Physical constant

A **physical constant** is a physical quantity that is generally believed to be both universal in nature and constant in time. It can be contrasted with a mathematical constant, which is a fixed numerical value but does not directly involve any physical measurement.

There are many physical constants in science, some of the most widely recognized being the speed of light in vacuum c, the gravitational constant G, Planck's constant h, the electric constant ε_0, and the elementary charge e. Physical constants can take many dimensional forms: the speed of light signifies a maximum speed limit of the universe and is expressed dimensionally as length divided by time; while the fine-structure constant α, which characterizes the strength of the electromagnetic interaction, is dimensionless.

Dimensional and dimensionless physical constants

Whereas the physical quantity indicated by any physical constant does not depend on the unit system used to express the quantity, the numerical values of dimensionful physical constants do depend on the unit used. Therefore, these numerical values (such as 299,792,458 for the constant speed of light c expressed in units of meters per second) are not values that a theory of physics can be expected to predict.

Because their units cancel, ratios of like-dimensioned physical constants do not depend on unit systems in this way, so they are pure dimensionless numbers whose values a future theory of physics could conceivably hope to predict. Additionally, all equations describing laws of physics can be expressed without dimensional physical constants via a process known as nondimensionalisation, but the dimensionless constants will remain. Thus, theoretical physicists tend to regard these dimensionless quantities as fundamental physical constants.

However, the term *fundamental physical constant* is also used in other ways. For example, the National Institute of Standards and Technology[1] uses the term to refer to any universal physical quantity believed to be constant, such as the speed of light, c, and the gravitational constant G.

The fine-structure constant α is probably the best known dimensionless fundamental physical constant. Many attempts have been made to derive its value (currently measured at about 1/137.035999) from theory, but so far none have succeeded. The same holds for the dimensionless ratios of masses of fundamental particles (the most apparent is m_p/m_e, approximately 1836.152673). With the development of quantum chemistry in the 20th century, however, a vast number of previously inexplicable dimensionless physical constants *were* successfully computed from theory. As such, some theoretical physicists still hope for continued progress in explaining the values of other dimensionless physical constants.

It is known that the universe would be very different if these constants took values significantly different from those we observe. For example, a few percent change in the value of the fine structure constant would be enough to eliminate stars like our Sun. This has prompted attempts at anthropic explanations of the values of some of the dimensionless fundamental physical constants.

How constant are the physical constants?

Beginning with Paul Dirac in 1937, some scientists have speculated that physical constants may actually decrease in proportion to the age of the universe. Scientific experiments have not yet pinpointed any definite evidence that this is the case, although they have placed upper bounds on the maximum possible relative change per year at very small amounts (roughly 10^{-5} per year for the fine structure constant α and 10^{-11} for the gravitational constant *G*).

It is currently disputed[2] [3] whether any changes in *dimensional* physical constants such as *G*, *c*, *ħ*, or ε_0 are operationally meaningful;[4] however, a sufficient change in a dimensionless constant such as α is generally agreed to be something that would definitely be noticed. If a measurement indicated that a dimensional physical constant had changed, this would be the result or *interpretation* of a more fundamental dimensionless constant changing, which is the salient metric. From John D. Barrow 2002:

> [An] important lesson we learn from the way that pure numbers like α define the world is what it really means for worlds to be different. The pure number we call the fine structure constant and denote by α is a combination of the electron charge, *e*, the speed of light, *c*, and Planck's constant, *h*. At first we might be tempted to think that a world in which the speed of light was slower would be a different world. But this would be a mistake. If *c*, *h*, and *e* were all changed so that the values they have in metric (or any other) units were different when we looked them up in our tables of physical constants, but the value of α remained the same, this new world would be *observationally indistinguishable* from our world. The only thing that counts in the definition of worlds are the values of the dimensionless constants of Nature. If all masses were doubled in value you cannot tell because all the pure numbers defined by the ratios of any pair of masses are unchanged.

