Lesson 2

Physical Quantities, System Units, and Measurement Error

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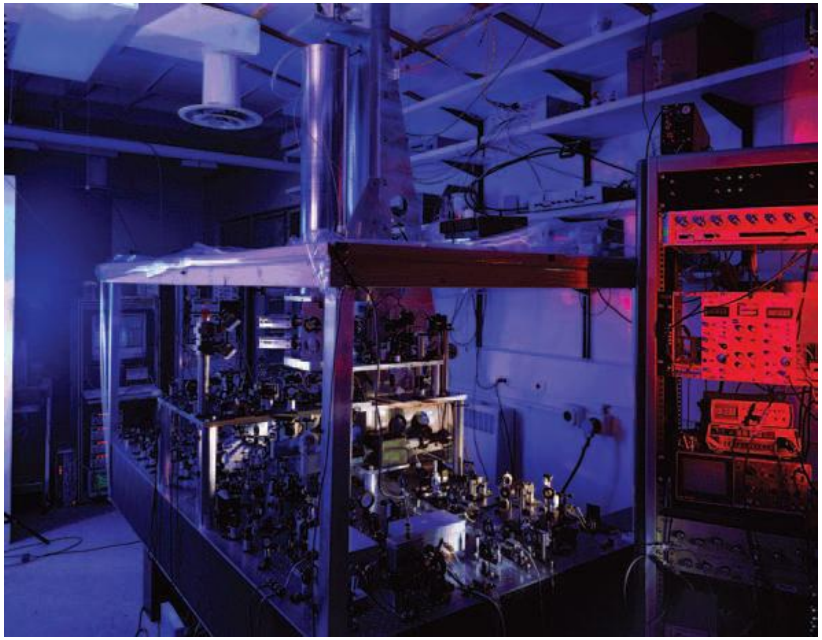
Standards of Length, Mass, and Time

- The **meter** was redefined as the distance traveled by light in vacuum during a time interval of 1/299 792 458 second.
- The **kilogram**, is defined as the mass of a specific platinumiridium alloy cylinder kept at the International Bureau of Weights and Measures at Sèvres, France (left picture).
- The **second** is now defined as 9 192 631 700 times the period of oscillation of radiation from the cesium atom (right picture).



SI Units

Vietnam has accepted SI units since 1960.

Basic SI quantities

Quantity	Dimension	Alternatives	Root definition
Length	m	**m**	**meter**
Mass	kg	**kg**	**kilogram**
Time	s	**s**	**second**
Current, electric	A	**A**	**ampere**
Temperature	K	**K**	**kelvin**
Quantity of substance	mol	**mol**	**mole**
Luminosity | Luminous intensity	cd	**cd**	**candle**

SI Units prefixes

Prefix	Symbol	Factor	Examples of usage	Origin
Yotta	**Y**	10^{24}	0.2 YW, 1.23Y [W]	Greek 'octo' (eight, 1000^{8})
Zetta	**Z**	10^{21}	3.33 Zs, 3.33Z [s]	French 'sept' (seven, 1000^{7})
Exa	**E**	10^{18}	1.23 Ekg, 1.23E [kg]	Greek 'six' (1000^{6})
Peta	**P**	10^{15}	7.5 Ps, 7.5P [s]	Greek 'five' (1000^{5})
Tera	**T**	10^{12}	0.5 Tm, 0.5T [m]	Greek 'teras' = monster
Giga	**G**	10^{9}	1.2 GΩ, 1.2G [Ω]	Greek 'gigas' = giant
Mega	**M**	10^{6}	7 MW, 7M [W]	Greek 'megas' = large
Kilo	**K, k**	10^{3}	33 km, 33K [m]	Greek 'kilioi' = thousand
hecto	**h**	100	**Deprecated by SI**	Greek 'hekaton' = hundred
deca	**da**	10	**Deprecated by SI**	Greek 'deka' = ten
deci	**d**	0.1	**Deprecated by SI**	Latin 'decima pars' = one tenth
centi	**c**	0.01	**Deprecated by SI**	Latin 'centesima pars' = one hundredth
milli	**m, k**	10^{-3}	22 mm , 1.2m [m]	Latin 'millesima pars' = one thousandth
micro	**µ, u**	10^{-6}	2.7 uJ , 2.7µ [J]	Greek 'mikros' = small
nano	**n**	10^{-9}	2.2 nF, 2.2n [F]	Latin 'nanus' = dwarf
pico	**p**	10^{-12}	1.5 pA, 1.5p [A]	Spanish 'pico' = minimal measure
femto	**f**	10^{-15}	4.8 fs, 4.8f [s]	Danish and Norvegian 'femten' = fifteen (10^{-15})
atto	**a**	10^{-18}	1.2 ag, 1.2a [g]	Danish and Norvegian 'atten' = eighteen (10^{-18})
zepto	**z**	10^{-21}	0.2 zm, 1.2z [m]	French 'sept' (seven, 1000^{-7})
yocto	**y**	10^{-24}	1 ys, 1y [s]	Greek 'octo' (eight, 1000^{-8})

