1.5 Dimensional and dimensionless ratios

1.5.1 Coefficients and factors

When a quantity A is proportional to another quantity B, the relationship is expressed by an equation of the form $A = k \cdot B$. The quantity k is usually given the name 'coefficient' or 'modulus' if A and B have different dimensions and 'factor' or 'index' if A and B have the same dimension.

Examples:

$\boldsymbol{E} = A_\mathrm{H}(\boldsymbol{B} \times \boldsymbol{J})$	A_H,	Hall coefficient
$\sigma = E\epsilon$	E,	Young's modulus
$\boldsymbol{J} = -D\,\boldsymbol{\nabla} n$	D,	diffusion coefficient
$L_{12} = k\sqrt{L_1 L_2}$	k,	coupling factor
$F = \mu F_\mathrm{n}$	μ,	friction factor

1.5.2 Parameters, numbers and ratios

Certain combinations of physical quantities often are useful in characterizing the behavior or properties of a physical system; it is then convenient to consider such a combination as a new quantity. In general this new quantity is called a 'parameter'; if, however, the quantity is dimensionless it is referred to as a 'number' or a 'ratio'. If such a ratio is inherently positive and less than 1 it is often denoted as a 'fraction'.

Examples:

Grüneisen parameter : γ	$\gamma = \alpha/\kappa\rho c_V$
Reynolds number : Re	$Re = \rho v l/\eta$
mobility ratio : b	$b = \mu_-/\mu_+$
mole fraction : x_B	$x_\mathrm{B} = n_\mathrm{B}/\Sigma_j n_{\mathrm{B}_j}$

2 SYMBOLS FOR ELEMENTS, PARTICLES, STATES AND TRANSITIONS

2.1 Chemical elements

Names and symbols for the chemical elements are given in table 2. Symbols for chemical elements should be written in roman (upright) type. The symbol is not followed by a full stop.

Examples:

Ca C H He

The nucleon number (mass number, baryon number) of a nuclide is shown as a left superscript (*e.g.*, ^{14}N).

In nuclear physics, when there will be no confusion with molecular compounds a left subscript may be used to indicate the number of protons and a right subscript to indicate the number of neutrons in the nucleus (*e.g.*, $^{235}_{92}U_{143}$). Although these subscripts are redundant they are often useful. The right subscript is usually omitted and should never be included unless the left subscript is also present.

The right subscript position is also used to indicate the number of atoms of a nuclide in a molecule (*e.g.*, $^{14}N_2{}^{16}O$). The right superscript position should be used, if required, to indicate a state of ionization (*e.g.*, Ca_2^+, PO_4^{3-}) or an excited *atomic* state (*e.g.*, He^*). A metastable *nuclear* state, however, often is treated as a distinct nuclide: *e.g.*, either $^{118}Ag^m$ or ^{118m}Ag.

Roman numerals are used in two different ways:

i. The spectrum of a z-fold ionized atom is specified by the small capital roman numeral corresponding to $z + 1$, written on the line with a thin space following the chemical symbol.

Examples:

H I (spectrum of neutral hydrogen) Ca II Al III

ii. Roman numerals in right superscript position are used to indicate the oxidation number.

Examples:

$Pb_2^{II}Pb^{IV}O_4$ $K_6Mn^{IV}Mo_9O_{32}$

Table 2. Names and symbols for the chemical elements.*

Atomic number	Name	Symbol	Atomic number	Name	Symbol
1	hydrogen	H	39	yttrium	Y
2	helium	He	40	zirconium	Zr
3	lithium	Li	41	niobium	Nb
4	beryllium	Be	42	molybdenum	Mo
5	boron	B	43	technetium	Tc
6	carbon	C	44	ruthenium	Ru
7	nitrogen	N	45	rhodium	Rh
8	oxygen	O	46	palladium	Pd
9	fluorine	F	47	silver	Ag
10	neon	Ne	48	cadmium	Cd
11	sodium	Na	49	indium	In
12	magnesium	Mg	50	tin	Sn
13	aluminum	Al	51	antimony	Sb
14	silicon	Si	52	tellurium	Te
15	phosphorus	P	53	iodine	I
16	sulfur	S	54	xenon	Xe
17	chlorine	Cl	55	cesium	Cs
18	argon	Ar	56	barium	Ba
19	potassium	K	57	lanthanum	La
20	calcium	Ca	58	cerium	Ce
21	scandium	Sc	59	praseodymium	Pr
22	titanium	Ti	60	neodymium	Nd
23	vanadium	V	61	promethium	Pm
24	chromium	Cr	62	samarium	Sm
25	manganese	Mn	63	europium	Eu
26	iron	Fe	64	gadolinium	Gd
27	cobalt	Co	65	terbium	Tb
28	nickel	Ni	66	dysprosium	Dy
29	copper	Cu	67	holmium	Ho
30	zinc	Zn	68	erbium	Er
31	gallium	Ga	69	thulium	Tm
32	germanium	Ge	70	ytterbium	Yb
33	arsenic	As	71	lutetium	Lu
34	selenium	Se	72	hafnium	Hf
35	bromine	Br	73	tantalum	Ta
36	krypton	Kr	74	tungsten	W
37	rubidium	Rb	75	rhenium	Re
38	strontium	Sr	76	osmium	Os