Anthropic principle

Some physicists have explored the notion that if the dimensionless physical constants had sufficiently different values, our universe would be so radically different that intelligent life would probably not have emerged, and that our universe therefore seems to be fine-tuned for intelligent life. The anthropic principle states a logical truism: the fact of our existence as intelligent beings who can measure physical constants requires those constants to be such that beings like us can exist. There are a variety of interpretations of the constants' values, including a divine creator (the apparent fine-tuning is actual and intentional), or that ours is one universe of many in a multiverse (e.g. the Many-worlds interpretation of quantum mechanics), or even that a universe without the capacity for conscious beings cannot exist.

Table of universal constants

Quantity	**Symbol**	**Value**[5]	**Relative Standard Uncertainty**
speed of light in vacuum	c	299 792 458 $m \cdot s^{-1}$	defined
Newtonian constant of gravitation	G	$6.67428(67) \times 10^{-11}\ m^3 \cdot kg^{-1} \cdot s^{-2}$	1.0×10^{-4}
Planck constant	h	$6.626\ 068\ 96(33) \times 10^{-34}$ J·s	5.0×10^{-8}
reduced Planck constant	$\hbar = h/(2\pi)$	$1.054\ 571\ 628(53) \times 10^{-34}$ J·s	5.0×10^{-8}

Table of electromagnetic constants

Quantity	Symbol	Value[5] (SI units)	Relative Standard Uncertainty
magnetic constant (vacuum permeability)	μ_0	$4\pi \times 10^{-7}$ N·A^{-2} = 1.256 637 061... × 10^{-6} N·A^{-2}	defined
electric constant (vacuum permittivity)	$\varepsilon_0 = 1/(\mu_0 c^2)$	8.854 187 817... × 10^{-12} F·m^{-1}	defined
characteristic impedance of vacuum	$Z_0 = \mu_0 c$	376.730 313 461... Ω	defined
Coulomb's constant	$k_e = 1/4\pi\varepsilon_0$	8.987 551 787... × 10^{9} N·m²·C^{-2}	defined
elementary charge	e	1.602 176 487(40) × 10^{-19} C	2.5 × 10^{-8}
Bohr magneton	$\mu_B = e\hbar/2m_e$	9.274 009 15(23) × 10^{-24} J·T^{-1}	2.5 × 10^{-8}
conductance quantum	$G_0 = 2e^2/h$	7.748 091 700 4(53) × 10^{-5} S	6.8 × 10^{-10}
inverse conductance quantum	$G_0^{-1} = h/2e^2$	12 906.403 778 7(88) Ω	6.8 × 10^{-10}
Josephson constant	$K_J = 2e/h$	4.835 978 91(12) × 10^{14} Hz·V^{-1}	2.5 × 10^{-8}
magnetic flux quantum	$\phi_0 = h/2e$	2.067 833 667(52) × 10^{-15} Wb	2.5 × 10^{-8}
nuclear magneton	$\mu_N = e\hbar/2m_p$	5.050 783 43(43) × 10^{-27} J·T^{-1}	8.6 × 10^{-8}
von Klitzing constant	$R_K = h/e^2$	25 812.807 557(18) Ω	6.8 × 10^{-10}

