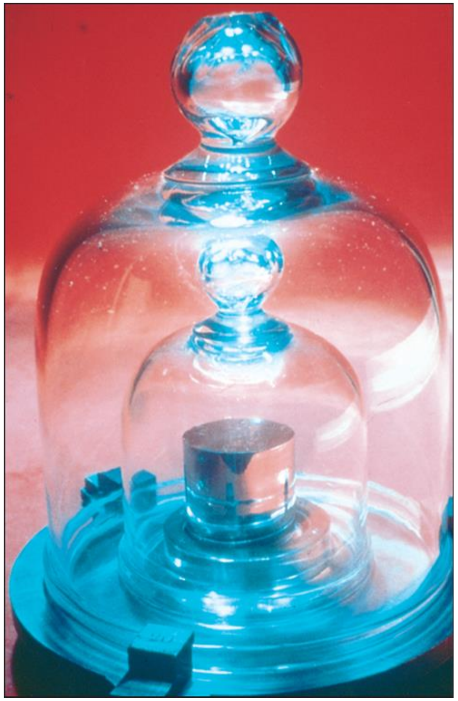
From the history:
1930: Bohr, after learning of the Dirac equation (for the electron), said, *"Physics as we know it will be over in six months".*

International System of Units (SI) in physics:

There are several units systems, the most important is the SI system:



The seven base units in the International System of Units



7 basic units

International System of Units (SI) in physics:

SI base units

Unit name	Unit symbol	Quantity name	Definition (incomplete)[n 1]	Dimension symbol
metre	m	length	• **Original** (1793): $\frac{1}{10\ 000\ 000}$ of the meridian through Paris between the North Pole and the Equator.FG • **Interim** (1960): 1 650 763.73 wavelengths in a vacuum of the radiation corresponding to the transition between the $2p^{10}$ and $5d^5$ quantum levels of the krypton-86 atom. • **Current** (1983): The distance travelled by light in vacuum in $\frac{1}{299\ 792\ 458}$ second.	L
kilogram[n 2]	kg	mass	• **Original** (1793): The **grave** was defined as being the weight [mass] of one cubic decimetre of pure water at its freezing point.FG • **Current** (1889): The mass of the international prototype kilogram.	M
second	s	time	• **Original** (Medieval): $\frac{1}{86\ 400}$ of a day. • **Interim** (1956): $\frac{1}{31\ 556\ 925.9747}$ of the tropical year for 1900 January 0 at 12 hours ephemeris time. • **Current** (1967): The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.	T

basic units

International System of Units (SI) in physics:

Unit name	Unit symbol	Quantity name	Definition (incomplete)[n 1]	Dimension symbol
ampere	A	electric current	• **Original** (1881): A tenth of the electromagnetic CGS unit of current. The [CGS] electromagnetic unit of current is that current, flowing in an arc 1 cm long of a circle 1 cm in radius creates a field of one oersted at the centre.[39] IEC • **Current** (1946): The constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newtons per metre of length.	I
kelvin	K	thermodynamic temperature	• **Original** (1743): The **centigrade scale** is obtained by assigning 0 °C to the freezing point of water and 100 °C to the boiling point of water. • **Interim** (1954): The triple point of water (0.01 °C) defined to be exactly 273.16 K.[n 3] • **Current** (1967): $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water	Θ
mole	mol	amount of substance	• **Original** (1900): The molecular weight of a substance in mass grams.ICAW • **Current** (1967): The amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.[n 4]	N
candela	cd	luminous intensity	• **Original** (1946): The value of the new candle is such that the brightness of the full radiator at the temperature of solidification of platinum is 60 new candles per square centimetre. • **Current** (1979): The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian.	J

basic units

International System of Units (SI) in physics:

New definitions – from 20 May 2019 !

Problems with the international *kg* prototype,

- made in 1889, saved in BIPM close to Paris,
- alloy of Platinum (90%) and Iridium (10%)
- 40 copies all around the world
- checked in 1946 and 1989

- it has lost its mass (in 1989 approx. -100 μg!)
- unknown reasons (lost of hydrogen atoms?, wearing away atoms during manipulation?, sticking molecules of air on the copies?...)
- definition of *kg* is influencing also other units..

The international prototype of the kilogram is inside three nested bell jars at the Bureau International des Poids et Mesures in Paris.

There was an urgent need to accept new definitions!

