Units of Measure in Science and Engineering

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Chapter-1

Units of Measurement

The former Weights and Measures office in Seven Sisters, London.

A **unit of measurement** is a definite magnitude of a physical quantity, defined and adopted by convention and/or by law, that is used as a standard for measurement of the same physical quantity. Any other value of the physical quantity can be expressed as a simple multiple of the unit of measurement.

For example, length is a physical quantity. The metre is a unit of length that represents a definite predetermined length. When we say 10 metres (or 10 m), we actually mean 10 times the definite predetermined length called "metre".

The definition, agreement, and practical use of units of measurement have played a crucial role in human endeavour from early ages up to this day. Different systems of units used to be very common. Now there is a global standard, the International System of Units (SI), the modern form of the metric system.

In trade, **weights and measures** is often a subject of governmental regulation, to ensure fairness and transparency. The Bureau international des poids et mesures (BIPM) is tasked with ensuring worldwide uniformity of measurements and their traceability to the International System of Units (SI). Metrology is the science for developing nationally and internationally accepted units of weights and measures.

In physics and metrology, units are standards for measurement of physical quantities that need clear definitions to be useful. Reproducibility of experimental results is central to the scientific method. A standard system of units facilitates this. Scientific systems of units are a refinement of the concept of weights and measures developed long ago for commercial purposes.

Science, medicine, and engineering often use larger and smaller units of measurement than those used in everyday life and indicate them more precisely. The judicious selection of the units of measurement can aid researchers in problem solving (see, for example, dimensional analysis).

In the social sciences, there are no standard units of measurement and the theory and practice of measurement is studied in psychometrics and the theory of conjoint measurement.

History

A unit of measurement is a standardised quantity of a physical property, used as a factor to express occurring quantities of that property. Units of measurement were among the earliest tools invented by humans. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

The earliest known uniform systems of weights and measures seem to have all been created sometime in the 4th and 3rd millennia BC among the ancient peoples of Mesopotamia, Egypt and the Indus Valley, and perhaps also Elam in Persia as well.

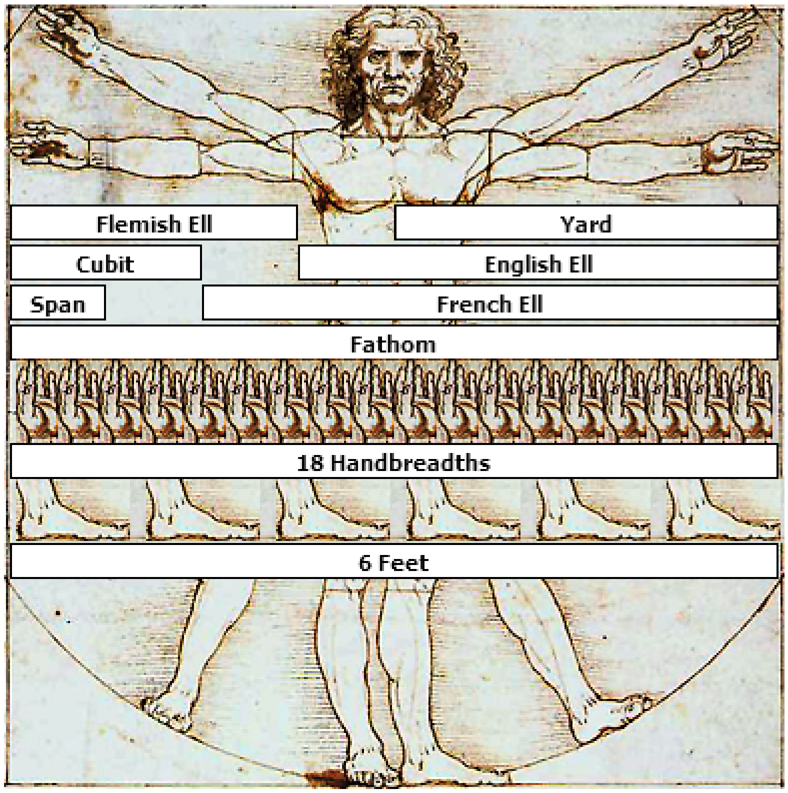
In "The Magna Carta" of 1215 (The Great Charter) with the seal of King John, put before him by the Barons of England, King John agreed in Clause 35 "There shall be one measure of wine throughout our whole realm, and one measure of ale and one measure of corn--namely, the London quart;--and one width of dyed and russet and hauberk cloths--

namely, two ells below the selvage….". The Magna Carta helped lay the foundations of freedom codified in English Law and subsequently American Law.

Many systems were based on the use of parts of the body and the natural surroundings as measuring instruments. Our present knowledge of early weights and measures comes from many sources.

Systems of units

Traditional systems



This derivation of the Vitruvian Man by Leonardo da Vinci, depicts nine historical units of measurement: the yard, the span, the cubit, the Flemish ell, the English ell, the French ell, the fathom, the hand, and the foot. The Vitruvian Man was drawn to scale, so the units depicted are displayed with their proper historical ratios.

Prior to the near global adoption of the metric system many different systems of measurement had been in use. Many of these were related to some extent or other. Often they were based on the dimensions of the human body according to the proportions described by Marcus Vitruvius Pollio. As a result, units of measure could vary not only from location to location, but from person to person.

Metric systems

A number of metric systems of units have evolved since the adoption of the original metric system in France in 1791. The current international standard metric system is the International System of Units. An important feature of modern systems is standardization. Each unit has a universally recognized size.

Both the Imperial units and US customary units derive from earlier English units. Imperial units were mostly used in the British Commonwealth and the former British Empire. US customary units are still the main system of measurement used in the United States despite Congress having legally authorized metric measure on 28 July 1866. Some steps towards US metrication have been made, particularly the redefinition of basic US units to derive exactly from SI units, so that in the US the inch is now defined as 0.0254 m (exactly), and the avoirdupois pound is now defined as 453.59237 g (exactly)

Natural systems

While the above systems of units are based on arbitrary unit values, formalised as standards, some unit values occur naturally in science. Systems of units based on these are called natural units. Similar to natural units, atomic units (au) are a convenient system of units of measurement used in atomic physics.

Also a great number of unusual and non-standard units may be encountered. These may include the Solar mass, the Megaton (1,000,000 tons of TNT).

Legal control of weights and measures

To reduce the incidence of retail fraud, many national statutes have standard definitions of weights and measures that may be used (hence "statute measure"), and these are verified by legal officers.

Base and derived units

Different systems of units are based on different choices of a set of fundamental units. The most widely used system of units is the International System of Units, or SI. There are seven SI base units. All other SI units can be derived from these base units.

For most quantities a unit is absolutely necessary to communicate values of that physical quantity. For example, conveying to someone a particular length without using some sort of unit is impossible, because a length cannot be described without a reference used to make sense of the value given.

But not all quantities require a unit of their own. Using physical laws, units of quantities can be expressed as combinations of units of other quantities. Thus only a small set of units is required. These units are taken as the *base units*. Other units are *derived units*.

Derived units are a matter of convenience, as they can be expressed in terms of basic units. Which units are considered base units is a matter of choice.

The base units of SI are actually not the smallest set possible. Smaller sets have been defined. For example, there are unit sets in which the electric and magnetic field have the same unit. This is based on physical laws that show that electric and magnetic field are actually different manifestations of the same phenomenon.

Calculations with units

Units as dimensions

Any value of a physical quantity is expressed as a comparison to a unit of that quantity. For example, the value of a physical quantity *Z* is expressed as the product of a unit [Z] and a numerical factor:

$Z = n \times [Z] = n[Z]$. For example, "2 candlesticks" Z = 2 [candlestick].

The multiplication sign is usually left out, just as it is left out between variables in scientific notation of formulas. The conventions used to express quantities is referred to as quantity calculus. In formulas the unit [Z] can be treated as if it were a specific magnitude of a kind of physical dimension.

Units can only be added or subtracted if they are the same type; however units can always be multiplied or divided, as George Gamow used to explain:

"2 candlesticks" times "3 cabdrivers" = 6 [candlestick][cabdriver].

A distinction should be made between units and standards. A unit is fixed by its definition, and is independent of physical conditions such as temperature. By contrast, a standard is a physical realization of a unit, and realizes that unit only under certain physical conditions. For example, the metre is a unit, while a metal bar is a standard. One metre is the same length regardless of temperature, but a metal bar will be one metre long only at a certain temperature.

Guidelines

- Treat units algebraically. Only add like terms. When a unit is divided by itself, the division yields a unitless one. When two different units are multiplied, the result is a new unit, referred to by the combination of the units. For instance, in SI, the unit of speed is metres per second (m/s).
- Some units have special names, however these should be treated like their equivalents. For example, one newton (N) is equivalent to one $kg{\cdot}m/s^2$. Thus a quantity may have several unit designations, for example: the unit for surface tension can be referred to as either N/m (newtons per metre) or kg/s^2 (kilograms

per second squared). Whether these designations are equivalent is disputed amongst metrologists.

Expressing a physical value in terms of another unit

Conversion of units involves comparison of different standard physical values, either of a single physical quantity or of a physical quantity and a combination of other physical quantities.

Starting with:

$$Z = n_i \times [Z]_i$$

just replace the original unit $[Z]_i$ with its meaning in terms of the desired unit $[Z]_j$, e.g. if $[Z]_i = c_{ij} \times [Z]_j$, then:

$$Z = n_i \times (c_{ij} \times [Z]_j) = (n_i \times c_{ij}) \times [Z]_j$$

Now n_i and c_{ij} are both numerical values, so just calculate their product.

Or, which is just mathematically the same thing, multiply Z by unity, the product is still Z:

$$Z = n_i \times [Z]_i \times (c_{ij} \times [Z]_j/[Z]_i)$$

For example, you have an expression for a physical value Z involving the unit *feet per second* ($[Z]_i$) and you want it in terms of the unit *miles per hour* ($[Z]_j$):

1. Find facts relating the original unit to the desired unit:

   1 mile = 5280 feet and 1 hour = 3600 seconds

2. Next use the above equations to construct a fraction that has a value of unity and that contains units such that, when it is multiplied with the original physical value, will cancel the original units:

   $$1 = \frac{1\,\mathrm{mi}}{5280\,\mathrm{ft}} \quad \mathrm{and} \quad 1 = \frac{3600\,\mathrm{s}}{1\,\mathrm{h}}$$

3. Last,multiply the original expression of the physical value by the fraction, called a *conversion factor*, to obtain the same physical value expressed in terms of a different unit. Note: since valid conversion factors are dimensionless and have a numerical value of one, multiplying any physical quantity by such a conversion factor (which is 1) does not change that physical quantity.

$$52.8\,\frac{\mathrm{ft}}{\mathrm{s}} = 52.8\,\frac{\mathrm{ft}}{\mathrm{s}}\,\frac{1\,\mathrm{mi}}{5280\,\mathrm{ft}}\,\frac{3600\,\mathrm{s}}{1\,\mathrm{h}} = \frac{52.8\times 3600}{5280}\,\mathrm{mi/h} = 36\,\mathrm{mi/h}$$

Or as an example using the metric system, you have a value of fuel economy in the unit *litres per 100 kilometres* and you want it in terms of the unit *microlitres per metre*:

$$\frac{9\,\mathrm{L}}{100\,\mathrm{km}} = \frac{9\,\mathrm{L}}{100\,\mathrm{km}}\,\frac{1000000\,\mu\mathrm{L}}{1\,\mathrm{L}}\,\frac{1\,\mathrm{km}}{1000\,\mathrm{m}} = \frac{9\times 1000000}{100\times 1000}\,\mu\mathrm{L/m} = 90\,\mu\mathrm{L/m}$$

Real-world implications

One example of the importance of agreed units is the failure of the NASA Mars Climate Orbiter, which was accidentally destroyed on a mission to the planet Mars in September 1999 instead of entering orbit, due to miscommunications about the value of forces: different computer programs used different units of measurement (newton versus pound force). Enormous amounts of effort, time, and money were wasted.