Table 2. Names and symbols for the chemical elements (continued).

Atomic number	Name	Symbol	Atomic number	Name	Symbol
77	iridium	Ir	91	protactinium	Pa
78	platinum	Pt	92	uranium	U
79	gold	Au	93	neptunium	Np
80	mercury	Hg	94	plutonium	Pu
81	thallium	Tl	95	americium	Am
82	lead	Pb	96	curium	Cm
83	bismuth	Bi	97	berkelium	Bk
84	polonium	Po	198	californium	Cf
85	astatine	At	199	einsteinium	Es
86	radon	Rn	100	fermium	Fm
87	francium	Fr	101	mendelevium	Md
88	radium	Ra	102	nobelium	No
89	actinium	Ac	103	lawrencium	Lr
90	thorium	Th			

* For values of the relative atomic masses of the elements, see *Pure and Applied Chemistry* **58** (1986) 1677.

2.2 Nuclear particles

The common designations for particles used as projectiles or products in nuclear reactions are listed in table 3. In addition to the symbols given in the table, an accepted designation for a general heavy ion (where there is no chance of ambiguity) is HI.

The charge of a particle may be indicated by adding a superscript $^+, ^0, ^-$ to the symbol for the particle.

Examples:

$$\pi^+, \pi^0, \pi^- \qquad e^+, e^- \qquad \beta^+, \beta^-$$

If no charge is indicated in connection with the symbols p and e, these symbols refer to the positive proton and the negative electron respectively. The bar $^-$ or the tilde $\tilde{}$ above the symbol for a particle is used to indicate the corresponding anti-particle; the notation $\bar{p}$ is preferable to p^- for the anti-proton, but both $\bar{e}$ and e^+ (or $\bar{\beta}$ and β^+) are commonly used for the positron.

The symbol e (roman) for the electron should not be confused with the symbol *e* (italic) for the elementary charge.

2.3 'Fundamental' particles

There is little information to be imparted by listing simply that the symbol for the P-particle is 'P'. Furthermore, a complete set of nomenclature rules.

Table 3. Symbols for nuclear particles.

photon	γ	nucleon	N
neutrino	$\nu, \nu_e, \nu_\mu, \nu_\tau$	neutron	n
electron	e, β	proton ($^1H^+$)	p
muon	μ	deuteron ($^2H^+$)	d
tauon	τ	triton ($^3H^+$)	t
pion	π	helion ($^3He^{2+}$)	h
		alpha particle ($^4He^{2+}$)	α

Note: The symbol τ has previously been used for the helion, but τ should be reserved for the tauon (heavy lepton).

in high energy physics is still being formulated. The biennial "Review of Particle Properties" issued by the Particle Data Group (Lawrence Berkeley Laboratory and CERN) is the best reference for this and for related topics. Since it is beyond the scope of this guide to present detailed information on the relationships among these particles, the list below gives only the broadest family groupings of those particles that are stable under the strong nuclear force and can truly be called 'particles' rather than 'resonances'. Each fermion listed has an associated anti-particle; bosons are their own anti-particles.

Gauge bosons	γ, W, Z
Leptons	e, ν_e, μ, ν_μ, τ, ν_τ
Quarks (q)	u, d, c, s, t, b
Mesons ($q\bar{q}$)	
nonstrange ($S = 0$)	π^+, π^0, π^-, η, D^+, D^0
strange ($S = 1$)	K^+, K^0, (K_L, K_S), F^+
Baryons (qqq)	
($S = 0$)	p, n, Λ_c^+
($S = -1$)	$\Lambda, \Sigma^+, \Sigma^0, \Sigma^-$
($S = -2$)	Ξ^0, Ξ^-
($S = -3$)	Ω^-

The names for quarks are the symbols themselves; the names 'up', 'down', 'charm', 'strange', 'top (truth)' and 'bottom (beauty)' are to be considered only as mnemonics for these symbols.