Table of atomic and nuclear constants

Quantity	Symbol	Value[5] (SI units)	Relative Standard Uncertainty
Bohr radius	$a_0 = \alpha/4\pi R_\infty$	5.291 772 108(18) × 10^{-11} m	3.3 × 10^{-9}
classical electron radius	$r_e = e^2/4\pi\varepsilon_0 m_e c^2$	2.817 940 289 4(58) × 10^{-15} m	2.1 × 10^{-9}
electron mass	m_e	9.109 382 15(45) × 10^{-31} kg	5.0 × 10^{-8}
Fermi coupling constant	$G_F/(\hbar c)^3$	1.166 39(1) × 10^{-5} GeV^{-2}	8.6 × 10^{-6}
fine-structure constant	$\alpha = \mu_0 e^2 c/(2h) = e^2/(4\pi\varepsilon_0 \hbar c)$	7.297 352 537 6(50) × 10^{-3}	6.8 × 10^{-10}
Hartree energy	$E_h = 2R_\infty hc$	4.359 744 17(75) × 10^{-18} J	1.7 × 10^{-7}
proton mass	m_p	1.672 621 637(83) × 10^{-27} kg	5.0 × 10^{-8}
quantum of circulation	$h/2m_e$	3.636 947 550(24) × 10^{-4} m² s^{-1}	6.7 × 10^{-9}
Rydberg constant	$R_\infty = \alpha^2 m_e c/2h$	10 973 731.568 525(73) m^{-1}	6.6 × 10^{-12}
Thomson cross section	$(8\pi/3)r_e^2$	6.652 458 73(13) × 10^{-29} m²	2.0 × 10^{-8}
weak mixing angle	$\sin^2\theta_W = 1 - (m_W/m_Z)^2$	0.222 15(76)	3.4 × 10^{-3}

Table of physico-chemical constants

Quantity		Symbol	Value[5] (SI units)	Relative Standard Uncertainty
atomic mass unit (unified atomic mass unit)		$m_u = 1\ u$	1.660 538 86(28) × 10^{-27} kg	1.7 × 10^{-7}
Avogadro's number		N_A, L	6.022 141 5(10) × 10^{23} mol^{-1}	1.7 × 10^{-7}
Boltzmann constant		$k = k_B = R/N_A$	1.380 650 4(24) × 10^{-23} $J{\cdot}K^{-1}$	1.8 × 10^{-6}
Faraday constant		$F = N_A e$	96 485.338 3(83)$C{\cdot}mol^{-1}$	8.6 × 10^{-8}
first radiation constant		$c_1 = 2\pi hc^2$	3.741 771 18(19) × 10^{-16} $W{\cdot}m^2$	5.0 × 10^{-8}
	for spectral radiance	c_{1L}	1.191 042 82(20) × 10^{-16} $W{\cdot}m^2\ sr^{-1}$	1.7 × 10^{-7}
Loschmidt constant	at T=273.15 K and p =101.325 kPa	$n_0 = N_A/V_m$	2.686 777 3(47) × 10^{25} m^{-3}	1.8 × 10^{-6}
gas constant		R	8.314 472(15) $J{\cdot}K^{-1}{\cdot}mol^{-1}$	1.7 × 10^{-6}
molar Planck constant		$N_A h$	3.990 312 716(27) × 10^{-10} $J{\cdot}s{\cdot}mol^{-1}$	6.7 × 10^{-9}
molar volume of an ideal gas	at T=273.15 K and p =100 kPa	$V_m = RT/p$	2.271 098 1(40) × 10^{-2} $m^3{\cdot}mol^{-1}$	1.7 × 10^{-6}
	at T=273.15 K and p =101.325 kPa		2.241 399 6(39) × 10^{-2} $m^3{\cdot}mol^{-1}$	1.7 × 10^{-6}
Sackur-Tetrode constant	at T=1 K and p=100 kPa	$S_0/R = \frac{5}{2} + \ln\left[(2\pi m_u kT/h^2)^{3/2} kT/p\right]$	−1.151 704 7(44)	3.8 × 10^{-6}
	at T=1 K and p =101.325 kPa		−1.164 867 7(44)	3.8 × 10^{-6}
second radiation constant		$c_2 = hc/k$	1.438 775 2(25) × 10^{-2} $m{\cdot}K$	1.7 × 10^{-6}
Stefan–Boltzmann constant		$\sigma = (\pi^2/60)k^4/\hbar^3 c^2$	5.670 400(40) × 10^{-8} $W{\cdot}m^{-2}{\cdot}K^{-4}$	7.0 × 10^{-6}
Wien displacement law constant		$b = (hc/k)/$ 4.965 114 231...	2.897 768 5(51) × 10^{-3} $m{\cdot}K$	1.7 × 10^{-6}

