Notazione

Symbol	Definition	Units or Value
α	Fine structure constant ($e^2/4\pi\epsilon_0\hbar c$)	$1/137.035\,999\,11(46)$
M	Incident particle mass	MeV$/c^2$
E	Incident particle energy $\gamma M c^2$	MeV
T	Kinetic energy	MeV
$m_e c^2$	Electron mass $\times\ c^2$	$0.510\,998\,918(44)$ MeV
r_e	Classical electron radius $e^2/4\pi\epsilon_0 m_e c^2$	$2.817\,940\,325(28)$ fm
N_A	Avogadro's number	$6.022\,1415(10) \times 10^{23}$ mol^{-1}
ze	Charge of incident particle	
Z	Atomic number of absorber	
A	Atomic mass of absorber	g mol^{-1}
K/A	$4\pi N_A r_e^2 m_e c^2/A$	$0.307\,075$ MeV g^{-1} cm^2 for A = 1 g mol^{-1}
I	Mean excitation energy	eV (*Nota bene!*)
δ	Density effect correction to ionization energy loss	
$\hbar\omega_p$	Plasma energy ($\sqrt{4\pi N_e r_e^3}\ m_e c^2/\alpha$)	$28.816\sqrt{\rho\langle Z/A\rangle}$ eV$^{(a)}$
N_c	Electron density	(units of r_e)$^{-3}$
w_j	Weight fraction of the jth element in a compound or mixture	
n_j	$\propto$ number of jth kind of atoms in a compound or mixture	
—	$4\alpha r_e^2 N_A/A$	$(716.408$ g cm$^{-2})^{-1}$ for $A = 1$ g mol^{-1}
X_0	Radiation length	g cm^{-2}
E_c	Critical energy for electrons	MeV
$E_{\mu c}$	Critical energy for muons	GeV
E_s	Scale energy $\sqrt{4\pi/\alpha}\ m_e c^2$	21.2052 MeV
R_M	Molière radius	g cm^{-2}

Costanti fondamentali (1/2)

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	$299\,792\,458$ m s^{-1}	exact*
Planck constant	h	$6.626\,0693(11)\times10^{-34}$ J s	170
Planck constant, reduced	$\hbar \equiv h/2\pi$	$1.054\,571\,68(18)\times10^{-34}$ J s	170
		$= 6.582\,119\,15(56)\times10^{-22}$ MeV s	85
electron charge magnitude	e	$1.602\,176\,53(14)\times10^{-19}$ C $= 4.803\,204\,41(41)\times10^{-10}$ esu	85, 85
conversion constant	$\hbar c$	$197.326\,968(17)$ MeV fm	85
conversion constant	$(\hbar c)^2$	$0.389\,379\,323(67)$ GeV^2 mbarn	170
electron mass	m_e	$0.510\,998\,918(44)$ MeV$/c^2 = 9.109\,3826(16)\times10^{-31}$ kg	86, 170
proton mass	m_p	$938.272\,029(80)$ MeV$/c^2 = 1.672\,621\,71(29)\times10^{-27}$ kg	86, 170
		$= 1.007\,276\,466\,88(13)$ u $= 1836.152\,672\,61(85)\ m_e$	0.13, 0.46
deuteron mass	m_d	$1875.612\,82(16)$ MeV$/c^2$	86
unified atomic mass unit (u)	(mass ^{12}C atom)/12 = (1 g)/(N_A mol)	$931.494\,043(80)$ MeV$/c^2 = 1.660\,538\,86(28)\times10^{-27}$ kg	86, 170
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854\,187\,817\ldots\times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi\times10^{-7}$ N A^{-2} $= 12.566\,370\,614\ldots\times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	$7.297\,352\,568(24)\times10^{-3} = 1/137.035\,999\,11(46)^\dagger$	3.3, 3.3
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$2.817\,940\,325(28)\times10^{-15}$ m	10
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	$3.861\,592\,678(26)\times10^{-13}$ m	6.7
Bohr radius ($m_{\text{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	$0.529\,177\,2108(18)\times10^{-10}$ m	3.3
wavelength of 1 eV/c particle	$hc/(1$ eV$)$	$1.239\,841\,91(11)\times10^{-6}$ m	85
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	$13.605\,6923(12)$ eV	85
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	$0.665\,245\,873(13)$ barn	20
Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\,381\,804(39)\times10^{-11}$ MeV T^{-1}	6.7
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\,451\,259(21)\times10^{-14}$ MeV T^{-1}	6.7
electron cyclotron freq./field	$\omega^e_{\text{cycl}}/B = e/m_e$	$1.758\,820\,12(15)\times10^{11}$ rad s^{-1} T^{-1}	86
proton cyclotron freq./field	$\omega^p_{\text{cycl}}/B = e/m_p$	$9.578\,833\,76(82)\times10^{7}$ rad s^{-1} T^{-1}	86
gravitational constant‡	G_N	$6.6742(10)\times10^{-11}$ m^3 kg^{-1} s^{-2}	1.5×10^5
		$= 6.7087(10)\times10^{-39}\ \hbar c$ (GeV$/c^2)^{-2}$	1.5×10^5
standard gravitational accel.	g_n	$9.806\,65$ m s^{-2}	exact