Physical Quantities and Units

	Quantity	Definition	Formula	Units	Dimensions
MECHANICAL	**Length or Distance**	*fundamental*	d	m (meter)	*L (Length)*
	Time	*fundamental*	t	s (second)	*T (Time)*
	Mass	*fundamental*	m	kg (kilogram)	*M (Mass)*
	Area	$distance^2$	$A = d^2$	m^2	L^2
	Volume	$distance^3$	$V = d^3$	m^3	L^3
	Density	mass / volume	d = m/V	kg/m^3	M/L^3
	Velocity	distance / time	v = d/t	m/s	*L/T*
	Acceleration	velocity / time	a = v/t	m/s^2	L/T^2
	Momentum	mass × velocity	p = mv	kg·m/s	*ML/T*
	Force Weight	mass × acceleration mass × (accel. of grav.)	F = ma W = mg	N (newton) = $kg{\cdot}m/s^2$	ML/T^2
	Pressure or Stress	force / area	p = F/A	Pa (pascal) = $N/m^2 = kg/(m{\cdot}s^2)$	M/LT^2
	Energy or Work Kinetic Energy Potential Energy	force × distance mass × $velocity^2$ / 2 mass × (accel. of grav.) × height	E = Fd $KE = mv^2/2$ PE = mgh	J (joule) = N·m = $kg{\cdot}m^2/s^2$	ML^2/T^2
	Power	energy / time	P = E/t	W (watt) = J/s = $kg{\cdot}m^2/s^3$	ML^2/T^3
	Impulse	force × time	I = Ft	N·s = kg·m/s	*ML/T*
	Action	energy × time momentum × distance	A = Et A = pd	J·s = $kg{\cdot}m^2/s$	ML^2/T

Physical Quantities and Units (cont.)

	Quantity	Definition	Formula	Units	Dimensions
ANGULAR	**Angle**	*fundamental*	θ	° (degree), rad (radian), or rev (revolution) 360° = 2π rad = 1 rev	*dimensionless*
	Cycles	*fundamental*	n	cyc (cycles)	*dimensionless*
	Frequency	cycles / time	$f = n/t$	Hz (hertz) = cyc/s = 1/s	*1/T*
	Angular Velocity	angle / time	$\omega = \theta/t$	rad/s = 1/s	*1/T*
	Angular Acceleration	angular velocity / time	$\alpha = \omega/t$	$rad/s^2 = 1/s^2$	$1/T^2$
	Moment of Inertia	mass × $radius^2$	$I = mr^2$	$kg \cdot m^2$	ML^2
	Angular Momentum	radius × momentum (mom. of inert.) × (ang. vel.)	$L = rp$ $L = I\omega$	$kg \cdot m^2/s$	ML^2/T
	Torque	radius × force (mom. of inert.) × (ang. accel.)	$T = rF$ $T = I\alpha$	$N \cdot m = kg \cdot m^2/s^2$	ML^2/T^2
THERMAL	**Temperature**	*fundamental*	T	°C (celsius) or K (kelvin)	*K (Temp.)*
	Heat	heat energy	Q	J (joule) = $kg \cdot m^2/s^2$	ML^2/T^2
	Entropy	heat / temperature	$S = Q/T$	J/K	ML^2/T^2K

Physical Quantities and Units (cont.)

	Quantity	Definition	Formula	Units	Dimensions
E L E C T R O M A G N E T I C	**Electric Charge (+/-)**	*fundamental*	q	C (coulomb)	*C (Charge)*
	Current	charge / time	$i = q/t$	A (amp) = C/s	C/T
	Voltage or Potential	energy / charge	$V = E/q$	V (volt) = J/C	ML^2/CT^2
	Resistance	voltage / current	$R = V/i$	Ω (ohm) = V/A	ML^2/C^2T
	Capacitance	charge / voltage	$C = q/V$	F (farad) = C/V	C^2T^2/ML^2
	Inductance	voltage / (current / time)	$L = V/(i/t)$	H (henry) = V·s/A	ML^2/T^2
	Electric Field	voltage / distance force / charge	$E = V/d$ $E = F/q$	V/m = N/C	ML/CT^2
	Electric Flux	electric field × area	$\phi_E = EA$	V·m = N·m²/C	ML^3/CT^2
	Magnetic Field	force / (charge × velocity)	$B = F/qv$	T (tesla) = Wb/m² = N·s/(C·m)	M/CT
	Magnetic Flux	magnetic field × area	$\phi_M = BA$	Wb (weber) = V·s = J·s/C	ML^2/CT

So, the experiment data is dominant authority for Physics. Experimental fact will decide about the validity for Theory.

