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Essential Graduate Physics

Lecture Notes and Problems

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Appendix UCA

Selected Units and Constants

Last edit: June 4, 2024

Table 1. Selected physical units in the SI and Gaussian systems

Quantity	SI unit and symbol	Gaussian unit and symbol	Conversion factor
time	second (s)	second (s)	–
length	meter (m)	centimeter (cm)	1 cm = 10^{-2} m
mass	kilogram (kg)	gram (g)	1 g = 10^{-3} kg
temperature	kelvin (K)	kelvin (K)	–
force	newton (N)	dyne	1 dyne = 10^{-5} N
energy and work	joule (J) = N·m	erg	1 erg = 10^{-7} J
electric charge	coulomb (C)	statcoulomb (statC)	1 statC = $(1/3)\times10^{-9}$ C
electric current	ampere (A) = C/s	statampere (statA)	1 statA = $(1/3)\times10^{-9}$ A
electric potential	volt (V) = J/C	statvolt (statV)	1 statV = 3×10^{2} V
electric field	V/m	statvolt/cm	1 statV/cm = 3×10^{4} V/m
capacitance	farad (F) = C/V	cm	1 cm = $(1/3)^2\times10^{-11}$ F
resistance	ohm (Ω) = V/A	s/cm	1 s/cm = $3^2\times10^{11}$ Ω
conductance	siemens (S) = Ω^{-1}	cm/s	1 cm/s = $(1/3)^2\times10^{-11}$ S
magnetic field (*H*)	ampere/meter (A/m)	oersted (Oe)	1 Oe = $(1/4\pi)\times10^{3}$ A/m
magnetic field (*B*)	tesla (T) = J/A·m^2	gauss (G)	1 G = 10^{-4} T
magnetic flux	weber (W) = T·m^2	maxwell (Mx)	1 Mx = 10^{-8} W
inductance	henry (H) = V·s/A	s/cm^2	1 s/cm^2 = $3^2\times10^{11}$ H

Comments to Table 1:

1. This table does not include the secondary units (e.g., those of velocity, torque, etc.) that have no special names/symbols in either system and are related to the listed units in an obvious way, and also the units (e.g., of luminous intensity, catalytic activity, etc.) not used in this series.

2. Each number "3" in the right column is shorthand for 2.997 924 58 (= $10^{-8}c_{\rm SI}$) – see Table 2.

3. In some older texts, the SI unit of conductance (siemens) is abbreviated as "mho".

4. In the SI, the electric permittivity ε is measured in units of the electric constant ε_0 (F/m), while is the Gaussian system, it is dimensionless and numerically equal to the dielectric constant $\kappa \equiv (\varepsilon/\varepsilon_0)_{\rm SI}$.

5. Similarly, in the SI, the magnetic permeability μ is measured in units of the magnetic constant μ_0 (N/A^2), while in the Gaussian system, it is dimensionless and numerically equal to $(\mu/\mu_0)_{\rm SI}$.

6. In both systems, the (volumic) electric and magnetic susceptibilities $\chi_{\rm e}$ and $\chi_{\rm m}$ are dimensionless, but not equal: $\chi_{\rm Gaussian} = \chi_{\rm SI}/4\pi$ – see EM Secs. 3.3 and 5.5.