On April 15, 1999 Korean Air cargo flight 6316 from Shanghai to Seoul was lost due to the crew confusing tower instructions (in metres) and altimeter readings (in feet). Three crew and five people on the ground were killed. Thirty seven were injured.

In 1983, a Boeing 767 (which came to be known as the Gimli Glider) ran out of fuel in mid-flight because of two mistakes in figuring the fuel supply of Air Canada's first aircraft to use metric measurements. This accident is apparently the result of confusion both due to the simultaneous use of metric & Imperial measures as well as mass & volume measures.

Chapter-2

Conversion of Units

Conversion of units refers to **conversion factors** between different units of measurement for the same quantity.

Techniques

Process

The process of conversion depends on the specific situation and the intended purpose. This may be governed by regulation, contract, Technical specifications or other published standards. Engineering judgment may include such factors as:

- The precision and accuracy of measurement and the associated uncertainty of measurement
- The statistical confidence interval or tolerance interval of the initial measurement
- The number of significant figures of the measurement
- The intended use of the measurement including the engineering tolerances

Some conversions from one system of units to another need to be exact, without increasing or decreasing the precision of the first measurement. This is sometimes called *soft conversion*. It does not involve changing the physical configuration of the item being measured.

By contrast, a *hard conversion* or an *adaptive conversion* may not be exactly equivalent. It changes the measurement to convenient and workable numbers and units in the new system. It sometimes involves a slightly different configuration, or size substitution, of the item.

Multiplication Factors

Conversion between units in the metric system can be discerned by their prefixes (for example, 1 kilogram = 1000 grams, 1 milligram = 0.001 grams) and are thus not listed here. Exceptions are made if the unit is commonly known by another name (for example, 1 micron = 10^{-6} metre).

Table Ordering

Within each table, the units are listed alphabetically, and the SI units (base or derived) are highlighted.

Tables of conversion factors

Here we, gives a lists of conversion factors for each of a number of physical quantities, which are listed in the index. For each physical quantity, a number of different units (some only of historical interest) are shown and expressed in terms of the corresponding SI unit.

Legend

Symbol	Definition
≡	exactly equal to
≈	approximately equal to
digits	indicates that *digits* repeat infinitely (e.g. 8.294369 corresponds to 8.294369369369369…)
(H)	of chiefly historical interest

Length

Length

Name of unit	Symbol	Definition	Relation to SI units
ångström	Å	≡ 1×10^{-10} m	≡ 0.1 nm
astronomical unit	AU	≈ Distance from Earth to Sun	≈ 149597871464 m
barleycorn (H)		= ⅓ in	≈ 8.46×10^{-3} m
bohr, atomic unit of length	a_0	≡ Bohr radius of hydrogen	≈ $5.2917720859\times10^{-11} \pm 3.6\times10^{-20}$ m
cable length (Imperial)		≡ 608 ft	≈ 185.3184 m
cable length (International)		≡ 1/10 nmi	≡ 185.2 m
cable length (U.S.)		≡ 720 ft	= 219.456 m
chain (Gunter's; Surveyor's)	ch	≡ 66 ft(US) ≡ 4 rods	≈ 20.11684 m

cubit (H)		≡ Distance from fingers to elbow ≈ 18 in	≈ 0.5 m
ell (H)	ell	≡ 45 in (In England usually)	= 1.143 m
fathom	fm	≡ 6 ft	= 1.8288 m
fermi	fm	≡ 1×10^{-15} m	≡ 1×10^{-15} m
finger		≡ 7/8 in	= 0.022225 m
finger (cloth)		≡ 4½ in	= 0.1143 m
foot (Benoît) (H)	ft (Ben)		≈ 0.304799735 m
foot (Clarke's; Cape) (H)	ft (Cla)		≈ 0.3047972654 m
foot (Indian) (H)	ft Ind		≈ 0.304799514 m
foot (International)	ft	≡ 1/3 yd ≡ 0.3048 m ≡ 12 inches	≡ 0.3048 m
foot (Sear's) (H)	ft (Sear)		≈ 0.30479947 m
foot (U.S. Survey)	ft (US)	≡ $^{1200}/_{3937}$ m	≈ 0.304800610 m
french; charriere	F	≡ $^{1}/_{3}$ mm	= 0.3×10^{-3} m
furlong	fur	≡ 10 chains = 660 ft = 220 yd	= 201.168 m
hand		≡ 4 in	≡ 0.1016 m
inch (International)	in	≡ 1/36 yd ≡ 1/12 ft	≡ 0.0254 m
league (land)	lea	≡ 3 US Statute miles	= 4828.032 m
light-day		≡ 24 light-hours	≡ $2.59020683712\times10^{13}$ m
light-hour		≡ 60 light-minutes	≡ $1.0792528488\times10^{12}$ m
light-minute		≡ 60 light-seconds	≡ 1.798754748×10^{10} m
light-second		≡ Distance light travels in one second in vacuum	≡ 299792458 m
light-year	ly	≡ Distance light travels in vacuum in 365.25 days	= $9.4607304725808\times10^{15}$ m
line	ln	≡ 1/12 in	= 0.002116 m
link (Gunter's; Surveyor's)	lnk	≡ 1/100 ch ≡ 0.66 ft ≡ 7.92in	= 0.201168 m
link (Ramsden's; Engineer's)	lnk	≡ 1 ft	= 0.3048 m

metre (SI base unit)	m	≡ Distance light travels in $\frac{1}{299792458}$ of a second in vacuum. ≈ $\frac{1}{10000000}$ of the distance from equator to pole.	≡ 1 m
mickey		≡ $\frac{1}{200}$ in	= 1.27×10^{-4} m
micron	µ		≡ 1×10^{-6} m
mil; thou	mil	≡ 1×10^{-3} in	≡ 2.54×10^{-5} m
mil (Sweden and Norway)	mil	≡ 10 km	= 10000 m
mile (geographical) (H)		≡ 6082 ft	= 1853.7936 m
mile (international)	mi	≡ 80 chains ≡ 5280 ft ≡ 1760 yd	≡ 1609.344 m
mile (tactical or data)		≡ 6000 ft	≡ 1828.8 m
mile (telegraph) (H)	mi	≡ 6087 ft	= 1855.3176 m
mile (U.S. Survey)	mi	≡ 5280 US Survey feet ≡ (5280 × $\frac{1200}{3937}$) m	≈ 1609.347219 m
nail (cloth)		≡ 2¼ in	= 0.057 15 m
nanometer	nm	≡ 1×10^{-9} m	≡ 1×10^{-9} m
nautical league	NL; nl	≡ 3 nmi	= 5556 m
nautical mile (Admiralty)	NM (Adm); nmi (Adm)	= 6080 ft	= 1853.184 m
nautical mile (international)	NM; nmi	≡ 1852 m	≡ 1852 m
nautical mile (US pre 1954)		≡ 1853.248 m	≡ 1853.248 m
pace		≡ 2.5 ft	= 0.762 m
palm		≡ 3 in	= 0.0762 m
parsec	pc	Distance of star with ***par***allax shift of one arc ***sec***ond from a base of one astronomical unit	≈ $3.085\,677\,82\times10^{16} \pm 6\times10^{6}$ m

pica		≡ 12 points	Dependent on point measures.
point (American, English)	pt	≡ 1/72.272 in	≈ 0.000 351 450 m
point (Didot; European)	pt	≡ 1/12 × 1/72 of pied du roi; After 1878: ≡ 5/133 cm	≈ 0.000 375 97 m; After 1878: ≈ 0.000 375 939 85 m
point (PostScript)	pt	≡ 1/72 in	= 0.000 352 7 m
point (TeX)	pt	≡ 1/72.27 in	= 0.000 351 4598 m
quarter		≡ ¼ yd	= 0.2286 m
rod; pole; perch (H)	rd	≡ 16½ ft	= 5.0292 m
rope (H)	rope	≡ 20 ft	= 6.096 m
span (H)		≡ 9 in	= 0.2286 m
spat			≡ 1×10^{12} m
stick (H)		≡ 2 in	= 0.0508 m
stigma; bicron (picometre)	pm		≡ 1×10^{-12} m
twip	twp	≡ 1/1440 in	= 1.7638×10^{-5} m
x unit; siegbahn	xu		≈ 1.0021×10^{-13} m
yard (International)	yd	≡ 0.9144 m ≡ 3 ft ≡ 36 in	≡ 0.9144 m

Area

Area

Name of unit	Symbol	Definition	Relation to SI units
acre (international)	ac	≡ 1 ch × 10 ch = 4840 sq yd	≡ 4 046.856 4224 m^2
acre (U. S. survey)	ac	≡ 10 sq ch = 4840 sq yd, also 43560 sq ft.	≈ 4 046.873 m^2
are	a	≡ 100 m^2	= 100 m^2
barn	b	≡ 10^{-28} m^2	= 10^{-28} m^2
barony		≡ 4000 ac	≈ $1.618\ 742\times10^{7}$ m^2
board	bd	≡ 1 in × 1 ft	= $7.741\ 92\times10^{-3}$ m^2
boiler horsepower equivalent direct radiation	bhp EDR	≡ (1 ft^2) (1 bhp) / (240 BTU_{IT}/h)	≈ 12.958 174 m^2

circular inch	circ in	≡ π/4 sq in	≈ 5.067 075×10^{-4} m^2
circular mil; circular thou	circ mil	≡ π/4 mil^2	≈ 5.067 075×10^{-10} m^2
cord		≡ 192 bd	= 1.486 448 64 m^2
dunam		≡ 1 000 m^2	= 1 000 m^2
guntha		≡ 121 sq yd	≈ 101.17 m^2
hectare	ha	≡ 10 000 m^2	≡ 10 000 m^2
hide		≈ 120 ac (variable)	≈ 5×10^5 m^2
rood	ro	≡ ¼ ac	= 1 011.714 1056 m^2
section		≡ 1 mi × 1 mi	= 2.589 988 110 336×10^6 m^2
shed		≡ 10^{-52} m^2	= 10^{-52} m^2
square (roofing)		≡ 10 ft × 10 ft	= 9.290 304 m^2
square chain (international)	sq ch	≡ 66 ft × 66 ft = 1/10 ac	≡ 404.685 642 24 m^2
square chain (U.S. Survey)	sq ch	≡ 66 ft(US) × 66 ft(US) = 1/10 ac	≈ 404.687 3 m^2
square foot	sq ft	≡ 1 ft × 1 ft	≡ 9.290 304×10^{-2} m^2
square foot (U.S. Survey)	sq ft	≡ 1 ft (US) × 1 ft (US)	≈ 9.290 341 161 327 49×10^{-2} m^2
square inch	sq in	≡ 1 in × 1 in	≡ 6.4516×10^{-4} m^2
square kilometre	km^2	≡ 1 km × 1 km	= 10^6 m^2
square link (Gunter's)(International)	sq lnk	≡ 1 lnk × 1 lnk ≡ 0.66 ft × 0.66 ft	= 4.046 856 4224×10^{-2} m^2
square link (Gunter's)(US Survey)	sq lnk	≡ 1 lnk × 1 lnk ≡ 0.66 ft(US) × 0.66 ft(US)	≈ 4.046 872×10^{-2} m^2
square link (Ramsden's)	sq lnk	≡ 1 lnk × 1 lnk ≡ 1 ft × 1 ft	= 0.09290304 m^2
square metre (SI unit)	m^2	≡ 1 m × 1 m	= 1 m^2
square mil; square thou	sq mil	≡ 1 mil × 1 mil	= 6.4516×10^{-10} m^2
square mile	sq mi	≡ 1 mi × 1 mi	= 2.589 988 110 336×10^6 m^2
square mile (U.S. Survey)	sq mi	≡ 1 mi (US) × 1 mi (US)	≈ 2.589 998 47×10^6 m^2
square rod/pole/perch	sq rd	≡ 1 rd × 1 rd	= 25.292 852 64 m^2
square yard (International)	sq yd	≡ 1 yd × 1 yd	≡ 0.836 127 36 m^2
stremma		≡ 1 000 m^2	= 1 000 m^2

township		≡ 36 sq mi (US)	≈ 9.323 994×10^{7} m^{2}
yardland		≈ 30 ac	≈ 1.2×10^{5} m^{2}