Table of adopted values

Quantity		Symbol	Value (SI units)	Relative Standard Uncertainty
conventional value of Josephson constant[6]		K_{J-90}	$4.835\,979 \times 10^{14}$ Hz·V^{-1}	defined
conventional value of von Klitzing constant[7]		R_{K-90}	25 812.807 Ω	defined
molar mass	constant	$M_u = M(\,^{12}\mathrm{C})/12$	1×10^{-3} kg·mol^{-1}	defined
	of carbon-12	$M(\,^{12}\mathrm{C}) = N_A m(\,^{12}\mathrm{C})$	1.2×10^{-2} kg·mol^{-1}	defined
standard acceleration of gravity (gee, free-fall on Earth)		g_n	9.806 65 m·s^{-2}	defined
standard atmosphere		atm	101 325 Pa	defined

Natural units

Using dimensional analysis, it is possible to combine fundamental physical constants to produce basic units of measurement. Depending on the choice and arrangement of constants used, the resulting natural units may have physical meaning. For example, Planck units, presented below, use c, G, $\hbar$, ε_0 and k to derive constants relevant to unified theories, including quantum gravity.

Name	Dimension	Expression	Value[8] (SI units)
Planck length	Length (L)	$l_\mathrm{P} = \sqrt{\frac{\hbar G}{c^3}}$	$1.616\,252(81) \times 10^{-35}$ m
Planck mass	Mass (M)	$m_\mathrm{P} = \sqrt{\frac{\hbar c}{G}}$	$2.176\,44(11) \times 10^{-8}$ kg
Planck time	Time (T)	$t_\mathrm{P} = \frac{l_\mathrm{P}}{c} = \frac{\hbar}{m_\mathrm{P} c^2} = \sqrt{\frac{\hbar G}{c^5}}$	$5.391\,24(27) \times 10^{-44}$ s
Planck charge	Electric charge (Q)	$q_\mathrm{P} = \sqrt{4\pi\varepsilon_0 \hbar c}$	$1.875\,545\,870(47) \times 10^{-18}$ C
Planck temperature	Temperature (Θ)	$T_\mathrm{P} = \frac{m_\mathrm{P} c^2}{k_B} = \sqrt{\frac{\hbar c^5}{G k_B^2}}$	$1.416\,785(71) \times 10^{32}$ K

Notes

[1] Latest (2006) Values of the Constants (http://physics.nist.gov/cuu/Constants/); NIST, 2006.
[2] Duff, Michael J. " Comment on time-variation of fundamental constants (http://www.arxiv.org/abs/hep-th/0208093)." High Energy Physics - Theory, 2004.
[3] Duff, M. J.; Okun, L. B.; Veneziano, G. " Trialogue on the number of fundamental constants (http://www.arxiv.org/abs/physics/0110060)." Classical Physics, 2002.
[4] *c*, and ε_0 now are *defined* numerical values, independent of experiment, so observations now are trained elsewhere, for example, upon a changing value of the meter.
[5] The values are given in the so-called *concise form*; the number in brackets is the *standard uncertainty*, which is the value multiplied by the *relative standard uncertainty*.
[6] This is the value adopted internationally for realizing representations of the volt using the Josephson effect.
[7] This is the value adopted internationally for realizing representations of the ohm using the quantum Hall effect.
[8] Fundamental Physical Constants from NIST (http://physics.nist.gov/cuu/Constants/index.html).

References

- Mohr, Peter J.; Taylor, Barry N.; Newell, David B. (2008). "CODATA Recommended Values of the Fundamental Physical Constants: 2006" (http://physics.nist.gov/cuu/Constants/codata.pdf). *Rev. Mod. Phys.* **80**: 633–730. doi:10.1103/RevModPhys.80.633.
- Barrow, John D., *The Constants of Nature; From Alpha to Omega - The Numbers that Encode the Deepest Secrets of the Universe*. Pantheon Books, 2002. ISBN 0-375-42221-8.

External links

- Sixty Symbols (http://www.sixtysymbols.com/#), University of Nottingham
- IUPAC - Gold Book (http://goldbook.iupac.org/list_goldbook_phys_constants_defs.html)

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