Table 2: Selected physical constants

Symbol	Constant	SI value and unit	Gaussian value and unit	Relative r.m.s. uncertainty
c	speed of light in vacuum	$2.997\,924\,58\times10^{8}$ m/s	$2.997\,924\,58\times10^{10}$ cm/s	0 (defined value)
N_A	Avogadro constant	$6.022\,140\,76\times10^{23}$ 1/mol	$6.022\,140\,76\times10^{23}$ 1/mol	0 (defined value)
$2\pi\hbar$	Planck constant	$6.626\,070\,15\times10^{-34}$ J/Hz	$6.626\,070\,15\times10^{-27}$ erg/Hz	0 (defined value)
k_B	Boltzmann constant	$1.380\,649\,000\times10^{-23}$ J/K	$1.380\,649\,000\times10^{-16}$ erg/K	0 (defined value)
e	elementary electric charge	$1.602\,176\,634\times10^{-19}$ C	$4.803\,204\,713\times10^{-10}$ statcoulomb	0 (defined value)
ε_0	electric constant	$8.854\,187\,8128\times10^{-12}$ F/m	–	$\sim1.5\times10^{-10}$
μ_0	magnetic constant	$1.256\,637\,062\,12\times10^{-6}$ N/A^2	–	$\sim1.5\times10^{-10}$
m_e	electron's rest mass	$0.910\,938\,370\times10^{-30}$ kg	$0.910\,938\,370\times10^{-27}$ g	$\sim3\times10^{-10}$
m_p	proton's rest mass	$1.672\,621\,923\times10^{-27}$ kg	$1.672\,621\,923\times10^{-24}$ g	$\sim3\times10^{-10}$
G	gravitation constant	$6.674\,30\times10^{-11}$ m^3/kg·s^2	$6.674\,30\times10^{-8}$ cm^3/g·s^2	$\sim2\times10^{-5}$

Comments to Table 2:

1. The values follow the 2018 International CODATA recommendation.[1] (CODATA is an interdisciplinary Committee on Data for Science and Technology of the International Council of Science (ISCU). Its recommendations, renewed every few years, are widely accepted by the scientific community.

2. The fixed value of c transfers the legal definition of the second (as "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 cesium-133 atom") to that of the meter. These values are back-compatible with the legacy definitions of the meter (initially, as the 1/40,000,000$^{\text{th}}$ part of the Earth's meridian length) and the second (for a long time, as the $1/(24\times60\times60) = 1/86{,}400^{\text{th}}$ part of the Earth's rotation period), within the experimental errors of those measures.

3. The exact value of the Avogadro number, prescribed by the last CODATA adjustment of fundamental constants in 2018, fixes 1 kg in the atomic units of mass (u), defined as 1/12 of the ^{12}C atom's mass, excluding the legacy etalons of the kilogram from the primary metrology – even though their masses are compatible with the new definition within the experimental accuracy.

4. The exact value of $\hbar$, also prescribed by CODATA in 2018, together with the fixed value of the second, enables the fundamental definition of energy units (in the SI system, the Joule) in terms of time/frequency.

5. The only role of the Boltzmann constant k_B is to express the kelvin (K) in energy units. If temperature is used in these units (as is done, for example, in the SM part of this series), this constant is unnecessary.

6. ε_0 and μ_0 are also not really fundamental constants; their role is just to fix the electric and magnetic units in the SI system. Their product is exactly fixed as $\varepsilon_0\mu_0 \equiv 1/c^2$, and μ_0 virtually coincides with the legacy value $4\pi\times10^{-7}$. (Before the 2018 adjustment, that value was considered exact, but the fixation of e in the new system gives μ_0 some experimental uncertainty, if only a very small one – see the right column of the table.)

7. The dimensionless fine-structure ("Sommerfeld's") constant α is numerically the same in any system of units:

$$\alpha \equiv \left\{ \begin{array}{ll} e^2/4\pi\varepsilon_0\hbar c & \text{in SI units} \\ e^2/\hbar c & \text{in Gaussian units} \end{array} \right\} \approx 7.297\,352\,563\times10^{-3} \approx \frac{1}{137}.$$

The relative uncertainty of the first value is smaller than 10^{-10}, while the accuracy of the second, mnemonic value is better than 0.03%.

8. The listed proton's rest mass m_p is close to 1.007 u, while the neutron's rest mass is close to 1.009 u; their differences from 1 u reflect mostly the binding energy of these baryons in the ^{12}C nucleus.

9. Note the relatively poor accuracy with which we know the Newtonian constant of gravitation – due to the extreme weakness of gravity on human scales of mass and distance.

[1] See, e.g., http://physics.nist.gov/cuu/Constants/index.html.