Volume

Volume

Name of unit	Symbol	Definition	Relation to SI units
acre-foot	ac ft	≡ 1 ac x 1 ft = 43 560 ft^{3}	= 1 233.481 837 547 52 m^{3}
acre-inch		≡ 1 ac × 1 in	= 102.790 153 128 96 m^{3}
barrel (Imperial)	bl (Imp)	≡ 36 gal (Imp)	= 0.163 659 24 m^{3}
barrel (petroleum)	bl; bbl	≡ 42 gal (US)	= 0.158 987 294 928 m^{3}
barrel (U.S. dry)	bl (US)	≡ 105 qt (US) = 105/32 bu (US lvl)	= 0.115 628 198 985 075 m^{3}
barrel (U.S. fluid)	fl bl (US)	≡ 31½ gal (US)	= 0.119 240 471 196 m^{3}
board-foot	fbm	≡ 144 cu in	≡ 2.359 737 216×10$^{−3}$ m^{3}
bucket (Imperial)	bkt	≡ 4 gal (Imp)	= 0.018 184 36 m^{3}
bushel (Imperial)	bu (Imp)	≡ 8 gal (Imp)	= 0.036 368 72 m^{3}
bushel (U.S. dry heaped)	bu (US)	≡ 1 ¼ bu (US lvl)	= 0.044 048 837 7086 m^{3}
bushel (U.S. dry level)	bu (US lvl)	≡ 2 150.42 cu in	= 0.035 239 070 166 88 m^{3}
butt, pipe		≡ 126 gal (wine)	= 0.476 961 884 784 m^{3}
coomb		≡ 4 bu (Imp)	= 0.145 474 88 m^{3}
cord (firewood)		≡ 8 ft × 4 ft × 4 ft	= 3.624 556 363 776 m^{3}
cord-foot		≡ 16 cu ft	= 0.453 069 545 472 m^{3}
cubic fathom	cu fm	≡ 1 fm × 1 fm × 1 fm	= 6.116 438 863 872 m^{3}
cubic foot	cu ft	≡ 1 ft × 1 ft × 1 ft	≡ 0.028 316 846 592 m^{3}
cubic inch	cu in	≡ 1 in × 1 in × 1 in	≡ 16.387 064×10$^{−6}$ m^{3}
cubic metre (SI unit)	m^{3}	≡ 1 m × 1 m × 1 m	≡ 1 m^{3}
cubic mile	cu mi	≡ 1 mi × 1 mi × 1 mi	≡ 4 168 181 825.440 579 584 m^{3}

cubic yard	cu yd	≡ 27 cu ft	≡ 0.764 554 857 984 m^3
cup (breakfast)		≡ 10 fl oz (Imp)	= 284.130 625×10^{-6} m^3
cup (Canadian)	c (CA)	≡ 8 fl oz (Imp)	= 227.3045×10^{-6} m^3
cup (metric)	c	≡ 250.0×10^{-6} m^3	= 250.0×10^{-6} m^3
cup (U.S. customary)	c (US)	≡ 8 US fl oz ≡ 1/16 gal (US)	= 236.588 2365×10^{-6} m^3
cup (U.S. food nutrition labeling)	c (US)	≡ 240 mL	= 2.4×10−4 m^3
dash (Imperial)		≡ 1/384 gi (Imp) = ½ pinch (Imp)	= 369.961 751 302 08 3×10^{-9} m^3
dash (U.S.)		≡ 1/96 US fl oz = ½ US pinch	= 308.057 599 609 375×10^{-9} m^3
dessertspoon (Imperial)		≡ 1/12 gi (Imp)	= 11.838 776 0416×10^{-6} m^3
drop (Imperial)	gtt	≡ 1/288 fl oz (Imp)	= 98.656 467 013 8×10^{-9} m^3
drop (Imperial) (alt)	gtt	≡ 1/1 824 gi (Imp)	≈ 77.886 684×10^{-9} m^3
drop (medical)		≡ 1/12 ml	= 83.03×10^{-9} m^3
drop (metric)		≡ 1/20 mL	= 50.0×10^{-9} m^3
drop (U.S.)	gtt	≡ 1/360 US fl oz	= 82.148 693 22916×10^{-9} m^3
drop (U.S.) (alt)	gtt	≡ 1/456 US fl oz	≈ 64.854 231×10^{-9} m^3
fifth		≡ 1/5 US gal	= 757.082 3568×10^{-6} m^3
firkin		≡ 9 gal (US)	= 0.034 068 706 056 m^3
fluid drachm (Imperial)	fl dr	≡ ⅛ fl oz (Imp)	= 3.551 632 8125×10^{-6} m^3
fluid dram (U.S.); U.S. fluidram	fl dr	≡ ⅛ US fl oz	= 3.696 691 195 3125×10^{-6} m^3
fluid scruple (Imperial)	fl s	≡ 1/24 fl oz (Imp)	= 1.183 877 60416×10^{-6} m^3
gallon (beer)	beer gal	≡ 282 cu in	= 4.621 152 048×10^{-3} m^3
gallon (Imperial)	gal (Imp)	≡ 4.546 09 L	≡ 4.546 09×10^{-3} m^3
gallon (U.S. dry)	gal (US)	≡ ⅛ bu (US lvl)	= 4.404 883 770 86×10^{-3} m^3
gallon (U.S. fluid; Wine)	gal (US)	≡ 231 cu in	≡ 3.785 411 784×10^{-3} m^3

gill (Imperial); Noggin	gi (Imp); nog	≡ 5 fl oz (Imp)	= 142.065 3125×10^{-6} m^3
gill (U.S.)	gi (US)	≡ 4 US fl oz	= 118.294 118 25×10^{-6} m^3
hogshead (Imperial)	hhd (Imp)	≡ 2 bl (Imp)	= 0.327 318 48 m^3
hogshead (U.S.)	hhd (US)	≡ 2 fl bl (US)	= 0.238 480 942 392 m^3
jigger (bartending)		≡ 1½ US fl oz	≈ 44.36×10^{-6} m^3
kilderkin		≡ 18 gal (Imp)	= 0.081 829 62 m^3
lambda	λ	≡ 1 mm^3	= 1×10^{-9} m^3
last		≡ 80 bu (Imp)	= 2.909 4976 m^3
litre	L	≡ 1 dm^3	≡ 0.001 m^3
load		≡ 50 cu ft	= 1.415 842 3296 m^3
minim (Imperial)	min	≡ 1/480 fl oz (Imp) = 1/60 fl dr (Imp)	= 59.193 880 208 3×10^{-9} m^3
minim (U.S.)	min	≡ 1/480 US fl oz = 1/60 US fl dr	= 61.611 519 921 875×10^{-9} m^3
ounce (fluid Imperial)	fl oz (Imp)	≡ 1/160 gal (Imp)	≡ 28.413 0625×10^{-6} m^3
ounce (fluid U.S. customary)	US fl oz	≡ 1/128 gal (US)	≡ 29.573 529 5625×10^{-6} m^3
ounce (fluid U.S. food nutrition labeling)	US fl oz	≡ 30 mL	≡ 3×10−5 m^3
peck (Imperial)	pk	≡ 2 gal (Imp)	= 9.092 18×10^{-3} m^3
peck (U.S. dry)	pk	≡ ¼ US lvl bu	= 8.809 767 541 72×10^{-3} m^3
perch	per	≡ 16½ ft × 1½ ft × 1 ft	= 0.700 841 953 152 m^3
pinch (Imperial)		≡ 1/192 gi (Imp) = ⅛ tsp (Imp)	= 739.923 502 60416×10^{-9} m^3
pinch (U.S.)		≡ 1/48 US fl oz = ⅛ US tsp	= 616.115 199 218 75×10^{-9} m^3
pint (Imperial)	pt (Imp)	≡ ⅛ gal (Imp)	= 568.261 25×10^{-6} m^3
pint (U.S. dry)	pt (US dry)	≡ 1/64 bu (US lvl) ≡ ⅛ gal (US dry)	= 550.610 471 3575×10^{-6} m^3
pint (U.S. fluid)	pt (US fl)	≡ ⅛ gal (US)	= 473.176 473×10^{-6} m^3
pony		≡ 3/4 US fl oz	= 22.180 147 171 875×10^{-6} m^3
pottle; quartern		≡ ½ gal (Imp) = 80 fl oz (Imp)	= 2.273 045×10^{-3} m^3

quart (Imperial)	qt (Imp)	≡ ¼ gal (Imp)	= 1.136 5225×10^{-3} m^3
quart (U.S. dry)	qt (US)	≡ 1/32 bu (US lvl) = ¼ gal (US dry)	= 1.101 220 942 715×10^{-3} m^3
quart (U.S. fluid)	qt (US)	≡ ¼ gal (US fl)	= 946.352 946×10^{-6} m^3
quarter; pail		≡ 8 bu (Imp)	= 0.290 949 76 m^3
register ton		≡ 100 cu ft	= 2.831 684 6592 m^3
sack (Imperial); bag		≡ 3 bu (Imp)	= 0.109 106 16 m^3
sack (U.S.)		≡ 3 bu (US lvl)	= 0.105 717 210 500 64 m^3
seam		≡ 8 bu (US lvl)	= 0.281 912 561 335 04 m^3
shot		≡ 1 US fl oz	≈ 29.57×10^{-6} m^3
strike (Imperial)		≡ 2 bu (Imp)	= 0.072 737 44 m^3
strike (U.S.)		≡ 2 bu (US lvl)	= 0.070 478 140 333 76 m^3
tablespoon (Australian metric)			≡ 20.0×10^{-6} m^3
tablespoon (Canadian)	tbsp	≡ ½ fl oz (Imp)	= 14.206 531 25×10^{-6} m^3
tablespoon (Imperial)	tbsp	≡ 5/8 fl oz (Imp)	= 17.758 164 0625×10^{-6} m^3
tablespoon (metric)			≡ 15.0×10^{-6} m^3
tablespoon (U.S. customary)	tbsp	≡ ½ US fl oz	= 14.786 764 7825×10^{-6} m^3
tablespoon (U.S. food nutrition labeling)	tbsp	≡ 15 mL	= 1.5×10^{-5} m^3
teaspoon (Canadian)	tsp	≡ 1/6 fl oz (Imp)	= 4.735 510 416×10^{-6} m^3
teaspoon (Imperial)	tsp	≡ 1/24 gi (Imp)	= 5.919 388 02083×10^{-6} m^3
teaspoon (metric)		≡ 5.0×10^{-6} m^3	= 5.0×10^{-6} m^3
teaspoon (U.S. customary)	tsp	≡ 1/6 US fl oz	= 4.928 921 595×10^{-6} m^3
teaspoon (U.S. food nutrition labeling)	tsp	≡ 5 mL	= 5×10^{-6} m^3
timber foot		≡ 1 cu ft	= 0.028 316 846 592 m^3
ton (displacement)		≡ 35 cu ft	= 0.991 089 630 72 m^3
ton (freight)		≡ 40 cu ft	= 1.132 673 863 68

		m^3
ton (water)	≡ 28 bu (Imp)	= 1.018 324 16 m^3
tun	≡ 252 gal (wine)	= 0.953 923 769 568 m^3
wey (U.S.)	≡ 40 bu (US lvl)	= 1.409 562 806 6752 m^3