The mesons D^+, D^0 and F^+ and the charm baryon Λ_c^+ have charm quantum number $C = +1$. The B-mesons have 'bottomness' (beauty) quantum number $B = +1$.

2.4 Spectroscopic notation

A letter symbol indicating a quantum number of a *single particle* should be printed in lower case upright type. A letter symbol indicating a quantum number of a *system* should be printed in capital upright type.

2.4.1 Atomic spectroscopy

The letter symbols indicating the orbital angular momentum quantum number are

$l =$	0	1	2	3	4	5	6	7	8	9	10	11	...
symbol	s	p	d	f	g	h	i	k	l	m	n	o	...
$L =$	0	1	2	3	4	5	6	7	8	9	10	11	...
symbol	S	P	D	F	G	H	I	K	L	M	N	O	...

A right subscript attached to the angular momentum symbol indicates the total angular momentum quantum number j or J. A left superscript indicates the spin multiplicity, $2s + 1$ or $2S + 1$.

Examples:

$d_{\frac{3}{2}}$ - electron	($j = \frac{3}{2}$)
^3D - term	(spin multiplicity = 3)
$^3D_2$ - level	$J = 2$

An atomic electron configuration is indicated symbolically by:

$$(nl)^k (n'l')^{k'} \ \ldots$$

in which $k, k', \ldots$ are the numbers of electrons with principal quantum numbers $n, n', \ldots$ and orbital angular momentum quantum numbers $l, l', \ldots$, respectively. Instead of $l = 0, 1, 2, 3, \ldots$ one uses the quantum number symbols s,p,d,f,..., and the parentheses are usually omitted.

Example:

the atomic electron configuration: $1s^2 2s^2 2p^3$

An atomic state is specified by giving all of its quantum numbers. In Russell–Saunders (LS) coupling an atomic *term* is specified by L and S and an atomic *level* by L, S and J. An atomic *state* is specified by L, S, J and M_J or by L, S, M_S and M_L.

2.4.2 Molecular spectroscopy

For *linear molecules* the letter symbols indicating the quantum number of the component of electronic orbital angular momentum along the molecular axis are

$\lambda =$	0	1	2	...
symbol	σ	π	δ	...
$\Lambda =$	0	1	2	...
symbol	Σ	Π	Δ	...

A left superscript indicates the spin multiplicity. For molecules having a symmetry center, the parity symbol g (*gerade*) or u (*ungerade*) indicating respectively symmetric or antisymmetric behavior on inversion is attached as a right subscript. A $^+$ or $^-$ sign attached as a right superscript indicates the symmetry with regard to reflection in any plane through the symmetry axis of the molecule.

Examples:

$$\Sigma_g^+,\ \Pi_u,\ {}^2\Sigma,\ {}^3\Pi, \text{ etc.}$$

The letter symbols indicating the quantum number of vibrational angular momentum are

$l =$	0	1	2	3	...
symbol	Σ	Π	Δ	Φ	...

2.4.3 Nuclear spectroscopy

The spin and parity assignment of a nuclear state is

$$J^\pi$$

where the parity symbol π is + for even parity and − for odd parity.

Examples:

$$3^+,\quad 2^-$$

A shell model configuration is indicated symbolically by:

$$\nu(nl_j)^\kappa(n'l'_{j'})^{\kappa'} \ldots \pi(n''l''_{j''})^{\kappa''}(n'''l'''_{j'''})^{\kappa'''} \ldots$$

where the letter π refers to the proton shell and the letter ν to the neutron shell. Negative values of the superscript indicate holes in a completed shell. Instead of $l = 0, 1, 2, 3, \ldots$ one uses the symbols s, p, d, f, ... as in atoms (except for $l = 7$ which is denoted by k in atoms and by j in nuclei).

Example:

the nuclear configuration: $\nu(2d_{\frac{5}{2}})^6\ \pi(2p_{\frac{1}{2}})^2(1g_{\frac{9}{2}})^3$

When the neutrons and protons are in the same shell with well-defined isospin T, the notation $(nl_j)^\alpha$ is used where α denotes the total number of nucleons.