Costanti fondamentali (2/2)

Quantity	Symbol, equation	Value	Uncertainty (ppb)
Avogadro constant	N_A	$6.022\ 1415(10)\times10^{23}\ \text{mol}^{-1}$	170
Boltzmann constant	k	$1.380\ 6505(24)\times10^{-23}\ \text{J K}^{-1}$	1800
		$= 8.617\ 343(15)\times10^{-5}\ \text{eV K}^{-1}$	1800
molar volume, ideal gas at STP	$N_A k(273.15\ \text{K})/(101\ 325\ \text{Pa})$	$22.413\ 996(39)\times10^{-3}\ \text{m}^3\ \text{mol}^{-1}$	1700
Wien displacement law constant	$b = \lambda_{\text{max}} T$	$2.897\ 7685(51)\times10^{-3}\ \text{m K}$	1700
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	$5.670\ 400(40)\times10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	7000
Fermi coupling constant**	$G_F/(\hbar c)^3$	$1.166\ 37(1)\times10^{-5}\ \text{GeV}^{-2}$	9000
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ $(\overline{\text{MS}})$	$0.23120(15)^{\dagger\dagger}$	6.5×10^5
$W^\pm$ boson mass	m_W	$80.425(38)\ \text{GeV}/c^2$	4.8×10^5
Z^0 boson mass	m_Z	$91.1876(21)\ \text{GeV}/c^2$	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	$0.1187(20)$	1.7×10^7

$\pi = 3.141\ 592\ 653\ 589\ 793\ 238$ $\qquad$ $e = 2.718\ 281\ 828\ 459\ 045\ 235$ $\qquad$ $\gamma = 0.577\ 215\ 664\ 901\ 532\ 861$

$1\ \text{in} \equiv 0.0254\ \text{m}$ $\quad$ $1\ \text{G} \equiv 10^{-4}\ \text{T}$ $\quad$ $1\ \text{eV} = 1.602\ 176\ 53(14)\times10^{-19}\ \text{J}$ $\quad$ kT at $300\ \text{K} = [38.681\ 684(68)]^{-1}\ \text{eV}$

$1\ \text{Å} \equiv 0.1\ \text{nm}$ $\quad$ $1\ \text{dyne} \equiv 10^{-5}\ \text{N}$ $\quad$ $1\ \text{eV}/c^2 = 1.782\ 661\ 81(15)\times10^{-36}\ \text{kg}$ $\quad$ $0\ ^\circ\text{C} \equiv 273.15\ \text{K}$

$1\ \text{barn} \equiv 10^{-28}\ \text{m}^2$ $\quad$ $1\ \text{erg} \equiv 10^{-7}\ \text{J}$ $\quad$ $2.997\ 924\ 58\times10^9\ \text{esu} = 1\ \text{C}$ $\quad$ $1\ \text{atmosphere} \equiv 760\ \text{Torr} \equiv 101\ 325\ \text{Pa}$