Plane angle

Plane angle

Name of unit	Symbol	Definition	Relation to SI units
angular mil	µ	≡ 2π/6400 rad	≈ 0.981 748×10^{-3} rad
arcminute; moa	'	≡ 1°/60	≈ 0.290 888×10^{-3} rad
arcsecond	"	≡ 1°/3600	≈ 4.848 137×10^{-6} rad
centesimal minute of arc	'	≡ 1 grad/100	≈ 0.157 080×10^{-3} rad
centesimal second of arc	"	≡ 1 grad/(10 000)	≈ 1.570 796×10^{-6} rad
degree (of arc)	°	≡ 1/360 of a revolution ≡ π/180 rad	≈ 17.453 293×10^{-3} rad
grad; gradian; gon	grad	≡ 1/400 of a revolution ≡ 2π/400 rad ≡ 0.9°	≈ 15.707 963×10^{-3} rad
octant		≡ 45°	≈ 0.785 398 rad
quadrant		≡ 90°	≈ 1.570 796 rad
radian (SI unit)	rad	The angle subtended at the center of a circle by an arc whose length is equal to the circle's radius. One full revolution encompasses 2π radians.	= 1 rad
sextant		≡ 60°	≈ 1.047 198 rad

sign	≡ 30°		≈ 0.523 599 rad

Solid angle

Solid angle

Name of unit	Symbol	Definition	Relation to SI units
steradian (SI unit)	sr	The solid angle subtended at the center of a sphere of radius r by a portion of the surface of the sphere having an area r^2. A sphere encompasses 4π sr.	= 1 sr

Mass

Notes:

- In this table, the unit *gee* is used to denote standard gravity in order to avoid confusion with the "g" symbol for grams.
- In physics, the pound of mass is sometimes written **lbm** to distinguish it from the pound-force (**lbf**). It should not be read as the mongrel unit "pound metre".

Mass

Name of unit	Symbol	Definition	Relation to SI units
atomic mass unit, unified	u; AMU		≈ 1.660 538 $73\times10^{-27} \pm 1.3\times10^{-36}$ kg
atomic unit of mass, electron rest mass	m_e		≈ 9.109 382 $15\times10^{-31} \pm 45\times10^{-39}$ kg
bag (coffee)		≡ 60 kg	= 60 kg
bag (Portland cement)		≡ 94 lb av	= 42.637 682 78 kg
barge		≡ 22½ sh tn	= 20 411.656 65 kg
carat	kt	≡ 3 1/6 gr	≈ 205.196 548 333 mg
carat (metric)	ct	≡ 200 mg	= 200 mg
clove		≡ 8 lb av	= 3.628 738 96 kg
crith			≈ 89.9349 mg
dalton	Da		≈ 1.660 902 $10\times10^{-27} \pm 1.3\times10^{-36}$ kg
dram (apothecary; troy)	dr t	≡ 60 gr	= 3.887 9346 g

dram (avoirdupois)	dr av	≡ 27 11/32 gr	= 1.771 845 195 3125 g
electronvolt	eV	≡ 1 eV (energy unit) / c^2	= 1.7826×10^{-36} kg
gamma	γ	≡ 1 μg	= 1 μg
grain	gr	≡ 1/7000 lb av	≡ 64.798 91 mg
grave	G	grave was the original name of the kilogram	≡ 1 kg
hundredweight (long)	long cwt or cwt	≡ 112 lb av	= 50.802 345 44 kg
hundredweight (short); cental	sh cwt	≡ 100 lb av	= 45.359 237 kg
hyl (CGS unit)		≡ 1 gee × 1 g × 1 s^2/m	= 9.806 65 g
hyl (MKS unit)		≡ 1 gee × 1 kg × 1 s^2/m	= 9.806 65 kg
kilogram	kg	≡ mass of the prototype near Paris (≈ mass of 1L of water)	≡ 1 kg (SI base unit)
kip	kip	≡ 1000 lb av	= 453.592 37 kg
mark		≡ 8 oz t	= 248.827 8144 g
mite		≡ 1/20 gr	= 3.239 9455 mg
mite (metric)		≡ 1/20 g	= 50 mg
ounce (apothecary; troy)	oz t	≡ 1/12 lb t	= 31.103 4768 g
ounce (avoirdupois)	oz av	≡ 1/16 lb	= 28.349 523 125 g
ounce (U.S. food nutrition labeling)	oz	≡ 28 g	= 28 g
pennyweight	dwt; pwt	≡ 1/20 oz t	= 1.555 173 84 g
point		≡ 1/100 ct	= 2 mg
pound (avoirdupois)	lb av	≡ 0.453 592 37 kg = 7000 grains	≡ 0.453 592 37 kg
pound (metric)		≡ 500 g	= 500 g
pound (troy)	lb t	≡ 5 760 grains	= 0.373 241 7216 kg
quarter (Imperial)		≡ 1/4 long cwt = 2 st = 28 lb av	= 12.700 586 36 kg
quarter (informal)		≡ ¼ short tn	= 226.796 185 kg
quarter, long (informal)		≡ ¼ long tn	= 254.011 7272 kg
quintal (metric)	q	≡ 100 kg	= 100 kg
scruple (apothecary)	s ap	≡ 20 gr	= 1.295 9782 g
sheet		≡ 1/700 lb av	= 647.9891 mg

slug; geepound	slug	≡ 1 gee × 1 lb av × 1 s^2/ft	≈ 14.593 903 kg
stone	st	≡ 14 lb av	= 6.350 293 18 kg
ton, assay (long)	AT	≡ 1 mg × 1 long tn ÷ 1 oz t	≈ 32.666 667 g
ton, assay (short)	AT	≡ 1 mg × 1 sh tn ÷ 1 oz t	≈ 29.166 667 g
ton, long	long tn or ton	≡ 2 240 lb	= 1 016.046 9088 kg
ton, short	sh tn	≡ 2 000 lb	= 907.184 74 kg
tonne (mts unit)	t	≡ 1 000 kg	= 1 000 kg
wey		≡ 252 lb = 18 st	= 114.305 277 24 kg (variants exist)
Zentner	Ztr.	Definitions vary	

Density

Density

Name of unit	Symbol	Definition	Relation to SI units
gram per millilitre	g/mL	≡ g/mL	= 1,000 kg/m^3
kilogram per cubic metre (SI unit)	kg/m^3	≡ kg/m^3	= 1 kg/m^3
kilogram per litre	kg/L	≡ kg/L	= 1,000 kg/m^3
ounce (avoirdupois) per cubic foot	oz/ft^3	≡ oz/ft^3	≈ 1.001153961 kg/m^3
ounce (avoirdupois) per cubic inch	oz/in^3	≡ oz/in^3	≈ 1.729994044×103 kg/m^3
ounce (avoirdupois) per gallon (Imperial)	oz/gal	≡ oz/gal	≈ 6.236023291 kg/m^3
ounce (avoirdupois) per gallon (U.S. fluid)	oz/gal	≡ oz/gal	≈ 7.489151707 kg/m^3
pound (avoirdupois) per cubic foot	lb/ft^3	≡ lb/ft^3	≈ 16.01846337 kg/m^3
pound (avoirdupois) per cubic inch	lb/in^3	≡ lb/in^3	≈ 2.767990471×104 kg/m^3
pound (avoirdupois) per gallon (Imperial)	lb/gal	≡ lb/gal	≈ 99.77637266 kg/m^3
pound (avoirdupois) per gallon (U.S. fluid)	lb/gal	≡ lb/gal	≈ 119.8264273 kg/m^3
slug per cubic foot	slug/ft^3	≡ slug/ft^3	≈ 515.3788184 kg/m^3

Time

Time, t

Name of unit	Symbol	Definition	Relation to SI units
atomic unit of time	au	≡ $a_0/(\alpha \cdot c)$	≈ 2.418 884 254×10^{-17} s
Callippic cycle		≡ 441 mo (hollow) + 499 mo (full) = 76 a of 365.25 d	= 2.398 3776×10^{9} s
century	c	≡ 100 a	= 100 × year
day	d	= 24 h	= 86400 s
day (sidereal)	d	≡ Time needed for the Earth to rotate once around its axis, determined from successive transits of a very distant astronomical object across an observer's meridian (International Celestial Reference Frame)	≈ 86 164.1 s
decade	dec	≡ 10 a	= 10 × year
fortnight	fn	≡ 2 wk	= 1 209 600 s
helek		≡ 1/1 080 h	= 3.3 s
Hipparchic cycle		≡ 4 Callippic cycles - 1 d	= 9.593 424×10^{9} s
hour	h	≡ 60 min	= 3 600 s
jiffy	j	≡ 1/60 s	= .016 s
jiffy (alternate)	ja	≡ 1/100 s	= 10 ms
ke (quarter of an hour)		≡ ¼ h = 1/96 d	= 60 × 60 / 4 s = 900 s = 60 / 4 min = 15 min
ke (traditional)		≡ 1/100 d	= 24 × 60 × 60 / 100 s = 864 s = 24 * 60 / 100 min = 14.4 min
lustre; lustrum		≡ 5 a of 365 d	= 1.5768×10^{8} s
Metonic cycle; enneadecaeteris		≡ 110 mo (hollow) + 125 mo (full) = 6940 d ≈ 19 a	= 5.996 16×10^{8} s
millennium		≡ 1 000 a	= 1000 × year
milliday	md	≡ 1/1 000 d	= 24 × 60 × 60 / 1 000 s = 86.4 s
minute	min	≡ 60 s, due to leap seconds sometimes 59 s or 61 s,	= 60 s