Example:

$$(1f_{\frac{7}{2}})^5$$

2.4.4 Spectroscopic transitions

The upper (higher energy) level and the lower (lower energy) level of a transition are indicated respectively by $'$ and $''$.

Example:

$$h\nu = E' - E'' \qquad\qquad \sigma = T' - T''$$

The designation of spectroscopic transitions is not uniform. In *atomic* spectroscopy* the convention is to write the *lower* state first and the *upper* state second; however, in *molecular* and *polyatomic* spectroscopy** the convention is reversed and one writes the *upper* state first and the *lower* state second.

In either case the two state designations are connected by a dash — or, if it is necessary to indicate whether the transition is an absorption or an emission process, by arrows ← and →. If there is any chance of ambiguity, the convention being used with regard to the ordering of the states should be clearly stated.

Examples:

$2\,{}^2S_{\frac{1}{2}} - 4\,{}^2P_{\frac{3}{2}}$	atomic transition
$(J', K') \leftarrow (J'', K'')$	molecular rotational absorption

The difference between two quantum numbers is that of the upper state minus that of the lower state.

Example:

$$\Delta J = J' - J''$$

The branches of the rotation–vibration band are designated as:

	$\Delta J = J' - J''$
O branch:	−2
P branch:	−1
Q branch:	0
R branch:	+1
S branch:	+2

2.5 Nomenclature conventions in nuclear physics

2.5.1 Nuclides

A species of atoms identical as regards atomic number (proton number) and mass number (nucleon number) should be indicated by the word 'nuclide', not by the word 'isotope'. Different nuclides having the same mass number are called *isobaric nuclides* or *isobars*.

Different nuclides having the same atomic number are called *isotopic nuclides* or *isotopes*. (Since nuclides with the same number of protons are 'isotopes', nuclides with the same number of neutrons have sometimes been designated as 'isotones'.)

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* See R. D. Cowan, *The Theory of Atomic Structure and Spectra* (Univ. of California Press, 1981).

** See *Report on Notation for the Spectra of Polyatomic Molecules*, J. Chem. Phys. **23** (1955) 1997.

The symbolic expression representing a nuclear reaction should follow the pattern:

$$\text{initial nuclide} \left(\text{incoming particle or photon} \;,\; \text{outgoing particle(s) or photon(s)} \right) \text{final nuclide}$$

Examples:

$^{14}N\,(\alpha, p)\,^{17}O$ $\quad$ $^{59}Co\,(n, \gamma)\,^{60}Co$

$^{23}Na\,(\gamma, 3n)\,^{20}Na$ $\quad$ $^{31}P\,(\gamma, pn)\,^{29}Si$

2.5.2 Characterization of interactions

Multipolarity of a transition:

electric or magnetic monopole	E0 or M0
electric or magnetic dipole	E1 or M1
electric or magnetic quadrupole	E2 or M2
electric or magnetic octopole	E3 or M3
electric or magnetic 2^n-pole	En or Mn

Designation of parity change in a transition:

transition *with* parity change :	(yes)
transition *without* parity change :	(no)

Notation for covariant character of coupling:

S	Scalar coupling	A	Axial vector coupling
V	Vector coupling	P	Pseudoscalar coupling
T	Tensor coupling		

2.5.3 Polarization conventions

Sign of polarization vector (Basel convention): In a nuclear interaction the positive polarization direction for particles with spin $\frac{1}{2}$ is taken in the direction of the vector product

$$\boldsymbol{k}_{\mathrm{i}} \times \boldsymbol{k}_{\mathrm{o}}$$

where $\boldsymbol{k}_{\mathrm{i}}$ and $\boldsymbol{k}_{\mathrm{o}}$ are the wave vectors of the incoming and outgoing particles respectively.

Description of polarization effects (Madison convention): In the symbolic expression for a nuclear reaction A(b,c)D, an arrow placed over a symbol denotes a particle which is initially in a polarized state or whose state of polarization is measured.

Examples:

$A(\vec{b}, c)D$	polarized incident beam
$A(\vec{b}, \vec{c})D$	polarized incident beam; polarization of the outgoing particle c is measured (polarization transfer)
$A(b, \vec{c})D$	unpolarized incident beam; polarization of the outgoing particle c is measured
$\vec{A}(b, c)D$	unpolarized beam incident on a polarized target
$\vec{A}(b, \vec{c})D$	unpolarized beam incident on a polarized target; polarization of the outgoing particle c is measured
$A(\vec{b}, c)\vec{D}$	polarized incident beam; measurement of the polarization of the residual nucleus