1. But **HOW TO** get data from experiments ?
2. And **HOW** we can be sure that the data is CORRECT?
3. Once we CAN NOT obtain absolutely true values of physical quantities, **HOW TO** minimize any possible error?

The Goals of Measurement

- **Validity**: The extent to which operational measures reflect the concepts they are intended to represent
- **Reliability**: The extent to which operational measures can be replicated
- In practice we may need to trade off between validity and reliability

Precision and number of significant figures

To determine the number of significant figures:

1. The leftmost non-zero digit is the most significant digit;
2. If there is no decimal point, the rightmost non-zero digit is the least significant;
3. If there is a decimal point, the rightmost digit is the least significant, even if it is zero.
4. All digits between the least significant and the most significant (inclusive) are themselves significant.

For example, what the following numbers have 4 significant figures?

2,314   2,314,000   2.314   9009   9.009   0.000009009   9.000

The more *number of significant figures*, the more **precise** measurement is.

The more **accurate** measurement is if the closer its *result to the true value*.

Ways of Expressing Error in Measurement

In general, the measurement errors exist in three categories:

1. **Systematic error** (bias) e_s:
   - when your measurements are usually *consistently* too high or too low from the accurate value
   - It is often very difficult to catch systematic errors and usually requires that you understand carefully the workings of your measuring device(s).
2. **Random errors e_r**:
   - when your measured value could be a bit high or a bit low of the correct value.
   - the variations in your measurements have no fixed or predictable pattern.
3. **Device error e_d**:
   - when each device surely takes some specific error into the measurement.
   - sometimes people treat it like a systematic error with. But the main difference between them is: the systematic error can be carefully eliminated, the device one – is *inevitable* .

Ways of Expressing Error in Measurement

Measurement can be done either ***directly,*** using some device acquitting information from the object, or ***indirectly***, obtaining information from other direct and/or indirect measurement(s).

Any measurement made with a measuring device is *approximate*. If you measure the same object two different times, the two measurements may not be exactly the same. The difference between two measurements is called a ***variation*** or ***error*** (is not a mistake!) in the measurements. Measured value *A* consists from the *true value T* and all-reason *error e*: $A = T + e$; $e = e_s + e_r + e_d$.

1. The **greatest possible error** when measuring is considered to be one half of that measuring unit.
2. Error in measurement may be represented by a **tolerance interval** (margin of error): the desired value may be any from the interval from $T - ½\ e$ *to* $T + ½\ e$.
3. Error in measurement may be represented in any of both absolute and relative forms. The **absolute error** of the measurement shows *how large the error actually is*, while the **relative error** of the measurement shows *how large the error is in relation to the correct value*.

Error estimation

I. The physical quantity *A* obtained from a ***direct*** measurement.

From n time repeated measurements one gets:

$$\left.\begin{array}{llll} n_1 & \text{times with} & A_1 & \text{value} \\ n_2 & \text{times with} & A_2 & \text{value} \\ \dots & \dots & \dots & \dots \quad \dots \\ n_m & \text{times with} & A_m & \text{value} \end{array}\right\} \Rightarrow$$

the average value $\bar{A} = \dfrac{n_1A_1 + n_2A_2 + \ldots + n_mA_m}{n_1 + n_2 + \ldots + n_m} = \dfrac{\sum_{i=1}^{m} n_iA_i}{n}$

$A = \bar{A} \pm \Delta\bar{A}$

the particular *i*-th deviation $\Delta A_i = \left|\bar{A} - A_i\right|$

the average deviation $\Delta\bar{A} = \dfrac{\sum_{i=1}^{m} n_i \Delta A_i}{n}$

If n $\rightarrow \infty$ then the average deviation $\rightarrow$ 0 and the average value approaches to the true value *A*. In this case we call the average deviation as the absolute error for the measurement.

Presentation of measured physical quantity's value

- In form of the ***absolute*** error:

$$A = \bar{A} \pm \Delta\bar{A} \qquad i.e., \quad \left|\bar{A} - \Delta\bar{A}\right| \le A \le \bar{A} + \Delta\bar{A}$$

- In form of the ***relative*** error:

$$A = \bar{A} \pm \frac{\Delta\bar{A}}{\bar{A}} 100\% = \bar{A} \pm \delta\bar{A}$$

Error estimation (cont.)

Rounding rules

- Firstly, try to diminish or better, eliminate systematic error (bias).
- If the rightmost figure is less than 5, omit it. If it not less than 5, append 1 into its left nearest figure.
- Keep only 2 significant figures in the results.
- All mentioned above actions are valid if the result will not shifted more than 10%.
- Among the random and device errors one can be also omitted if the action does not shift the result more than 10%.
- The average value must be written with the same decimal rightmost significant figure as in the rounded error.