moment		≡ 90 s	= 90 s
month (full)	mo	≡ 30 d	= 2 592 000 s
month (Greg. av.)	mo	Average Gregorian month = 365.2425/12 d = 30.436875 d	≈ 2.6297×10^{6} s
month (hollow)	mo	≡ 29 d	= 2 505 600 s
month (synodic)	mo	Cycle time of moon phases ≈ 29.530589 days (Average)	≈ 2.551×10^{6} s
octaeteris		= 48 mo (full) + 48 mo (hollow) + 3 mo (full) = 8 a of 365.25 d = 2922 d	= $2.524\,608 \times 10^{8}$ s
Planck time		≡ $(G\hbar/c^{5})^{½}$	≈ $1.351\,211\,868 \times 10^{-43}$ s
second	s	time of 9 192 631 770 periods of the radiation corresponding to the transition between the 2 hyperfine levels of the ground state of the caesium 133 atom at 0 K (but other seconds are sometimes used in astronomy)	(SI base unit)
shake		≡ 10^{-8} s	= 10 ns
sigma		≡ 10^{-6} s	= 1 μs
Sothic cycle		≡ 1 461 a of 365 d	= $4.607\,4096 \times 10^{10}$ s
svedberg	S	≡ 10^{-13} s	= 100 fs
week	wk	≡ 7 d	= 604 800 s
year (Gregorian)	a, y, *or* yr	= 365.2425 d average, calculated from common years (365 d) plus leap years (366 d) on most years divisible by 4.	= 31 556 952 s
year (Julian)	a, y, *or* yr	= 365.25 d average, calculated from common years (365 d) plus one leap year (366 d) every four years	= 31 557 600 s
year (sidereal)	a, y, *or* yr	≡ time taken for Sun to return to the same position with respect to the stars of the celestial sphere	≈ 365.256 363 d ≈ 31 558 149.7632 s
year (tropical)	a, y, *or* yr	≡ Length of time it takes for the Sun to return to the same position in the cycle of seasons	≈ 365.242 190 d ≈ 31 556 925 s

Where UTC is observed, the length of time units longer than 1 s may increase or decrease by 1 s if a leap second occurs during the time interval of interest.

Frequency

Frequency

Name of unit	Symbol	Definition	Relation to SI units
hertz (SI unit)	Hz	≡ Number of cycles per second	= 1 Hz = 1/s
revolutions per minute	rpm	≡ One unit rpm equals one rotation completed around a fixed axis in one minute of time.	≈ 0.104719755 rad/s

Speed or velocity

Speed

Name of unit	Symbol	Definition	Relation to SI units
foot per hour	fph	≡ 1 ft/h	≈ $8.466\,667\times10^{-5}$ m/s
foot per minute	fpm	≡ 1 ft/min	= 5.08×10^{-3} m/s
foot per second	fps	≡ 1 ft/s	= 3.048×10^{-1} m/s
furlong per fortnight		≡ furlong/fortnight	≈ $1.663\,095\times10^{-4}$ m/s
inch per minute	ipm	≡ 1 in/min	≈ $4.23\,333\times10^{-4}$ m/s
inch per second	ips	≡ 1 in/s	= 2.54×10^{-2} m/s
kilometre per hour	km/h	≡ 1 km/h	≈ $2.777\,778\times10^{-1}$ m/s
knot	kn	≡ 1 NM/h = 1.852 km/h	≈ 0.514 444 m/s
knot (Admiralty)	kn	≡ 1 NM (Adm)/h = 1.853 184 km/h	= 0.514 773 m/s
mach number	*M*	Ratio of the speed to the speed of sound in the medium. Varies especially with temperature. About 1225 km/h (761 mph) in air at sea level to about 1062 km/h (660 mph) at jet altitudes. Unitless	≈ 340 to 295 m/s for aircraft
metre per second (SI unit)	m/s	≡ 1 m/s	= 1 m/s
mile per hour	mph	≡ 1 mi/h	= 0.447 04 m/s

mile per minute	mpm	≡ 1 mi/min	= 26.8224 m/s
mile per second	mps	≡ 1 mi/s	= 1 609.344 m/s
speed of light in vacuum	*c*	≡ 299 792 458 m/s	= 299 792 458 m/s
speed of sound in air	*s*	Varies especially with temperature. About 1225 km/h (761 mph) in air at sea level to about 1062 km/h (660 mph) at jet altitudes.	≈ 340 to 295 m/s at aircraft altitudes

A velocity consists of a speed combined with a direction; the speed part of the velocity takes units of speed.

Flow (volume)

Flow

Name of unit	Symbol	Definition	Relation to SI units
cubic foot per minute	CFM	≡ 1 ft^3/min	= 4.719474432×10^{-4} m^3/s
cubic foot per second	ft^3/s	≡ 1 ft^3/s	= 0.028316846592 m^3/s
cubic inch per minute	in^3/min	≡ 1 in^3/min	= 2.7311773×10^{-7} m^3/s
cubic inch per second	in^3/s	≡ 1 in^3/s	= 1.6387064×10^{-5} m^3/s
cubic metre per second (SI unit)	m^3/s	≡ 1 m^3/s	= 1 m^3/s
gallon (U.S. fluid) per day	GPD	≡ 1 gal/d	= 4.381263638×10^{-8} m^3/s
gallon (U.S. fluid) per hour	GPH	≡ 1 gal/h	= 1.051503273×10^{-6} m^3/s
gallon (U.S. fluid) per minute	GPM	≡ 1 gal/min	= 6.30901964×10^{-5} m^3/s
litre per minute	LPM	≡ 1 L/min	= 1.6×10^{-5} m^3/s

Acceleration

Acceleration

Name of unit	Symbol	Definition	Relation to SI units
foot per hour per second	fph/s	≡ 1 ft/(h·s)	≈ $8.466\,667\times10^{-5}$ m/s^2
foot per minute per second	fpm/s	≡ 1 ft/(min·s)	= 5.08×10^{-3} m/s^2
foot per second squared	fps^2	≡ 1 ft/s^2	= 3.048×10^{-1} m/s^2
gal; galileo	Gal	≡ 1 cm/s^2	= 10^{-2} m/s^2

inch per minute per second	ipm/s	≡ 1 in/(min·s)	≈ 4.233 333×10^{-4} m/s^2
inch per second squared	ips^2	≡ 1 in/s^2	= 2.54×10^{-2} m/s^2
knot per second	kn/s	≡ 1 kn/s	≈ 5.144 444×10^{-1} m/s^2
metre per second squared (SI unit)	m/s^2	≡ 1 m/s^2	= 1 m/s^2
mile per hour per second	mph/s	≡ 1 mi/(h·s)	= 4.4704×10^{-1} m/s^2
mile per minute per second	mpm/s	≡ 1 mi/(min·s)	= 26.8224 m/s^2
mile per second squared	mps^2	≡ 1 mi/s^2	= 1.609 344×10^3 m/s^2
standard gravity	*g*	≡ 9.806 65 m/s^2	= 9.806 65 m/s^2

Force

Force

Name of unit	Symbol	Definition	Relation to SI units
atomic unit of force		≡ $m_e·\alpha^2·c^2/a_0$	≈ 8.238 722 06×10^{-8} N
dyne (cgs unit)	dyn	≡ g·cm/s^2	= 10^{-5} N
kilogram-force; kilopond; grave-force	kgf; kp; Gf	≡ *g* × 1 kg	= 9.806 65 N
kip; kip-force	kip; kipf; klbf	≡ *g* × 1 000 lb	= 4.448 221 615 2605×10^3 N
milligrave-force, gravet-force	mGf; gf	≡ *g* × 1 g	= 9.806 65 mN
newton (SI unit)	N	A force capable of giving a mass of one kg an acceleration of one metre per second, per second.	= 1 N = 1 kg·m/s^2
ounce-force	ozf	≡ *g* × 1 oz	= 0.278 013 850 953 7812 N
pound	lb	≡ slug·ft/s^2	= 4.448 230 531 N
pound-force	lbf	≡ *g* × 1 lb	= 4.448 221 615 2605 N
poundal	pdl	≡ 1 lb·ft/s^2	= 0.138 254 954 376 N
sthene (mts unit)	sn	≡ 1 t·m/s^2	= 1×10^3 N
ton-force	tnf	≡ *g* × 1 sh tn	= 8.896 443 230 521×10^3 N

Pressure or mechanical stress

Pressure

Name of unit	Symbol	Definition	Relation to SI units
atmosphere (standard)	atm		≡ 101 325 Pa
atmosphere (technical)	at	≡ 1 kgf/cm^2	= 9.806 65×10^4 Pa
bar	bar		≡ 10^5 Pa
barye (cgs unit)		≡ 1 dyn/cm^2	= 0.1 Pa
centimetre of mercury	cmHg	≡ 13 595.1 kg/m^3 × 1 cm × g	≈ 1.333 22×10^3 Pa
centimetre of water (4 °C)	cmH_2O	≈ 999.972 kg/m^3 × 1 cm × g	≈ 98.0638 Pa
foot of mercury (conventional)	ftHg	≡ 13 595.1 kg/m^3 × 1 ft × g	≈ 40.636 66×10^3 Pa
foot of water (39.2 °F)	ftH_2O	≈ 999.972 kg/m^3 × 1 ft × g	≈ 2.988 98×10^3 Pa
inch of mercury (conventional)	inHg	≡ 13 595.1 kg/m^3 × 1 in × g	≈ 3.386 389×10^3 Pa
inch of water (39.2 °F)	inH_2O	≈ 999.972 kg/m^3 × 1 in × g	≈ 249.082 Pa
kilogram-force per square millimetre	kgf/mm^2	≡ 1 kgf/mm^2	= 9.806 65×10^6 Pa
kip per square inch	ksi	≡ 1 kipf/sq in	≈ 6.894 757×10^6 Pa
micron (micrometre) of mercury	μmHg	≡ 13 595.1 kg/m^3 × 1 μm × g ≈ 0.001 torr	≈ 0.133 3224 Pa
millimetre of mercury	mmHg	≡ 13 595.1 kg/m^3 × 1 mm × g ≈ 1 torr	≈ 133.3224 Pa
millimetre of water (3.98 °C)	mmH_2O	≈ 999.972 kg/m^3 × 1 mm × g = 0.999 972 kgf/m^2	= 9.806 38 Pa
pascal (SI unit)	Pa	≡ N/m^2 = kg/(m·s^2)	= 1 Pa
pièze (mts unit)	pz	≡ 1 000 kg/m·s^2	= 1×10^3 Pa = 1 kPa
pound per square foot	psf	≡ 1 lbf/ft^2	≈ 47.880 26 Pa
pound per square inch	psi	≡ 1 lbf/in^2	≈ 6.894 757×10^3 Pa
poundal per square foot	pdl/sq ft	≡ 1 pdl/sq ft	≈ 1.488 164 Pa
short ton per square foot		≡ 1 sh tn × g / 1 sq ft	≈ 95.760 518×10^3 Pa

torr	torr	≡ 101 325/760 Pa	≈ 133.3224 Pa

Torque or moment of force

Torque

Name of unit	Symbol	Definition	Relation to SI units
foot-pound force	ft lbf	≡ g × 1 lb × 1 ft	= 1.355 817 948 331 4004 N·m
foot-poundal	ft pdl	≡ 1 lb·ft^2/s^2	= 4.214 011 009 380 48×10^{-2} N·m
inch-pound force	in lbf	≡ g × 1 lb × 1 in	= 0.112 984 829 027 6167 N·m
metre kilogram	m kg	≡ N × m / g	≈ 0.101 971 621 N·m
Newton metre (SI unit)	N·m	≡ N × m = kg·m^2/s^2	= 1 N·m