Named units derived from SI base units

Name	Symbol	Quantity	Expressed in terms of other SI units	Expressed in terms of SI base units
radian	rad	angle		$m \cdot m^{-1}$
steradian	sr	solid angle		$m^2 \cdot m^{-2}$
hertz	Hz	frequency		s^{-1}
newton	N	force, weight		$kg \cdot m \cdot s^{-2}$
pascal	Pa	pressure, stress	N/m^2	$kg \cdot m^{-1} \cdot s^{-2}$
joule	J	energy, work, heat	$N \cdot m$	$kg \cdot m^2 \cdot s^{-2}$
watt	W	power, radiant flux	J/s	$kg \cdot m^2 \cdot s^{-3}$
coulomb	C	electric charge or quantity of electricity		$s \cdot A$
volt	V	voltage (electrical potential difference), electromotive force	W/A	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
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	A/V	$kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2$
weber	Wb	magnetic flux	$V \cdot s$	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-1}$
tesla	T	magnetic field strength	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
henry	H	inductance	Wb/A	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-2}$
degree Celsius	°C	temperature relative to 273.15 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)		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		$mol \cdot s^{-1}$

Notes

1. The radian and steradian, once given special status, are now considered dimensionless derived units.[33]:3
2. The ordering of this table is such that any derived unit is based only on base units or derived units that precede it in the table.

derived units

constants:

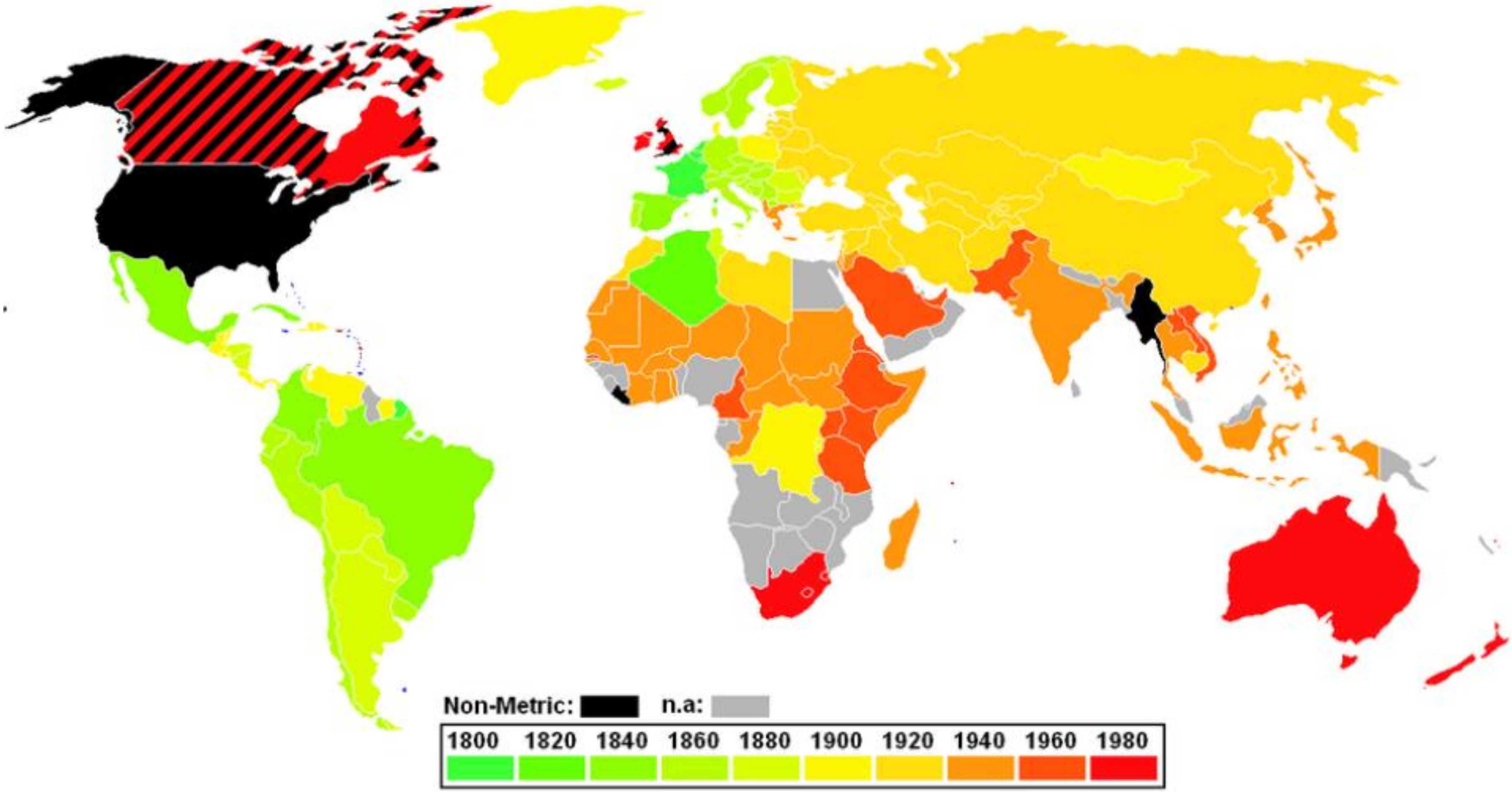
Table of universal constants

Quantity V·T·E	Symbol	Value[8][9]	Relative Standard Uncertainty
speed of light in vacuum	c	$299\,792\,458\ \mathrm{m{\cdot}s^{-1}}$	defined
Newtonian constant of gravitation	G	$6.674\,08(31) \times 10^{-11}\ \mathrm{m^3{\cdot}kg^{-1}{\cdot}s^{-2}}$	4.7×10^{-5}
Planck constant	h	$6.626\,070\,040(81) \times 10^{-34}\ \mathrm{J{\cdot}s}$	1.2×10^{-8}
reduced Planck constant	$\hbar = h/(2\pi)$	$1.054\,571\,800(13) \times 10^{-34}\ \mathrm{J{\cdot}s}$	1.2×10^{-8}

...electromagnetic constants, atomic and nuclear constants, physico-chemical constants, adopted values (elementary charge, Boltzman const., Avogadro const.,...)

New definitions of SI units are founded on basic physical constants!

International System of Units (SI) in physics:



World map showing metrication, colour-coded by year of conversion: from ca 1800 (green) to 1980 (red).
Black indicates the nations that have not yet adopted the SI-system: Burma, Liberia, and the United States. Canada and the United Kingdom both have fairly common use of previously used units.

Physical quantities vs. units:

Physical quantities must always have ***dimensions (units).***

Units will be often given in brackets [ ] in this lecture.

We can only compare quantities with the same dimensions

$$v = s/t$$

$$[L]/[T] = [L]/[T]$$ … e.g. [m/s] or [km/h]

$$v = v(0) + a \cdot t$$

$$[L]/[T] = [L]/[T] + [L]/[T]^2\,[T]$$

Comparing quantities with different dimensions is nonsense

$$v = a \cdot t^2$$

$$[L]/[T] = [L]/[T]^2\,[T]^2 = [L]\ldots?$$

Comment (in this example):

a – acceleration, v – velocity, t – time.

Physical quantities vs. units:

next example (free fall equation):

$$x_f - x_i = v_i t + \frac{1}{2} a t^2$$

[L]

([L]/[T])[T] = [L]

$([L]/[T]^2)T^2=[L]$

mathematical apparatus in physics

don't be scared !

Calculus – derivatives and integrals express in a much better way the infinitesimal properties of various parameters.

e.g.: velocity – when it is constant, then v = s/t

but when it is not a constant value...(?)

$$v = \frac{ds}{dt} = s' \quad \left[\mathrm{m \cdot s^{-1}}\right]$$

e.g.: work – when the force is constant, then A = F·s

$$A = \int_S \vec{F} \cdot d\vec{s} \quad [\mathrm{J}] = [\mathrm{N \cdot m}]$$

mathematical apparatus in physics

scalars (they do have only size/magnitude
(time, temperature,...) t

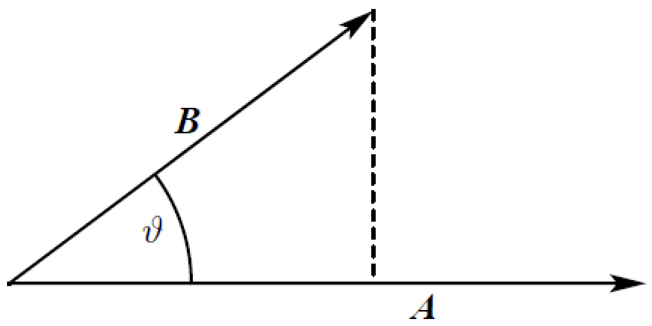
vectors (they have size and direction)
(strength, velocity, ...) $\vec{\mathrm{F}}$ or **F**