Example

$$0.987654 \rightarrow 0.98765 \rightarrow 0.9877 \rightarrow 0.988 \rightarrow 0.99$$

$$9.810762834 \pm 0.11375 \rightarrow 9.810762834 \pm 0.11 \rightarrow 9.81 \pm 0.11$$

Error estimation (cont.)

Reading direct output from measuring devices

❖ **Analog meters**

- **Device error = (Class of accuracy) x (Maximal meaning of measuring scale)**.

Example: amper meter 100 mA scale, class of accuracy 1.5 (%)

$$e_d = 100\ (\text{mA}) \times 1.5\ \% = 1.5\ (\text{mA})$$

❖ **Analog resistive or capacitance etalons**

- **Device error = (Class of accuracy for maximal measuring scale) x (Measured value)**.

Example: resistive etalon $0 \div 999.9\ \Omega$ at $1000\ \Omega$ scale, with accuracy $\delta = 0.2$, measured value $840\ \Omega$

$$e_d = 0.2\% \times 840.0\ (\Omega) = 1.68\ (\Omega) \rightarrow 1.7\ (\Omega)$$

❖ **Digital meters**

- **Device error = (Class of accuracy) x (Measured value) + (n) x (Resolution)**.

(with n – index given by manufacture and depending from measuring scales.)

Example: constant current digital voltmeter – 2000 digits, 19.99 V scale, δ = 0.5, n = 1, measured value 15.78 V. The resolution is $U_{max}/2000 = 19.99\ (\text{V})/2000 \approx 0.01\ (\text{V})$

$$e_d = (0.5\ \% \times 15.78\ \text{V}) + (1 \times 0.01\ \text{V}) = 0.0789\ \text{V} + 0.01 \rightarrow 0.1\ \text{V}$$

Error estimation (cont.)

II. The physical quantity *F* obtained from a ***indirect*** measurement.

Assuming physical value *F* = *F*(*u, v, w, s*) is deducted from direct measurements for the values *u, v, w, s*. Better to fix *firstly* the relative error by the following steps:

1. Take the natural logarithm of *F* $\ln F = \ln F(u, v, w, s)$
2. Take total derivative
$$\frac{dF}{F} = \left(\frac{\partial F}{\partial u}\right) + \left(\frac{\partial F}{\partial v}\right) + \left(\frac{\partial F}{\partial w}\right) + \left(\frac{\partial F}{\partial s}\right)$$
3. Simplify and take the differential
$$dF = \left(\frac{\partial F}{\partial u}\right) du + \left(\frac{\partial F}{\partial v}\right) dv + \left(\frac{\partial F}{\partial w}\right) dw + \left(\frac{\partial F}{\partial s}\right) ds$$
4. Take the absolute value (subtraction is replaced by addition)

$$\boxed{\Delta F = \left|\frac{\partial F}{\partial u}\right| \Delta u + \left|\frac{\partial F}{\partial v}\right| \Delta v + \left|\frac{\partial F}{\partial w}\right| \Delta w + \left|\frac{\partial F}{\partial s}\right| \Delta s}$$

Error estimation (cont.)

- Error of given values is taken as the unity of the rightmost significant figure.
- Error of constants is taken as less than the 10 % of the relative error for *F.*

<u>*Example*</u>:

$$a = \frac{m_1 \omega^2 r}{m_1 + m_2} g \quad , \quad \left(\Delta \bar{m}_1 = \Delta \bar{m}_2, \Delta \bar{\omega}, \Delta \bar{r}, \Delta g \text{ are readily fixed} \right) \quad \Rightarrow$$

$$\ln a = \ln m_1 + 2 \ln \omega + \ln r - \ln\left(m_1 + m_2\right) + \ln g \quad \Rightarrow$$

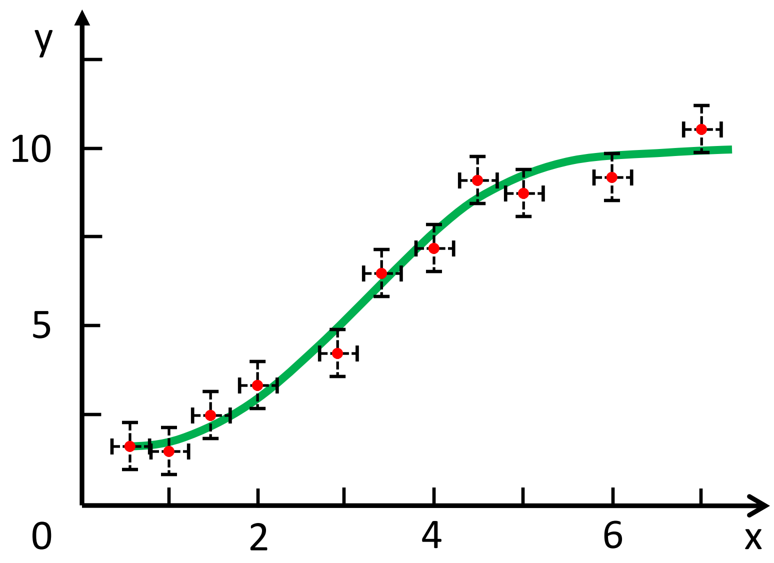
$$\frac{da}{a} = \frac{dm_1}{m_1} + 2\frac{d\omega}{\omega} + \frac{dr}{r} - \frac{d\left(m_1 + m_2\right)}{m_1 + m_2} + \frac{dg}{g} \quad \Rightarrow$$