Energy, work, or amount of heat

Energy

Name of unit	Symbol	Definition	Relation to SI units
barrel of oil equivalent	bboe	≈ 5.8×10^6 BTU$_{59\,°F}$	≈ 6.12×10^9 J
British thermal unit (ISO)	BTU$_{ISO}$	≡ 1.0545×10^3 J	= 1.0545×10^3 J
British thermal unit (International Table)	BTU$_{IT}$		= 1.055 055 852 62×10^3 J
British thermal unit (mean)	BTU$_{mean}$		≈ 1.055 87×10^3 J
British thermal unit (thermochemical)	BTU$_{th}$		≈ 1.054 350×10^3 J
British thermal unit (39 °F)	BTU$_{39\,°F}$		≈ 1.059 67×10^3 J
British thermal unit (59 °F)	BTU$_{59\,°F}$	≡ 1.054 804×10^3 J	= 1.054 804×10^3 J
British thermal unit (60 °F)	BTU$_{60\,°F}$		≈ 1.054 68×10^3 J
British thermal unit (63 °F)	BTU$_{63\,°F}$		≈ 1.0546×10^3 J
calorie (International Table)	cal$_{IT}$	≡ 4.1868 J	= 4.1868 J
calorie (mean)	cal$_{mean}$	$^1\!/_{100}$ of the energy required to warm one	≈ 4.190 02 J

		gram of air-free water from 0 °C to 100 °C @ 1 atm	
calorie (thermochemical)	cal_{th}	≡ 4.184 J	= 4.184 J
calorie (3.98 °C)	$cal_{3.98\,°C}$		≈ 4.2045 J
calorie (15 °C)	$cal_{15\,°C}$	≡ 4.1855 J	= 4.1855 J
calorie (20 °C)	$cal_{20\,°C}$		≈ 4.1819 J
Celsius heat unit (International Table)	CHU_{IT}	≡ 1 BTU_{IT} × 1 K/°R	= 1.899 100 534 716×10^3 J
cubic centimetre of atmosphere; standard cubic centimetre	cc atm; scc	≡ 1 atm × 1 cm^3	= 0.101 325 J
cubic foot of atmosphere; standard cubic foot	cu ft atm; scf	≡ 1 atm × 1 ft^3	= 2.869 204 480 9344×10^3 J
cubic foot of natural gas		≡ 1 000 BTU_{IT}	= 1.055 055 852 62×10^6 J
cubic yard of atmosphere; standard cubic yard	cu yd atm; scy	≡ 1 atm × 1 yd^3	= 77.468 520 985 2288×10^3 J
electronvolt	eV	≡ e × 1 V	≈ 1.602 177 33×10^{-19} ± 4.9×10^{-26} J
erg (cgs unit)	erg	≡ 1 g·cm^2/s^2	= 10^{-7} J
foot-pound force	ft lbf	≡ g × 1 lb × 1 ft	= 1.355 817 948 331 4004 J
foot-poundal	ft pdl	≡ 1 lb·ft^2/s^2	= 4.214 011 009 380 48×10^{-2} J
gallon-atmosphere (imperial)	imp gal atm	≡ 1 atm × 1 gal (imp)	= 460.632 569 25 J
gallon-atmosphere (US)	US gal atm	≡ 1 atm × 1 gal (US)	= 383.556 849 0138 J
hartree, atomic unit of energy	E_h	≡ $m_e·\alpha^2·c^2$ (= 2 Ry)	≈ 4.359 744×10^{-18} J
horsepower-hour	hp·h	≡ 1 hp × 1 h	= 2.684 519 537 696 172 792×10^6 J
inch-pound force	in lbf	≡ g × 1 lb × 1 in	= 0.112 984 829 027 6167 J
joule (SI unit)	J	The work done when a force of one newton	= 1 J = 1 m·N = 1 kg·m^2/s^2 =

		moves the point of its application a distance of one metre in the direction of the force.	1 C·V = 1 W·s
kilocalorie; large calorie	kcal; Cal	≡ 1 000 cal_{IT}	= 4.1868×10^3 J
kilowatt-hour; Board of Trade Unit	kW·h; B.O.T.U.	≡ 1 kW × 1 h	= 3.6×10^6 J
litre-atmosphere	l atm; sl	≡ 1 atm × 1 L	= 101.325 J
quad		≡ 10^{15} BTU_{IT}	= 1.055 055 852 62×10^{18} J
rydberg	Ry	≡ $R_\infty \cdot h \cdot c$	≈ 2.179 872×10^{-18} J
therm (E.C.)		≡ 100 000 BTU_{IT}	= 105.505 585 262×10^6 J
therm (U.S.)		≡ 100 000 $BTU_{59\,°F}$	= 105.4804×10^6 J
thermie	th	≡ 1 $Mcal_{IT}$	= 4.1868×10^6 J
ton of coal equivalent	TCE	≡ 7 $Gcal_{th}$	= 29.3076×10^9 J
ton of oil equivalent	TOE	≡ 10 $Gcal_{th}$	= 41.868×10^9 J
ton of TNT	tTNT	≡ 1 $Gcal_{th}$	= 4.184×10^9 J

Power or heat flow rate

Power

Name of unit	Symbol	Definition	Relation to SI units
atmosphere-cubic centimetre per minute	atm ccm	≡ 1 atm × 1 cm^3/min	= 1.688 75×10^{-3} W
atmosphere-cubic centimetre per second	atm ccs	≡ 1 atm × 1 cm^3/s	= 0.101 325 W
atmosphere-cubic foot per hour	atm cfh	≡ 1 atm × 1 cu ft/h	= 0.797 001 244 704 W
atmosphere-cubic foot per minute	atm·cfm	≡ 1 atm × 1 cu ft/min	= 47.820 074 682 24 W
atmosphere-cubic foot per second	atm cfs	≡ 1 atm × 1 cu ft/s	= 2.869 204 480 9344×10^3 W
BTU (International Table) per hour	BTU_{IT}/h	≡ 1 BTU_{IT}/h	≈ 0.293 071 W
BTU (International Table) per minute	BTU_{IT}/min	≡ 1 BTU_{IT}/min	≈ 17.584 264 W

BTU (International Table) per second	BTU_{IT}/s	≡ 1 BTU_{IT}/s	= 1.055 055 852 62×10^3 W
calorie (International Table) per second	cal_{IT}/s	≡ 1 cal_{IT}/s	= 4.1868 W
foot-pound-force per hour	ft lbf/h	≡ 1 ft lbf/h	≈ 3.766 161×10^{-4} W
foot-pound-force per minute	ft lbf/min	≡ 1 ft lbf/min	= 2.259 696 580 552 334×10^{-2} W
foot-pound-force per second	ft lbf/s	≡ 1 ft lbf/s	= 1.355 817 948 331 4004 W
horsepower (boiler)	bhp	≈ 34.5 lb/h × 970.3 BTU_{IT}/lb	≈ 9.810 657×10^3 W
horsepower (European electrical)	hp	≡ 75 kp·m/s	= 736 W
horsepower (Imperial electrical)	hp	≡ 746 W	= 746 W
horsepower (Imperial mechanical)	hp	≡ 550 ft lbf/s	= 745.699 871 582 270 22 W
horsepower (metric)	hp	≡ 75 m kgf/s	= 735.498 75 W
litre-atmosphere per minute	L·atm/min	≡ 1 atm × 1 L/min	= 1.688 75 W
litre-atmosphere per second	L·atm/s	≡ 1 atm × 1 L/s	= 101.325 W
lusec	lusec	≡ 1 L·µmHg/s	≈ 1.333×10^{-4} W
poncelet	p	≡ 100 m kgf/s	= 980.665 W
square foot equivalent direct radiation	sq ft EDR	≡ 240 BTU_{IT}/h	≈ 70.337 057 W
ton of air conditioning		≡ 1 t ice melted / 24 h	≈ 3 504 W
ton of refrigeration (Imperial)		≡ 1 BTU_{IT} × 1 lng tn/lb ÷ 10 min/s	≈ 3.938 875×10^3 W
ton of refrigeration (IT)		≡ 1 BTU_{IT} × 1 sh tn/lb ÷ 10 min/s	≈ 3.516 853×10^3 W
watt (SI unit)	W	The power which in one second of time gives rise to one joule of energy.	= 1 W = 1 J/s = 1 N·m/s = 1 kg·m^2/s^3

Action

Action

Name of unit	Symbol	Definition	Relation to SI units
atomic unit of action	au	$\equiv \hbar \equiv h/2\pi$	$\approx 1.054\ 571\ 68 \times 10^{-34}$ J·s

Dynamic viscosity

Dynamic viscosity

Name of unit	Symbol	Definition	Relation to SI units
pascal second (SI unit)	Pa·s	≡ N·s/m^2 , kg/(m·s)	= 1 Pa·s
poise (cgs unit)	P	≡ 10^{-1} Pa·s	= 0.1 Pa·s
pound per foot hour	lb/(ft·h)	≡ 1 lb/(ft·h)	$\approx 4.133\ 789 \times 10^{-4}$ Pa·s
pound per foot second	lb/(ft·s)	≡ 1 lb/(ft·s)	≈ 1.488164 Pa·s
pound-force second per square foot	lbf·s/ft^2	≡ 1 lbf·s/ft^2	≈ 47.88026 Pa·s
pound-force second per square inch	lbf·s/in^2	≡ 1 lbf·s/in^2	≈ 6,894.757 Pa·s

Kinematic viscosity

Kinematic viscosity

Name of unit	Symbol	Definition	Relation to SI units
square foot per second	ft^2/s	≡ 1 ft^2/s	= 0.09290304 m^2/s
square metre per second (SI unit)	m^2/s	≡ 1 m^2/s	= 1 m^2/s
stokes (cgs unit)	St	≡ 10^{-4} m^2/s	= 10^{-4} m^2/s

Electric current

Electric current

Name of unit	Symbol	Definition	Relation to SI units
ampere (SI base unit)	A	≡ The constant current needed to produce a force of 2 $\times 10^{-7}$ newton per metre between two straight parallel conductors of infinite length and negligible circular cross-section placed one metre apart in a vacuum.	= 1 A

electromagnetic unit; abampere (cgs unit)	abamp	≡ 10 A	= 10 A
esu per second; statampere (cgs unit)	esu/s	≡ (0.1 A·m/s) / *c*	≈ 3.335641×10−10 A

Electric charge

Electric charge

Name of unit	Symbol	Definition	Relation to SI units
abcoulomb; electromagnetic unit (cgs unit)	abC; emu	≡ 10 C	= 10 C
atomic unit of charge	au	≡ *e*	≈ 1.602 176 462×10^{-19} C
coulomb (SI unit)	C	≡ The amount of electricity carried in one second of time by one ampere of current.	= 1 C = 1 A·s
faraday	F	≡ 1 mol × $N_A \cdot e$	≈ 96 485.3383 C
statcoulomb; franklin; electrostatic unit (cgs unit)	statC; Fr; esu	≡ (0.1 A·m) / *c*	≈ 3.335 641×10^{-10} C

