

Physical constants sheet: 2018 CODATA values, units and where each one appears

Constant	Symbol	Value	Units	Appears in
Permittivity of free space (epsilon naught)	ϵ_0	$8.8541878128 \times 10^{-12}$	$F/m = C^2/(N \cdot m^2)$	Coulomb's law, capacitance
Coulomb's constant	$k = 1/(4\pi\epsilon_0)$	8.9875517923×10^9	$N \cdot m^2/C^2$	$F = kq_1q_2/r^2$
Permeability of free space (mu naught)	μ_0	$1.25663706212 \times 10^{-6}$ ($= 4\pi \times 10^{-7}$)	$N/A^2 = H/m = T \cdot m/A$	fields of wires and coils
Speed of light in vacuum	c	299,792,458 (exact)	m/s	$E = mc^2$, $c = f\lambda$, $c^2 = 1/(\mu_0\epsilon_0)$
Elementary charge	e	$1.602176634 \times 10^{-19}$ (exact)	C	proton charge; 1 eV = 1.602×10^{-19} J
Planck's constant	h	$6.62607015 \times 10^{-34}$ (exact)	J·s	$E = hf$; $\lambda = h/p$
Reduced Planck constant	$\hbar = h/2\pi$	$1.054571817 \times 10^{-34}$	J·s	quantum mechanics
Boltzmann's constant	k , k_B	1.380649×10^{-23} (exact)	J/K	$KE = (3/2)kT$; $S = k \ln W$
Avogadro's number	N_A	$6.02214076 \times 10^{23}$ (exact)	mol^{-1}	particles in a mole
Gas constant	$R = N_A k$	8.314462618	J/(mol·K)	$PV = nRT$
Faraday constant	$F = N_A e$	96,485.33212	C/mol	electrolysis $Q = nF$
Atomic mass unit	u (Da)	$1.66053906660 \times 10^{-27}$	kg	$= 931.494 \text{ MeV}/c^2$
Proton mass	m_p	$1.67262192369 \times 10^{-27}$	kg	1.007276 u; 938.272 MeV/ c^2
Neutron mass	m_n	$1.67492749804 \times 10^{-27}$	kg	1.008665 u; 939.565 MeV/ c^2
Electron mass	m_e	$9.1093837015 \times 10^{-31}$	kg	0.000549 u; 0.510999 MeV/ c^2
Gravitational constant	G	6.67430×10^{-11}	$N \cdot m^2/kg^2$	$F = Gm_1m_2/r^2$
Standard gravity	g	9.80665 (defined)	m/s^2	weight = mg
Stefan-Boltzmann constant	σ	$5.670374419 \times 10^{-8}$	$W/(m^2 \cdot K^4)$	$P = \sigma AT^4$
Rydberg constant	R_∞	1.0973731568×10^7	m^{-1}	hydrogen spectrum
Bohr radius	a_0	$5.29177210903 \times 10^{-11}$	m	size of the hydrogen atom
Fine-structure constant	α	$7.2973525693 \times 10^{-3}$ (1/137.036)	none	strength of electromagnetism
Wien's constant	b	$2.897771955 \times 10^{-3}$	$m \cdot K$	$\lambda_{\text{max}} = b/T$
Standard atmosphere	atm	101,325 (exact)	Pa	pressure conversions
Absolute zero		-273.15	°C	$K = ^\circ C + 273.15$

Since the 2019 SI redefinition e , h , k and N_A are exact; μ_0 and ϵ_0 are now measured (via α), differing from $4\pi \times 10^{-7}$ only in the tenth figure.

The particle masses in all three units

Particle	kg	u	MeV/ c^2
proton	1.67262×10^{-27}	1.007276	938.272
neutron	1.67493×10^{-27}	1.008665	939.565
electron	9.10938×10^{-31}	0.000549	0.510999
hydrogen-1 atom	1.67353×10^{-27}	1.007825	938.783
alpha particle	6.64466×10^{-27}	4.001506	3,727.38
1 u	1.66054×10^{-27}	1	931.494

From

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R in every unit, the formulas, and practice

The gas constant R: match the pressure and volume units of the question

Pressure	Volume	R
Pa	m ³	8.314 J/(mol·K)
kPa	L	8.314 kPa·L/(mol·K)
atm	L	0.08206 L·atm/(mol·K)
Torr or mmHg	L	62.36 L·Torr/(mol·K)
bar	L	0.08314 L·bar/(mol·K)
thermochemistry		1.987 cal/(mol·K)

The formulas the constants live in

- [] Coulomb's law $F = q_1q_2 / (4\pi\epsilon_0 r^2) = kq_1q_2/r^2$; capacitor $C = \epsilon_0 A/d$; Gauss: flux = Q/ϵ_0
- [] Wire $B = \mu_0 I/(2\pi r)$; solenoid $B = \mu_0 nI$; parallel wires $F/L = \mu_0 I_1 I_2/(2\pi d)$; $c = 1/\sqrt{\mu_0 \epsilon_0}$
- [] Gas: $PV = nRT$; per molecule $KE = (3/2)kT$; per mole $(3/2)RT$; $R = N_A k$; $F = N_A e$
- [] Mass-energy: $E = mc^2$; $1 \text{ u} = 931.494 \text{ MeV}/c^2$; binding energy = mass defect (u) $\times 931.494 \text{ MeV}$
- [] Photons: $E = hf = hc/\lambda$; de Broglie $\lambda = h/p$; Wien $\lambda_{\text{max}} = b/T$; Stefan $P = \sigma AT^4$
- [] Conversions: $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$; $K = ^\circ\text{C} + 273.15$; $1 \text{ atm} = 101,325 \text{ Pa} = 760 \text{ Torr}$

Practice

- [] 1. Write k in terms of ϵ_0 and compute it.
- [] 2. $+2 \mu\text{C}$ and $-3 \mu\text{C}$, 0.2 m apart: the force?
- [] 3. Magnetic field 2 cm from a wire carrying 5 A?
- [] 4. Convert the proton mass 1.007276 u into kg and MeV/c^2 .
- [] 5. Binding energy for a mass defect of 0.1 u?
- [] 6. 0.5 mol of gas at 2 atm and 27 $^\circ\text{C}$: volume in litres?
- [] 7. The same in SI units: convert and check.
- [] 8. Average kinetic energy of a gas molecule at 500 K?
- [] 9. Molecules in 9 g of water ($M = 18 \text{ g/mol}$)?
- [] 10. Show from μ_0 and ϵ_0 that c is about $3 \times 10^8 \text{ m/s}$.

Answers

- 1) $1/(4\pi \times 8.854 \times 10^{-12}) = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ 2) 1.35 N attractive 3) $5 \times 10^{-5} \text{ T}$ 4) $1.6726 \times 10^{-27} \text{ kg}$; $938.27 \text{ MeV}/c^2$ 5) 93.1 MeV 6) 6.15 L 7) $P = 202,650 \text{ Pa}$, $V = 0.00615 \text{ m}^3 = 6.15 \text{ L}$ 8) $1.04 \times 10^{-20} \text{ J}$ 9) 3.01×10^{23} 10) $1/\sqrt{(1.1127 \times 10^{-17})} = 2.998 \times 10^8 \text{ m/s}$