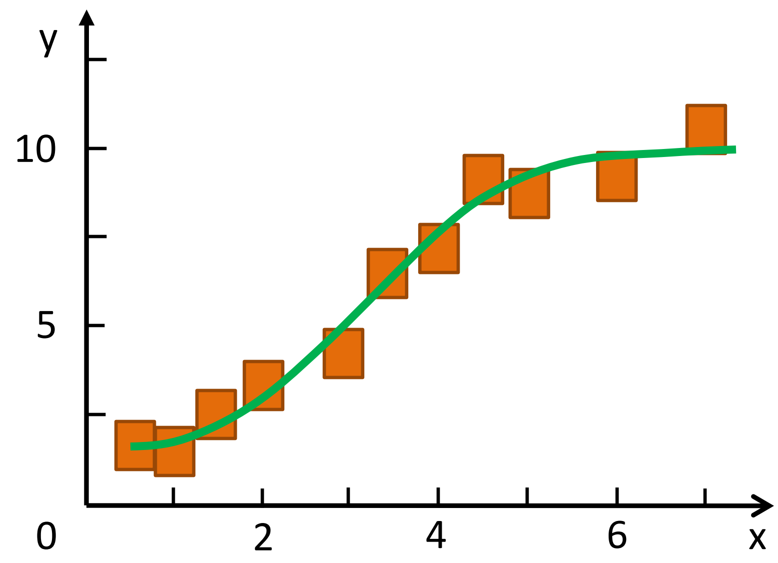
$$\frac{\Delta \bar{a}}{\bar{a}} = \frac{\Delta \bar{m}_1}{\bar{m}_1} + 2\frac{\Delta \bar{\omega}}{\bar{\omega}} + \frac{\Delta \bar{r}}{\bar{r}} + 2\frac{\Delta \bar{m}_1}{\bar{m}_1 + \bar{m}_2} + \frac{\Delta g}{g}$$

Error estimation (cont.)

Graphical representation of measurement results

- Error must be represented on graphics either with "tails" parallel to abscis and ordinate axes (left graphic) or by rectangles (the same graphic on the right).
- The lengths of the "tails" or the dimensions of the rectangles correspond to the errors (on the graphics: Δx and Δy)





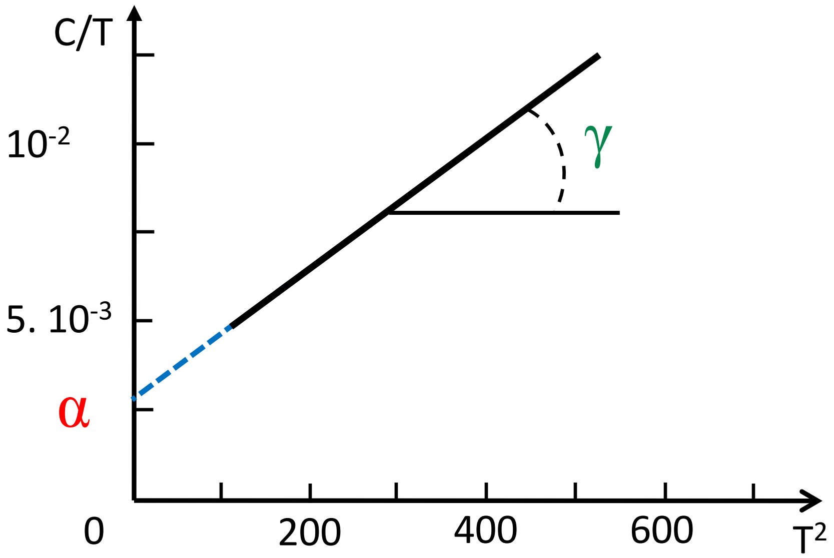
Error estimation (cont.)

• Try as much as possible to transform the formula of dependency for measured physical quantity into linear form, *e.g.*, for the low-temperature dependence of thermal capacity in metals:

$$C(T) = \alpha T + \gamma T^3$$

$$\Downarrow$$

$$\frac{C(T)}{T} = F(T^2) = \alpha + \gamma \cdot T^2$$



• The first derivative from the investigated dependency is usually determined by the slope of graphics, the second derivative – by graphic maximum/minimum. The cross point between extrapolated lines with axis point the resolution – usually some critical points for the dependence under study.