Electric dipole

Electric dipole

Name of unit	Symbol	Definition	Relation to SI units
atomic unit of electric dipole moment	ea_0		≈ 8.478 352 81×10^{-30} C·m
coulomb meter	C·m		= 1 C · 1 m
debye	D	= 10^{-10} esu·Å	= 3.33564095×10^{-30} C·m

Electromotive force, electric potential difference

Voltage, electromotive force

Name of unit	Symbol	Definition	Relation to SI units
abvolt (cgs unit)	abV	≡ 1×10^{-8} V	= 1×10^{-8} V

statvolt (cgs unit)	statV	≡ $c\cdot$ (1 μJ/A·m)	= 299.792 458 V
volt (SI unit)	V	The difference in electric potential across two points along a conducting wire carrying one ampere of constant current when the power dissipated between the points equals one watt.	= 1 V = 1 W/A = 1 $kg\cdot m^2/(A\cdot s^3)$

Electrical resistance

Electrical resistance

Name of unit	Symbol	Definition	Relation to SI units
ohm (SI unit)	Ω	The resistance between two points in a conductor when one volt of electric potential difference, applied to these points, produces one ampere of current in the conductor.	= 1 Ω = 1 V/A = 1 $kg\cdot m^2/(A^2\cdot s^3)$

Capacitance

Capacitor's ability to store charge

Name of unit	Symbol	Definition	Relation to SI units
farad (SI unit)	F	The capacitance between two parallel plates that results in one volt of potential difference when charged by one coulomb of electricity.	= 1 F = 1 C/V = 1 $A^2\cdot s^4/(kg\cdot m^2)$

Magnetic flux

magnetic flux

Name of unit	Symbol	Definition	Relation to SI units
maxwell (CGS unit)	Mx	≡ 10^{-8} Wb	= 1×10^{-8} Wb
weber (SI unit)	Wb	Magnetic flux which, linking a circuit of one turn, would produce in it an electromotive force of 1 volt if it were reduced to zero at a uniform rate in 1 second.	= 1 Wb = 1 V·s = 1 $kg\cdot m^2/(A\cdot s^2)$

Magnetic flux density

What physicists call Magnetic field is called Magnetic flux density by electrical engineers and magnetic induction by applied mathematicians and electrical engineers.

Name of unit	Symbol	Definition	Relation to SI units
gauss (CGS unit)	G	≡ Mx/cm^2 = 10^{-4} T	= 1×10^{-4} T
tesla (SI unit)	T	≡ Wb/m^2	= 1 T = 1 Wb/m^2 = 1 kg/(A·s^2)

Inductance

Inductance

Name of unit	Symbol	Definition	Relation to SI units
henry (SI unit)	H	The inductance of a closed circuit that produces one volt of electromotive force when the current in the circuit varies at a uniform rate of one ampere per second.	= 1 H = 1 Wb/A = 1 kg·m^2/(A·s)^2

Temperature

Temperature

Name of unit	Symbol	Definition	Conversion to kelvin
degree Celsius	°C	°C ≡ K − 273.15	[K] ≡ [°C] + 273.15
degree Delisle	°De		[K] = 373.15 − [°De] × 2/3
degree Fahrenheit	°F	°F ≡ °C × 9/5 + 32	[K] ≡ ([°F] + 459.67) × 5/9
degree Newton	°N		[K] = [°N] × 100/33 + 273.15
degree Rankine	°R; °Ra	°R ≡ K × 9/5	[K] ≡ [°R] × 5/9
degree Réaumur	°Ré		[K] = [°Ré] × 5/4 + 273.15
degree Rømer	°Rø		[K] = ([°Rø] − 7.5) × 40/21 + 273.15
kelvin (SI base unit)	K	≡ 1/273.16 of the thermodynamic temperature of the triple point of water.	≡ 1 K

Information entropy

Information entropy

Name of unit	Symbol	Definition	Relation to SI units	Relation to bits
SI unit	J/K	≡ J/K	= 1 J/K	
nat; nip; nepit	nat	≡ k_B	= 1.380 650 5(23)×$10^{−23}$ J/K	
bit; shannon	bit; b; Sh	≡ ln(2) × k_B	= 9.569 940 (16)×$10^{−24}$ J/K	= 1 bit
ban; hartley	ban; Hart	≡ ln(10) × k_B	= 3.179 065 3(53)×$10^{−23}$ J/K	
nibble		≡ 4 bits	= 3.827 976 0(64)×$10^{−23}$ J/K	= 2^2 bit
byte	B	≡ 8 bits	= 7.655 952 (13)×$10^{−23}$ J/K	= 2^3 bit
kilobyte (decimal)	kB	≡ 1 000 B	= 7.655 952 (13)×$10^{−20}$ J/K	= 8×10^3 bit = 8000 bit
kilobyte (kibibyte)	KB; KiB	≡ 1 024 B	= 7.839 695 (13)×$10^{−20}$ J/K	= 2^{13} bit = 8192 bit

Often, information entropy is measured in shannons, whereas the (discrete) storage space of digital devices is measured in bits. Thus, uncompressed redundant data occupy more than one bit of storage per shannon of information entropy. The multiples of a bit listed above are usually used with this meaning. Other times the bit is used as a measure of information entropy and is thus a synonym of shannon.

Luminous intensity

The candela is the preferred nomenclature for the SI unit.

Luminous intensity

Name of unit	Symbol	Definition	Relation to SI units
candela (SI base unit); candle	cd	The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.	= 1 cd
candlepower (new)	cp	≡ cd The use of *candlepower* as a unit is discouraged due to its ambiguity.	= 1 cd

candlepower (old, pre-1948)	cp	Varies and is poorly reproducible. Approximately 0.981 cd.	≈ 0.981 cd

Luminance

Luminance

Name of unit	Symbol	Definition	Relation to SI units
candela per square foot	cd/ft^2	≡ cd/ft^2	≈ 10.763910417 cd/m^2
candela per square inch	cd/in^2	≡ cd/in^2	≈ 1,550.0031 cd/m^2
candela per square metre (SI unit); nit (deprecated)	cd/m^2	≡ cd/m^2	= 1 cd/m^2
footlambert	fL	≡ (1/π) cd/ft^2	≈ 3.4262590996 cd/m^2
lambert	L	≡ $(10^4/\pi)$ cd/m^2	≈ 3,183.0988618 cd/m^2
stilb (CGS unit)	sb	≡ 10^4 cd/m^2	≈ 1×10^4 cd/m^2

Luminous flux

Luminous flux

Name of unit	Symbol	Definition	Relation to SI units
lumen (SI unit)	lm	≡ cd·sr	= 1 lm = 1 cd·sr

Illuminance

Illuminance

Name of unit	Symbol	Definition	Relation to SI units
footcandle; lumen per square foot	fc	≡ lm/ft^2	= 10.763910417 lx
lumen per square inch	lm/in^2	≡ lm/in^2	≈ 1,550.0031 lx
lux (SI unit)	lx	≡ lm/m^2	= 1 lx = 1 lm/m^2
phot (CGS unit)	ph	≡ lm/cm^2	= 1×10^4 lx

Radiation - source activity

Radioactivity

Name of unit	Symbol	Definition	Relation to SI units
becquerel (SI unit)	Bq	≡ Number of disintegrations per second	= 1 Bq = 1/s
curie	Ci	≡ 3.7×10^{10} Bq	= 3.7×10^{10} Bq
rutherford (H)	rd	≡ 1 MBq	= 1×10^6 Bq

Please note that although becquerel (Bq) and hertz (Hz) both ultimately refer to the same SI base unit (s^{-1}), Hz is used only for periodic phenomena, and Bq is only used for stochastic processes associated with radioactivity.

Radiation - exposure

Radiation - exposure

Name of unit	Symbol	Definition	Relation to SI units
roentgen	R	1 R ≡ 2.58×10^{-4} C/kg	= 2.58×10^{-4} C/kg

The roentgen is not a SI unit and the NIST strongly discourages its continued use.

Radiation - absorbed dose

Radiation - absorbed dose

Name of unit	Symbol	Definition	Relation to SI units
gray (SI unit)	Gy	≡ 1 J/kg = 1 m^2/s^2	= 1 Gy
rad	rad	≡ 0.01 Gy	= 0.01 Gy

Radiation - equivalent dose

Radiation - equivalent dose

Name of unit	Symbol	Definition	Relation to SI units
Röntgen equivalent man	rem	≡ 0.01 Sv	= 0.01 Sv
sievert (SI unit)	Sv	≡ 1 J/kg	= 1 Sv

Although the definitions for sievert (Sv) and gray (Gy) would seem to indicate that they measure the same quantities, this is not the case. The effect of receiving a certain dose of radiation (given as Gy) is variable and depends on many factors, thus a new unit was needed to denote the biological effectiveness of that dose on the body; this is known as the equivalent dose and is shown in Sv. The general relationship between absorbed dose and equivalent dose can be represented as

$$H = Q \cdot D$$

where H is the equivalent dose, D is the absorbed dose, and Q is a dimensionless quality factor. Thus, for any quantity of D measured in Gy, the numerical value for H measured in Sv may be different.

Software tools

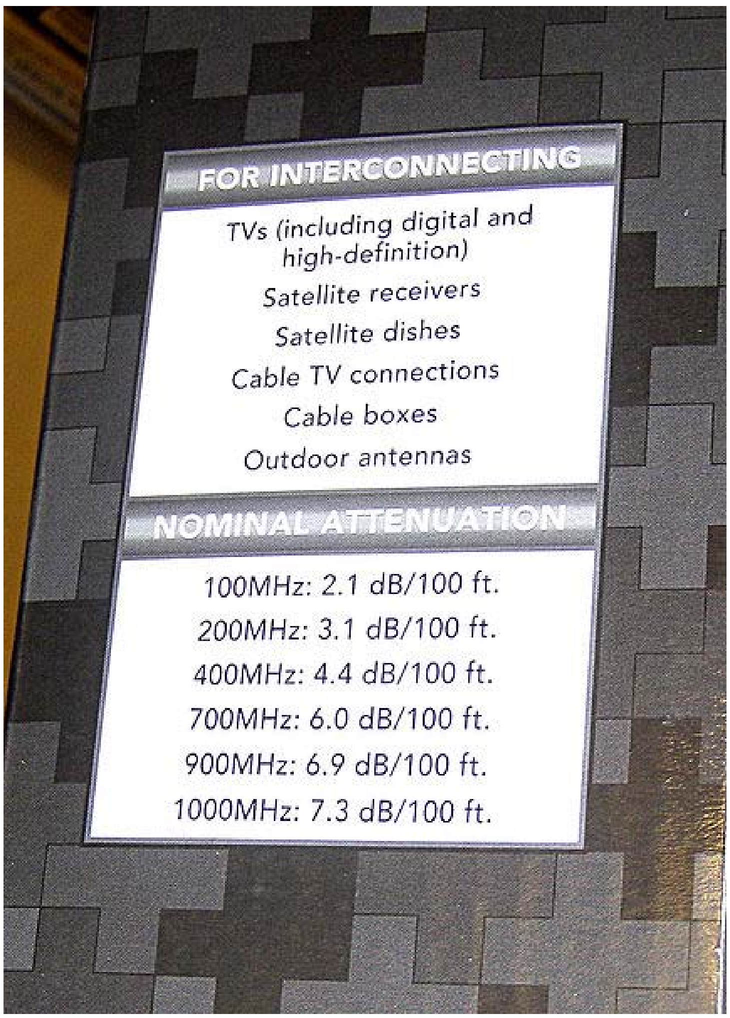
Home and office computers come with converters in bundled spreadsheet applications or can access free converters via the Internet. Units and measurements can be easily converted using these tools, but only if the units are explicitly defined and the conversion is compatible (e.g., cmHg to kPa).