Proprieta' dei materiali (1/2)

Material	Z	A	$\langle Z/A \rangle$	Nuclear [a] collision length λ_T {g/cm^2}	Nuclear [a] interaction length λ_I {g/cm^2}	$dE/dx\|_{\min}$ [b] $\left\{\frac{\text{MeV}}{\text{g/cm}^2}\right\}$	Radiation length [c] X_0 {g/cm^2}	Radiation length X_0 {cm}	Density {g/cm^3} ({g/ℓ} for gas)	Liquid boiling point at 1 atm(K)	Refractive index n ($(n-1)\times 10^6$ for gas)
H_2 gas	1	1.00794	0.99212	43.3	50.8	(4.103)	61.28 [d]	(731000)	(0.0838)[0.0899]		[139.2]
H_2 liquid	1	1.00794	0.99212	43.3	50.8	4.034	61.28 [d]	866	0.0708	20.39	1.112
D_2	1	2.0140	0.49652	45.7	54.7	(2.052)	122.4	724	0.169[0.179]	23.65	1.128 [138]
He	2	4.002602	0.49968	49.9	65.1	(1.937)	94.32	756	0.1249[0.1786]	4.224	1.024 [34.9]
Li	3	6.941	0.43221	54.6	73.4	1.639	82.76	155	0.534		—
Be	4	9.012182	0.44384	55.8	75.2	1.594	65.19	35.28	1.848		—
C	6	12.011	0.49954	60.2	86.3	1.745	42.70	18.8	2.265 [e]		—
N_2	7	14.00674	0.49976	61.4	87.8	(1.825)	37.99	47.1	0.8073[1.250]	77.36	1.205 [298]
O_2	8	15.9994	0.50002	63.2	91.0	(1.801)	34.24	30.0	1.141[1.428]	90.18	1.22 [296]
F_2	9	18.9984032	0.47372	65.5	95.3	(1.675)	32.93	21.85	1.507[1.696]	85.24	[195]
Ne	10	20.1797	0.49555	66.1	96.6	(1.724)	28.94	24.0	1.204[0.9005]	27.09	1.092 [67.1]
Al	13	26.981539	0.48181	70.6	106.4	1.615	24.01	8.9	2.70		—
Si	14	28.0855	0.49848	70.6	106.0	1.664	21.82	9.36	2.33		3.95
Ar	18	39.948	0.45059	76.4	117.2	(1.519)	19.55	14.0	1.396[1.782]	87.28	1.233 [283]
Ti	22	47.867	0.45948	79.9	124.9	1.476	16.17	3.56	4.54		—
Fe	26	55.845	0.46556	82.8	131.9	1.451	13.84	1.76	7.87		—
Cu	29	63.546	0.45636	85.6	134.9	1.403	12.86	1.43	8.96		—
Ge	32	72.61	0.44071	88.3	140.5	1.371	12.25	2.30	5.323		—
Sn	50	118.710	0.42120	100.2	163	1.264	8.82	1.21	7.31		—
Xe	54	131.29	0.41130	102.8	169	(1.255)	8.48	2.87	2.953[5.858]	165.1	[701]
W	74	183.84	0.40250	110.3	185	1.145	6.76	0.35	19.3		—
Pt	78	195.08	0.39984	113.3	189.7	1.129	6.54	0.305	21.45		—
Pb	82	207.2	0.39575	116.2	194	1.123	6.37	0.56	11.35		—
U	92	238.0289	0.38651	117.0	199	1.082	6.00	≈0.32	≈18.95		—

Proprieta' dei materiali (2/2)