Appendix

Physical constants

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Universal constants				
Speed of light c	**2.997 924 580 e+8**	$m.s^{-1}$	m/s	Now **assigned** (see SI units)
Gravitation constant G	**6.67428[67] e-11**	$kg^{-1}.m^{3}.s^{-2}$		force = $G\ M_1 M_2 / r_{12}^2$
Planck constant h	**6.626 068 96[33] e-34**	$kg.m^{2}.s^{-1}$	J.s	= energy quantum / frequency
Angular Planck constant	1.054 571 628[53] e-34	$kg.m^{2}.s^{-1}$	J.s	$h/2\pi$
Planck mass m_p	2.176 44[11] e-8	kg	kg	$m_p^2 = (h/2\pi)\ c / G$
Planck time t_p	5.391 24[27] e-44	s	s	$= (h/2\pi) / (m_p c^2)$
Planck length l_p	1.616 252[81] e-35	m	m	$= ct_p$
Planck temperature	1.416 785[71] e+32	K	K	$= m_p c^2 / k$
Hubble constant	**2.29[13] e-18**	s^{-1}		Universe expansion rate, 70.8±4.0 (km/s)/Mpc

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Electromagnetic constants				
Permeability of vacuum μ_0	**12.566 370 614... e-7**	$kg.m.s^{-2}.A^{-2}$	H/m | N/A^2	$= 4\pi.10^{-7}$. **Assigned**.
Permittivity of vacuum ε_0	**8.854 187 817... e-12**	$kg^{-1}.m^{-3}.s^4.A^2$	F/m	$= 1 / (c^2 \mu_0)$. **Assigned**.
Impedance of vacuum Z_0	**376.730 313 461 ...**	$kg.m^2.s^{-3}.A^{-2}$	Ω	**Assigned** by $Z_0^2 = \mu_0/\varepsilon_0$.
Elementary charge e	**1.602 176 487[40] e-19**	s.A	C	
Charge/Quantum ratio	2.417 989 454[60] e14	$kg^{-1}.m^{-2}.s^2.A$	A/J	= e / h
Quantum/Charge ratio	4.135 667 33[10] e-15	$kg.m^2.s^{-2}.A^{-1}$	J/A	= h / e
Fine structure constant α	7.297 352 5376[50] e-3	Dimensionless		$= \mu_0 c e^2 / 2h$. **July 2006 .**
Inverse of fine structure constant	137.035 999 679[94]	Dimensionless		$= 1/\alpha = 2h / (\mu_0 c e^2)$. See ref.[1].
Magnetic flux quantum Φ_0	2.067 833 667[52] e-15	$kg.m^2.s^{-2}.A^{-1}$	Wb	= h / 2e
Conductance quantum G_0	7.748 091 7004[53] e-5	$kg^{-1}.m^{-2}.s^3.A^2$	S	$= 2e^2 / h$
Inverse of conductance quantum	1.290 640 377 87[88] e+4	$kg.m^2.s^{-3}.A^{-2}$	Ω	$= R_K / 2$
Josephson constant K_J	4.835 978 91[12] e14	$kg^{-1}.m^{-2}.s^2.A$	Hz/V	= 2e / h . Conventional: **483597.9 GHz/V**
von Klitzing constant R_K	2.581 280 755 7[18] e+4	$kg.m^2.s^{-3}.A^{-2}$	Ω	$= h / e^2$. Conventional: **25812.807 Ω**

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Electron and atomic physics constants				
Electron rest mass m_e	**9.109 382 15[45] e-31**	kg	kg	= 0.510 998 910[13] MeV
Electron rest mass m_e in atomic units	5.485 799 094 2[23] e-4	u	u	
Electron charge/mass ratio	- 1.758 820 150[44] e11	$kg^{-1}.s.A$	C/kg	$= e / m_e$
Compton wavelength of electron	2.426 310 217 5[33] e-12	m	m	$\lambda_{C,e} = h / c\, m_e$
Classical electron radius r_e	2.817 940 289 4[58] e-15	m	m	$= e^2 / (4\pi\varepsilon_0 m_e c^2)$
Thomson cross section σ_e	0.665 245 855 8[27] e-28	m^2	m^2	$= (8\pi/3)\, r_e^2$
Quantum of circulation	3.636 947 519 9[50] e-4	$m^2.s^{-1}$	m^2/s	$= h / 2m_e$
Bohr magneton μ_B	9.274 009 15[23] e-24	$m^2.A$	J/T	$= 2\pi\, h\, e / m_e$
Electron spin S_e	**1/2**	Dimensionless		
Electron magnetic moment μ_e	**- 9.284 763 77[23] e-24**	$m^2.A$	J/T	**Last update July 2006**
Electron g-factor	- 2.002 319 304 362 2[15]	Dimensionless		$= \mu_e / (S_e\, \mu_B)$.
Electron/Proton magnetic moments ratio	- 658.210 684 8[54]	Dimensionless		
Electron/Proton magnetic moments ratio	- 658.227 597 1[72]	Dimensionless		**Shielded** in water; standard conditions
Electron gyromagnetic ratio γ_e	28.024 953 64[70] e+9	$kg^{-1}.s.A$	Hz/T	$\gamma_e = \mu_e / h\, S_e$
Rydberg constant R∞	1.097373 156 852 7[73] e+7	m^{-1}	m^{-1}	$= c\, \alpha^2\, m_e / 2h$
Hartree energy E_H	4.359 743 94[22] e-18	$kg.m^2.s^{-2}$	J	$= \alpha^2\, m_e\, c^2 = 2h\, c\, R_\infty$
Bohr radius	5.291 772 08 59[36] e-11	m	m	$= \alpha / (4\pi\, R_\infty)$