tensors (generalisation of a vector –
they have several dimensions)
(tensor of press,...) $\overline{\mathrm{T}}$

mathematical apparatus in physics

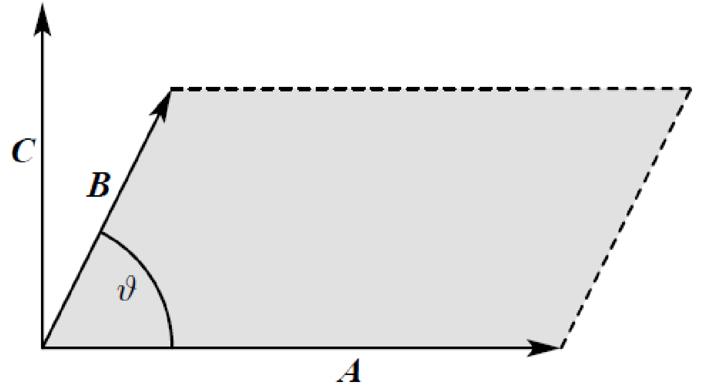
Multiplication of vectors

scalar product (result is scalar): $\boldsymbol{A} \cdot \boldsymbol{B} = |\boldsymbol{A}|\,|\boldsymbol{B}| \cos\vartheta,$



vector product (result is vector):

$\boldsymbol{A} \times \boldsymbol{B} = \boldsymbol{C} \qquad |\boldsymbol{C}| = |\boldsymbol{A}|\,|\boldsymbol{B}| \sin\vartheta,$



repetition – prefixes of units:

Prefix	Symbol	1000^m	10^n	Decimal	Short scale	Long scale	Since[n 1]
yotta	Y	1000^8	10^{24}	1 000 000 000 000 000 000 000 000	Septillion	Quadrillion	1991
zetta	Z	1000^7	10^{21}	1 000 000 000 000 000 000 000	Sextillion	Trilliard	1991
exa	E	1000^6	10^{18}	1 000 000 000 000 000 000	Quintillion	Trillion	1975
peta	P	1000^5	10^{15}	1 000 000 000 000 000	Quadrillion	Billiard	1975
tera	T	1000^4	10^{12}	1 000 000 000 000	Trillion	Billion	1960
giga	G	1000^3	10^9	1 000 000 000	Billion	Milliard	1960
mega	M	1000^2	10^6	1 000 000	Million		1960
kilo	k	1000^1	10^3	1 000	Thousand		1795
hecto	h	$1000^{2/3}$	10^2	100	Hundred		1795
deca	da	$1000^{1/3}$	10^1	10	Ten		1795
		1000^0	10^0	1	One		–
deci	d	$1000^{-1/3}$	10^{-1}	0.1	Tenth		1795
centi	c	$1000^{-2/3}$	10^{-2}	0.01	Hundredth		1795
milli	m	1000^{-1}	10^{-3}	0.001	Thousandth		1795
micro	μ	1000^{-2}	10^{-6}	0.000 001	Millionth		1960
nano	n	1000^{-3}	10^{-9}	0.000 000 001	Billionth	Milliardth	1960
pico	p	1000^{-4}	10^{-12}	0.000 000 000 001	Trillionth	Billionth	1960
femto	f	1000^{-5}	10^{-15}	0.000 000 000 000 001	Quadrillionth	Billiardth	1964
atto	a	1000^{-6}	10^{-18}	0.000 000 000 000 000 001	Quintillionth	Trillionth	1964
zepto	z	1000^{-7}	10^{-21}	0.000 000 000 000 000 000 001	Sextillionth	Trilliardth	1991
yocto	y	1000^{-8}	10^{-24}	0.000 000 000 000 000 000 000 001	Septillionth	Quadrillionth	1991

1. ^ The metric system was introduced in 1795 with six prefixes. The other dates relate to recognition by a resolution of the CGPM.

interesting video: https://www.youtube.com/watch?v=bhofN1xX6u0

Orders of magnitude (summary):