Material	Z	A	$\langle Z/A \rangle$	Nuclear [a] collision length λ_T {g/cm^2}	Nuclear [a] interaction length λ_I {g/cm^2}	$dE/dx\|_{\min}$ [b] $\left\{\frac{\text{MeV}}{\text{g/cm}^2}\right\}$	Radiation length [c] X_0 {g/cm^2}	{cm}	Density {g/cm^3} ({g/ℓ} for gas)	Liquid boiling point at 1 atm(K)	Refractive index n (($n-1$)$\times 10^6$ for gas)
Air, (20°C, 1 atm.), [STP]			0.49919	62.0	90.0	(1.815)	36.66	[30420]	(1.205)[1.2931]	78.8	(273) [293]
H_2O			0.55509	60.1	83.6	1.991	36.08	36.1	1.00	373.15	1.33
CO_2 gas			0.49989	62.4	89.7	(1.819)	36.2	[18310]	[1.977]		[410]
CO_2 solid (dry ice)			0.49989	62.4	89.7	1.787	36.2	23.2	1.563	sublimes	—
Shielding concrete [f]			0.50274	67.4	99.9	1.711	26.7	10.7	2.5		—
SiO_2 (fused quartz)			0.49926	66.5	97.4	1.699	27.05	12.3	2.20 [g]		1.458
Dimethyl ether, $(CH_3)_2O$			0.54778	59.4	82.9	—	38.89	—	—	248.7	—
Methane, CH_4			0.62333	54.8	73.4	(2.417)	46.22	[64850]	0.4224[0.717]	111.7	[444]
Ethane, C_2H_6			0.59861	55.8	75.7	(2.304)	45.47	[34035]	0.509(1.356) [h]	184.5	(1.038) [h]
Propane, C_3H_8			0.58962	56.2	76.5	(2.262)	45.20	—	(1.879)	231.1	—
Isobutane, $(CH_3)_2CHCH_3$			0.58496	56.4	77.0	(2.239)	45.07	[16930]	[2.67]	261.42	[1900]
Octane, liquid, $CH_3(CH_2)_6CH_3$			0.57778	56.7	77.7	2.123	44.86	63.8	0.703	398.8	1.397
Paraffin wax, $CH_3(CH_2)_{n\approx 23}CH_3$			0.57275	56.9	78.2	2.087	44.71	48.1	0.93		—
Nylon, type 6 [i]			0.54790	58.5	81.5	1.974	41.84	36.7	1.14		—
Polycarbonate (Lexan) [j]			0.52697	59.5	83.9	1.886	41.46	34.6	1.20		—
Polyethylene terephthlate (Mylar) [k]			0.52037	60.2	85.7	1.848	39.95	28.7	1.39		—
Polyethylene [l]			0.57034	57.0	78.4	2.076	44.64	≈47.9	0.92–0.95		—
Polyimide film (Kapton) [m]			0.51264	60.3	85.8	1.820	40.56	28.6	1.42		—
Lucite, Plexiglas [n]			0.53937	59.3	83.0	1.929	40.49	≈34.4	1.16–1.20		≈1.49
Polystyrene, scintillator [o]			0.53768	58.5	81.9	1.936	43.72	42.4	1.032		1.581
Polytetrafluoroethylene (Teflon) [p]			0.47992	64.2	93.0	1.671	34.84	15.8	2.20		—
Polyvinyltolulene, scintillator [q]			0.54155	58.3	81.5	1.956	43.83	42.5	1.032		—
Aluminum oxide (Al_2O_3)			0.49038	67.0	98.9	1.647	27.94	7.04	3.97		1.761
Barium fluoride (BaF_2)			0.42207	92.0	145	1.303	9.91	2.05	4.89		1.56
Bismuth germanate (BGO) [r]			0.42065	98.2	157	1.251	7.97	1.12	7.1		2.15
Cesium iodide (CsI)			0.41569	102	167	1.243	8.39	1.85	4.53		1.80
Lithium fluoride (LiF)			0.46262	62.2	88.2	1.614	39.25	14.91	2.632		1.392
Sodium fluoride (NaF)			0.47632	66.9	98.3	1.69	29.87	11.68	2.558		1.336
Sodium iodide (NaI)			0.42697	94.6	151	1.305	9.49	2.59	3.67		1.775
Silica Aerogel [s]			0.50093	66.3	96.9	1.740	27.25	136@ρ=0.2	0.04–0.6		1.0+0.21ρ
NEMA G10 plate [t]				62.6	90.2	1.87	33.0	19.4	1.7		—