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Physico-chemical constants				
Atomic mass constant u	**1.660 538 782[83] e-27**	kg	kg	Mass of ^{12}C nuclide / 12
Molar mass of ^{12}C	**12 e-3**	kg	kg	**Assigned**
Molar mass constant	**1 e-3**	$kg.mol^{-1}$	kg/mol	**Assigned**
Boltzmann constant k	**1.380 6504[24] e-23**	$kg.m^2.s^{-2}.K^{-1}$	J/K	Sets thermodynamic temperature
Boltzmann constant in eV/K	**86.173 43[15] e-6**	$kg.m^2.s^{-3}.A^{-1}.K^{-1}$	V/K	= k/e. Electrochemical potential ~ (k/e)T ln(c1/c2)
Avogadro's number N_A	**6.022 141 79[30] e+23**	mol^{-1}	mol^{-1}	Particles in a mole of substance
Molar Planck constant	3.990 312 682 1[57] e-10	$kg.m^2.s^{-1}.mol^{-1}$	J.s/mol	= h N_A
Molar Planck constant by c	0.119 626 564 72[17]	$kg.m^3.s^{-2}.mol^{-1}$	J.m/mol	= h c N_A
Electron molar mass	5.485 799 094 3[23] e-7	$kg.mol^{-1}$	kg/mol	= m_e N_A
Electron molar charge	-9.648 533 99[24] e+4	$s.A.mol^{-1}$	C/mol	= e N_A.
Faraday constant F	9.648 533 99[24] e+4	$s.A.mol^{-1}$	C/mol	= |electron molar charge|.
Molar gas constant R	8.314 472[15]	$kg.m^2.s^{-2}.K^{-1}.mol^{-1}$	J/K.mol	= k N_A
Molar volume of ideal gas V_m	22.413 996[39] e-3	$m^3.mol^{-1}$	m^3/mol	= (RT/p) at T=273.15 K, p=101325 Pa
Loschmidt constant n_0	2.686 777 4[47] e25	m^{-3}	m^{-3}	= N_A / V_m at T=273.15 K, p=101325 Pa
Sackur-Tetrode constant S_0/R	- 1.151 704 7[44]	Dimensionless		$(5/2)+\ln[(2\pi m_u kT/h^2)(kT/p)]$ at T=1K, p=100 kPa.

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Electromagnetic radiation constants				
Stefan-Boltzmann const. σ	5.670 400[40] e-8	$kg.s^{-3}.K^{-4}$	$W/m^2.K^4$	$= 2\ \pi^5\ k^4 / 15\ h^3\ c^2$
1st radiation constant c_1	3.741 771 18[19] e-16	$kg.m^4.s^{-3}$	$W.m^2$	$= 2\ \pi\ h\ c^2$
2nd radiation constant c_2	1.438 775 2[25] e-2	m.K	m.K	= h c / k
Wien displacement constant	2.897 768 5[51] e-3	m.K	m.K	$= \lambda_{max}T = c_2 /$ 4.9651423...
Max.luminous efficacy; absolute	683	$cd.sr.kg^{-1}.m^{-1}.s^3$	lm/W	100% efficient, ideal 555 nm light source.
Max.luminous efficacy: black-body	95	$cd.sr.kg^{-1}.m^{-1}.s^3$	lm/W	Achieved at 7000 °K.
Solar luminous efficacy	93	$cd.sr.kg^{-1}.m^{-1}.s^3$	lm/W	
Solar illuminance	1.280[10] e5	$cd.sr.m^{-2}$	lx	in the brightest sunlight, on Earth
Solar constant	1.36594[48] e3	$kg.s^{-3}$	W/m^2	total solar elmag irradiation at 1 AU distance