Physical quantities span an immense range

Length	size of nucleus	$\sim 10^{-15}$ m
	size of universe	$\sim 10^{30}$ m
Time	nuclear vibration	$\sim 10^{-20}$ s
	age of universe	$\sim 10^{18}$ s
Mass	electron	$\sim 10^{-30}$ kg
	universe	$\sim 10^{28}$ kg

Solving Problems
(in physics)

Problem Solving Strategy

- Each profession has its own specialized knowledge and patterns of thought.
- The knowledge and thought processes that you use in each of the steps will depend on the discipline in which you operate.
- Taking into account the specific nature of ***physics***, we choose to label and interpret the ***five steps*** of the general problem solving strategy as follows:

Problem Solving Strategy

A. Everyday language:

1) Make a sketch.
2) What do you want to find out?
3) What are the physics ideas?

B. Physics description:

1) Make a physics diagram (figure).
2) Define your variables.
3) Write down general equations.

C. Combine equations:

1) Select an equation with the target variable.
2) Which of the variables are not known?
3) Substitute in a different equation.
4) Continue for all of the unknown variables .
5) Solve for the target variable.
6) Check units.

D. Calculate solution:

1) Plug in numerical values.

E. Evaluate the answer:

1) Is it properly stated?
2) Is it reasonable?
3) Answered the question asked?

So why do we need physics in biology and chemistry?

To get answers about the principles of many fundamental processes and reactions.

How a biological membrane works?

How the heart pumps blood?

How muscles contract?

How plants use light for grow in photosynthesis?

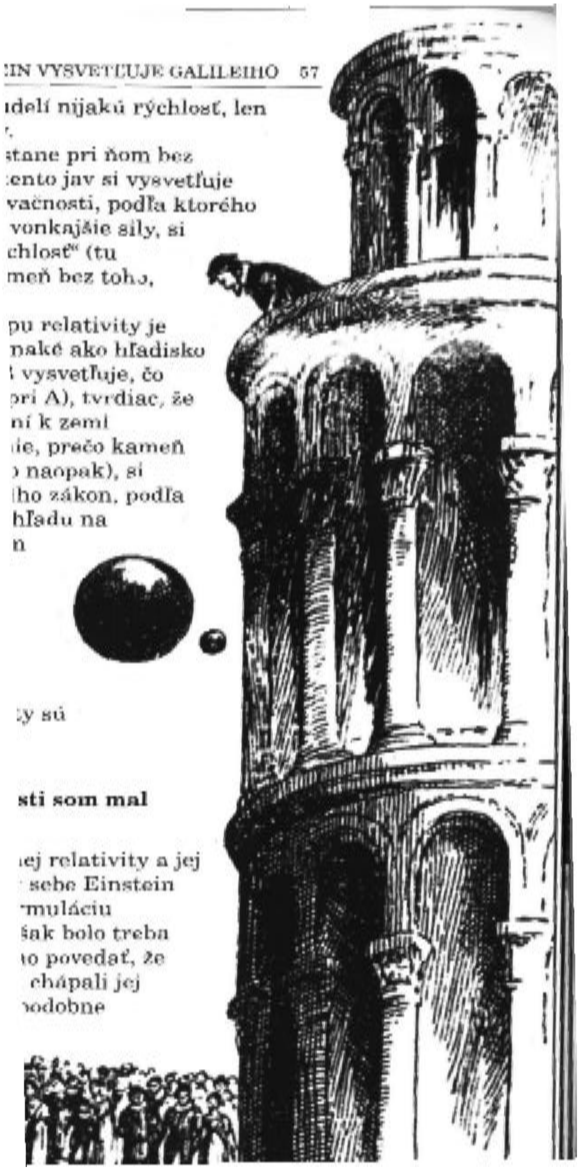
How genes are switched on and off?

How brain processes and stores information?

How does the atomic structure influence chemical reactions?

Lecture 1: something from the early history of physics

Classical mechanics



The Ancient Greeks

Aristotle (384-322 B.C.) is regarded as the first person to attempt physics, and actually gave physics its name.

On the nature of matter:

Matter was composed of:

Air **Earth** **Water** **Fire**

Every compound was a mixture of these ***elements***

Unfortunately there is **no predictive power** (science should have it).

On the Nature of Motion

- ***Natural*** motion - like a falling body
  - Objects seek their natural place
    - Heavy objects fall fast
    - Light objects fall slow
      - Objects fall at a constant speed.