Sorgenti

Nuclide	Half-life	Type of decay	Particle Energy (MeV)	Particle Emission prob.	Photon Energy (MeV)	Photon Emission prob.
$^{22}_{11}$Na	2.603 y	β^+, EC	0.545	90%	0.511 1.275	Annih. 100%
$^{54}_{25}$Mn	0.855 y	EC			0.835 Cr K x rays	100% 26%
$^{55}_{26}$Fe	2.73 y	EC			Mn K x rays: 0.00590 0.00649	 24.4% 2.86%
$^{57}_{27}$Co	0.744 y	EC			0.014 0.122 0.136 Fe K x rays	9% 86% 11% 58%
$^{60}_{27}$Co	5.271 y	β^-	0.316	100%	1.173 1.333	100% 100%
$^{68}_{32}$Ge	0.742 y	EC			Ga K x rays	44%
$\rightarrow ^{68}_{31}$Ga		β^+, EC	1.899	90%	0.511 1.077	Annih. 3%
$^{90}_{38}$Sr	28.5 y	β^-	0.546	100%		
$\rightarrow ^{90}_{39}$Y		β^-	2.283	100%		
$^{106}_{44}$Ru	1.020 y	β^-	0.039	100%		
$\rightarrow ^{106}_{45}$Rh		β^-	3.541	79%	0.512 0.622	21% 10%
$^{109}_{48}$Cd	1.267 y	EC	0.063 e^- 0.084 e^- 0.087 e^-	41% 45% 9%	0.088 Ag K x rays	3.6% 100%

Nuclide	Half-life	Type of decay	Particle Energy (MeV)	Particle Emission prob.	Photon Energy (MeV)	Photon Emission prob.
$^{113}_{50}$Sn	0.315 y	EC	0.364 e^- 0.388 e^-	29% 6%	0.392 In K x rays	65% 97%
$^{137}_{55}$Cs	30.2 y	β^-	0.514 e^- 1.176 e^-	94% 6%	0.662	85%
$^{133}_{56}$Ba	10.54 y	EC	0.045 e^- 0.075 e^-	50% 6%	0.081 0.356 Cs K x rays	34% 62% 121%
$^{207}_{83}$Bi	31.8 y	EC	0.481 e^- 0.975 e^- 1.047 e^-	2% 7% 2%	0.569 1.063 1.770 Pb K x rays	98% 75% 7% 78%
$^{228}_{90}$Th	1.912 y	6α: $3\beta^-$:	5.341 to 8.785 0.334 to 2.246		0.239 0.583 2.614	44% 31% 36%
($\rightarrow ^{224}_{88}$Ra $\rightarrow ^{220}_{86}$Rn $\rightarrow ^{216}_{84}$Po $\rightarrow ^{212}_{82}$Pb $\rightarrow ^{212}_{83}$Bi $\rightarrow ^{212}_{84}$Po)						
$^{241}_{95}$Am	432.7 y	α	5.443 5.486	13% 85%	0.060 Np L x rays	36% 38%
$^{241}_{95}$Am/Be	432.2 y	6×10^{-5} neutrons (4–8 MeV) and $4 \times 10^{-5} \gamma$'s (4.43 MeV) per Am decay				
$^{244}_{96}$Cm	18.11 y	α	5.763 5.805	24% 76%	Pu L x rays	$\sim$ 9%
$^{252}_{98}$Cf	2.645 y	α (97%) Fission (3.1%) $\approx$ 20 γ's/fission; 80% $<$ 1 MeV $\approx$ 4 neutrons/fission; $\langle E_n \rangle = 2.14$ MeV	6.076 6.118	15% 82%		