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Conventional constants				
Standard gravity acceleration	**9.806 65**	$m.s^{-2}$	m/s^2	**Assigned**. Called **1 g** (gee).
Standard atmosphere	**101 325**	Pa		**Assigned**. Called **1 atm**.
Molar mass constant	**0.001**	$kg.mol^{-1}$	kg/mol	**Assigned (exact)**
Molar mass of ^{12}C	**0.012**	kg	kg	**Assigned (exact)**
SI conversion factors				
Electron volt	1.602 176 487[40] e-19	$kg.m^2.s^{-2}$	J	
Astronomical unit ua, au	1.495 978 70[30] e+11	m	m	Mean Earth-to-Sun distance
Atomic mass constant u, m_u	1.660 538 782[83] e-27	kg	kg	Mass of ^{12}C nuclide / 12

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Nuclear and particle physics constants				
Fermi coupling $G_F/(hc/2\pi)^3$	**3.670 336[31] e+48**	kg^{-2}		= (1.026 8365[88] e-5) / m_p^2
Fermi coupling in eV^{-2}	1.166 37[1] e+4	eV^{-2}		
Weak mixing angle $\sin^2\theta_W$	**0.222 55[56]**	Dimensionless		= 1- $(m_W/m_Z)^2$
Proton rest mass m_p	**1.672 621 637[83] e-27**	kg	kg	938.272 013[23] MeV = 1.007 276 466 77[10] u
Nuclear magneton μ_N	5.050 783 24[13] e-27	m^2.A	J/T	= 2π h e / m_p
Nuclear magneton in Hz/T	7.622 593 84[19] e+6	kg^{-1}.s.A	Hz/T	= μ_N/h = [Larmor freq.]/[g-factor].
Compton wavelength of proton	1.321 409 844 6[19] e-15	m	m	$\lambda_{C,p}$ = h / c m_p
Proton magnetic moment	**1.410 606 662[37] e-26**	m^2.A	J/T	$\boldsymbol{\mu_p}$
Proton g-factor	5.585 694 713[46]	Dimensionless		= μ_p / (S_p μ_N)
Proton gyromagnetic ratio	42.577 482 1[11] e+6	kg^{-1}.s.A	Hz/T	$\boldsymbol{\gamma_p}$ = μ_p / h S_p.
Proton gyromagnetic ratio shielded	42.576 388 1[12] e+6	kg^{-1}.s.A	Hz/T	In H_2O, standard conditions
Proton magnetic shielding	**25.694[14] e-6**	Dimensionless		Relative value
Proton rms charge radius	**0.8768[69] e-15**	m	m	
Neutron rest mass m_n	**1.674 927 211[84] e-27**	kg	kg	939.565 346[23] MeV = 1.008 664 915 97[43] u
Compton wavelength of neutron	1.319 590 895 1[20] e-15	m	m	$\lambda_{C,n}$ = h / c m_n

Constants of physics and mathematics

Constant	Value	Dimension	Alias	Definition & Notes
Nuclear and particle physics constants				
Neutron magnetic moment	**- 0.966 236 41[23] e-26**	$m^2.A$	/T	$\boldsymbol{\mu_n}$
Neutron g-factor	-3.826 085 45[90]	Dimensionless		$= \mu_n / (S_n\ \mu_N)$
Neutron gyromagnetic ratio	29.164 695 4[69] e+6	$kg^{-1}.s.A$	Hz/T	$\boldsymbol{\gamma_n} = \mu_n / h\ S_n$
Muon rest mass	**1.883 531 30[11] e-28**	kg	kg	105.658 3668[38] MeV = 0.113 428 925 6[29] u
Muon magnetic moment	**-4.490 447 86[16] e-26**	$m^2.A$	J/T	
Muon g-factor	-2.002 331 841 4[12]	Dimensionless		
Muon gyromagnetic ratio	135.538 817[12] e+6	$kg^{-1}.s.A$	Hz/T	$= \mu_n / h\ S_n$
Tau rest mass	**3.167 77[52] e-27**	kg	kg	1776.99[29] MeV = 1.907 68[31] u
Deuteron rest mass	**3.343 583 20[17] e-27**	kg	kg	1875.612 793[47] MeV = 2.013 553 212 724[78] u
Deuteron magnetic moment	**0.433 073 465[11] e-26**	$m^2.A$	J/T	
Deuteron g-factor	0.857 438 2308[72]	Dimensionless		
Deuteron gyromagnetic ratio	6.535 903 381 41 e+6	$kg^{-1}.s.A$	Hz/T	
Helion rest mass	**5.006 411 92[25] e-27**	kg	kg	2808.391 383[70] MeV = 3.014 932 247 3[26] u
Helion magnetic moment	**-1.074 5532 982[30] e-26**	$m^2.A$	J/T	Shielded
Helion gyromagnetic ratio	32.434 101 98[90] e+6	$kg^{-1}.s.A$	Hz/T	Shielded
α-particle rest mass	**6.644 656 20[33] e-27**	kg	kg	3727.379 109[93] MeV = 4.001 506 179 127[62] u

Thank you for attention!

Any suggestion or comment, please, send to:

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