- ***Unnatural*** motion - like a cart being pushed
  - The moving body comes to a stand still when the force pushing it along no longer acts
    - The natural state of a body is at rest.

Aristotelian Physics

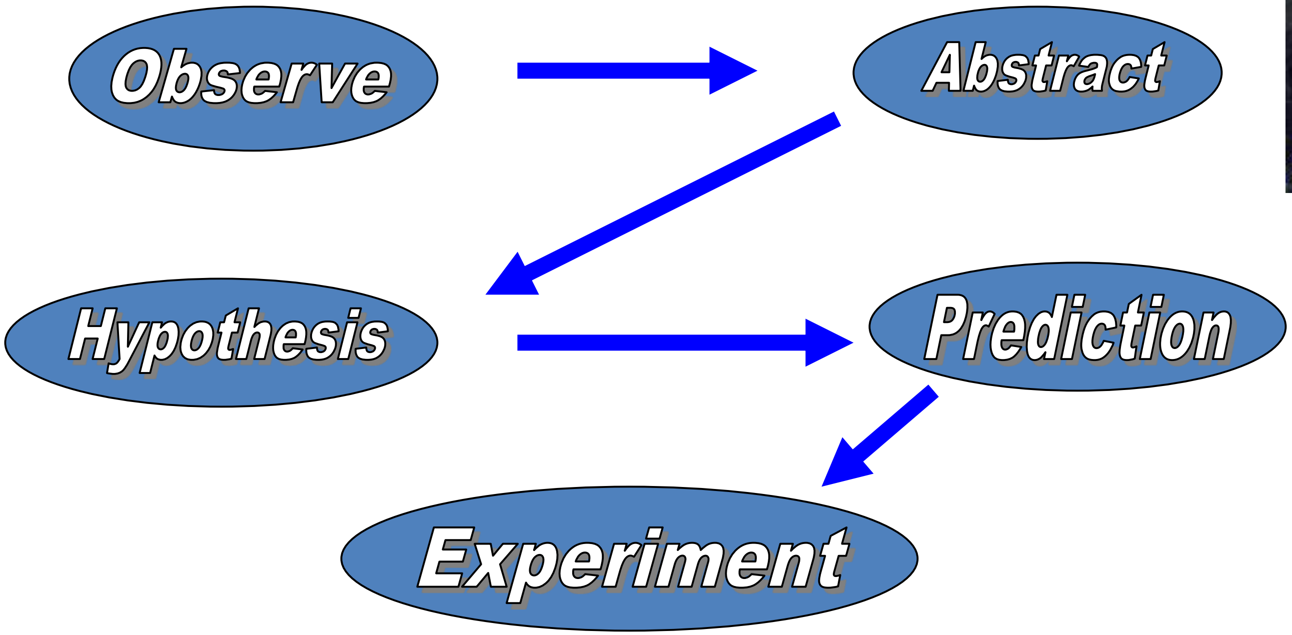
- Aristotelian Physics was based on logic
  - It provided a framework for understanding nature
  - It was logically consistent

It was wrong !!!

- Aristotelian physics relied on logic - not experiment!

The Renaissance

Galileo Galilei (1564 -1642) was one of the first to use the scientific method of observation and experimentation. He laid the groundwork for modern science.



Classical Mechanics

Mechanics: the study of ***motion***

Galileo (1564 -1642) laid the groundwork for Mechanics

Newton (1642-1727) completed its development (~*almost*~)

Newton's Laws work fine for

- Large Objects - Ball's, planes, planets, ...
  - Small objects (atoms) → Quantum Mechanics
- Slow Objects - people, cars, planes, ...
  - Fast objects (near the speed of light) → Relativity
- ➢ Classical Mechanics - essentially complete at the end of the 19th Century

Later during the class we will come also to specific/general relativity and quantum mechanics.

Classical mechanics

Galileo’s vs Newton’s understanding of inertia:

Galileo:

- developed the idea of force, as a cause for motion
- determined that the natural state of an object is rest or uniform motion, i.e. objects always have a velocity, sometimes that velocity has a magnitude of zero = rest.
- objects resist change in motion, which is called **inertia**

Newton (further and more detailed understanding):

- change in velocity = acceleration caused by force
- **inertia** = resistance to change in velocity and is proportional to the mass of the object.