General commercial sources of converters

- Advanced electronic calculators have unit-conversion functionality.
- Spreadsheet programs usually provide conversion functions or formulas or the user can write their own.
- Commercial mathematical, scientific and technical applications often include converters.

Chapter-3

Decibel



Attenuation chart of an RG-6 Coaxial cable, measured in decibels per 100 feet of cable

The **decibel** (**dB**) is a logarithmic unit that indicates the ratio of a physical quantity (usually power or intensity) relative to a specified or implied reference level. A ratio in decibels is ten times the logarithm to base 10 of the ratio of two power quantities. Being a ratio of two measurements of a physical quantity in the same units, it is a dimensionless unit. A decibel is one tenth of a **bel**, a seldom-used unit.

The decibel is used for a wide variety of measurements in science and engineering, most prominently in acoustics, electronics, and control theory. In electronics, the gain of amplifiers, attenuation of signals, and signal-to-noise ratios are often expressed in decibels. The decibel confers a number of advantages, such as the ability to conveniently represent very large or small numbers, and the ability to carry out multiplication of ratios by simple addition and subtraction.

The decibel symbol is often qualified with a suffix, that indicates which reference quantity or frequency weighting function has been used. For example, *dBm* indicates that the reference quantity is one milliwatt, while *dBu* is referenced to 0.775 volts RMS. and *dBμV/m* referenced to microvolts per meter for radio frequency signal strength.

The definitions of the decibel and bel use logarithms to base 10. The neper, used in electronics, uses natural logarithm to base (*e*).

History

The decibel originates from methods used to quantify reductions in audio levels in telephone circuits. These losses were originally measured in units of *Miles of Standard Cable* (MSC), where 1 MSC corresponded to the loss of power over a 1 mile (approximately 1.6 km) length of standard telephone cable at a frequency of 5000 radians per second (795.8 Hz), and roughly matched the smallest attenuation detectable to an average listener. Standard telephone cable was defined as "*a cable having uniformly distributed resistance of 88 ohms per loop mile and uniformly distributed shunt capacitance of .054 microfarad per mile*" (approximately 19 gauge).

The *transmission unit* (TU) was devised by engineers of the Bell Telephone Laboratories in the 1920s to replace the MSC. 1 TU was defined as ten times the base-10 logarithm of the ratio of measured power to a reference power level. The definitions were conveniently chosen such that 1 TU approximately equaled 1 MSC (specifically, 1.056 TU = 1 MSC). In 1928, the Bell system renamed the TU to the decibel. Along with the decibel, the Bell System defined the *bel*, the base-10 logarithm of the power ratio, in honor of their founder and telecommunications pioneer Alexander Graham Bell. The bel has seldom been used, as the decibel was the proposed working unit.

The naming and early definition of the decibel is described in the NBS Standard's Yearbook of 1931:

Since the earliest days of the telephone, the need for a unit in which to measure the transmission efficiency of telephone facilities has been recognized. The introduction of

cable in 1896 afforded a stable basis for a convenient unit and the "mile of standard" cable came into general use shortly thereafter. This unit was employed up to 1923 when a new unit was adopted as being more suitable for modern telephone work. The new transmission unit is widely used among the foreign telephone organizations and recently it was termed the "decibel" at the suggestion of the International Advisory Committee on Long Distance Telephony.
The decibel may be defined by the statement that two amounts of power differ by 1 decibel when they are in the ratio of $10^{0.1}$ and any two amounts of power differ by N decibels when they are in the ratio of $10^{N(0.1)}$. The number of transmission units expressing the ratio of any two powers is therefore ten times the common logarithm of that ratio. This method of designating the gain or loss of power in telephone circuits permits direct addition or subtraction of the units expressing the efficiency of different parts of the circuit...

In April 2003, the International Committee for Weights and Measures (CIPM) considered a recommendation for the decibel's inclusion in the International System of Units (SI), but decided not to adopt the decibel as an SI unit. However, the decibel is recognized by other international bodies such as the International Electrotechnical Commission (IEC). The IEC permits the use of the decibel with field quantities as well as power and this recommendation is followed by many national standards bodies, such as NIST, which justifies the use of the decibel for voltage ratios.

Definition

A decibel (dB) is one tenth of a bel (B), i.e. 1B = 10dB. The bel is the logarithm of the ratio of two power quantities of 10:1, and for two field quantities in the ratio $\sqrt{10} : 1$. A *field quantity* is a quantity such as voltage, current, sound pressure, electric field strength, velocity and charge density, the square of which in linear systems is proportional to power. A *power quantity* is a power or a quantity directly proportional to power, e.g. energy density, acoustic intensity and luminous intensity.

The calculation of the ratio in decibels varies depending on whether the quantity being measured is a *power quantity* or a *field quantity*.

Power quantities

When referring to measurements of *power* or *intensity*, a ratio can be expressed in decibels by evaluating ten times the base-10 logarithm of the ratio of the measured quantity to the reference level. Thus, the ratio of a power value P_1 to another power value P_0 is represented by L_{dB}, that ratio expressed in decibels, which is calculated using the formula:

$$L_{\mathrm{dB}} = 10 \log_{10} \left(\frac{P_1}{P_0} \right)$$

P_1 and P_0 must measure the same type of quantity, and have the same units before calculating the ratio. If $P_1 = P_0$ in the above equation, then $L_{dB} = 0$. If P_1 is greater than P_0 then L_{dB} is positive; if P_1 is less than P_0 then L_{dB} is negative.

Rearranging the above equation gives the following formula for P_1 in terms of P_0 and L_{dB}:

$$P_1 = 10^{\frac{L_{\mathrm{dB}}}{10}} P_0.$$

Since a bel is equal to ten decibels, the corresponding formulae for measurement in bels (L_B) are

$$L_{\mathrm{B}} = \log_{10}\left(\frac{P_1}{P_0}\right)$$
$$P_1 = 10^{L_{\mathrm{B}}} P_0.$$

Field quantities

When referring to measurements of field *amplitude* it is usual to consider the ratio of the squares of A_1 (measured amplitude) and A_0 (reference amplitude). This is because in most applications power is proportional to the square of amplitude, and it is desirable for the two decibel formulations to give the same result in such typical cases. Thus the following definition is used:

$$L_{\mathrm{dB}} = 10\log_{10}\left(\frac{A_1^2}{A_0^2}\right) = 20\log_{10}\left(\frac{A_1}{A_0}\right).$$

This formula is sometimes called the **20 log rule,** and similarly the formula for ratios of powers is the **10 log rule,** and similarly for other factors. The equivalence of $10\log_{10}\frac{a^2}{b^2}$ and $20\log_{10}\frac{a}{b}$ is one of the standard properties of logarithms.

The formula may be rearranged to give

$$A_1 = 10^{\frac{L_{\mathrm{dB}}}{20}} A_0$$

Similarly, in electrical circuits, dissipated power is typically proportional to the square of voltage or current when the impedance is held constant. Taking voltage as an example, this leads to the equation:

$$G_{\mathrm{dB}} = 20\log_{10}\left(\frac{V_1}{V_0}\right)$$

where V_1 is the voltage being measured, V_0 is a specified reference voltage, and G_{dB} is the power gain expressed in decibels. A similar formula holds for current.

Examples

10 Log X	X
100	10000000000
90	1000000000
80	100000000
70	10000000
60	1000000
50	100000
40	10000
30	1000
20	100
10	10
0	1
-10	0.1
-20	0.01
-30	0.001
-40	0.0001
-50	0.00001
-60	0.000001
-70	0.0000001
-80	0.00000001
-90	0.000000001
-100	0.0000000001

An example scale showing x and 10 log x. It is easier to grasp and compare 2 or 3 digit numbers than to compare up to 10 digits.

Note that all of these examples yield dimensionless answers in dB because they are relative ratios expressed in decibels.

- To calculate the ratio of 1 kW (one kilowatt, or 1000 watts) to 1 W in decibels, use the formula

$$G_{\mathrm{dB}} = 10 \log_{10} \left(\frac{1000 \text{ W}}{1 \text{ W}} \right) \equiv 30 \text{ dB}$$

- To calculate the ratio of $\sqrt{1000} \text{ V} \approx 31.62 \text{ V}$ to 1 V in decibels, use the formula

$$G_{\mathrm{dB}} = 20\log_{10}\left(\frac{31.62\ \mathrm{V}}{1\ \mathrm{V}}\right) \equiv 30\ \mathrm{dB}$$

Notice that $(31.62\,\mathrm{V}/1\,\mathrm{V})^2 \approx 1\,\mathrm{kW}/1\,\mathrm{W}$, illustrating the consequence from the definitions above that G_{dB} has the same value, $30\ \mathrm{dB}$, regardless of whether it is obtained with the 10-log or 20-log rules; provided that in the specific system being considered power ratios are equal to amplitude ratios squared.

- To calculate the ratio of 1 mW (one milliwatt) to 10 W in decibels, use the formula

$$G_{\mathrm{dB}} = 10\log_{10}\left(\frac{0.001\ \mathrm{W}}{10\ \mathrm{W}}\right) \equiv -40\ \mathrm{dB}$$

- To find the power ratio corresponding to a 3 dB change in level, use the formula

$$G = 10^{\frac{3}{10}} \times 1\ = 1.99526... \approx 2$$

A change in power ratio by a factor of 10 is a 10 dB change. A change in power ratio by a factor of two is approximately a 3 dB change. More precisely, the factor is $10^{3/10}$, or 1.9953, about 0.24% different from exactly 2. Similarly, an increase of 3 dB implies an increase in voltage by a factor of approximately $\sqrt{2}$, or about 1.41, an increase of 6 dB corresponds to approximately four times the power and twice the voltage, and so on. In exact terms the power ratio is $10^{6/10}$, or about 3.9811, a relative error of about 0.5%.

Merits

The use of the decibel has a number of merits:

- The decibel's logarithmic nature means that a very large range of ratios can be represented by a convenient number, in a similar manner to scientific notation. This allows one to clearly visualize huge changes of some quantity.
- The mathematical properties of logarithms mean that the overall decibel gain of a multi-component system (such as consecutive amplifiers) can be calculated simply by summing the decibel gains of the individual components, rather than needing to multiply amplification factors. Essentially this is because log(A × B × C × ...) = log(A) + log(B) + log(C) + ...
- The human perception of the intensity of, for example, sound or light, is more nearly proportional to the logarithm of intensity than to the intensity itself, per the Weber–Fechner law, so the dB scale can be useful to describe perceptual levels or level differences.

Uses

Acoustics

The decibel is commonly used in acoustics to quantify sound levels relative to a 0 dB reference which has been defined as a sound pressure level of .0002 microbar. The reference level is set at the typical threshold of perception of an average human and there are common comparisons used to illustrate different levels of sound pressure. As with other decibel figures, normally the ratio expressed is a power ratio (rather than a pressure ratio).

The human ear has a large dynamic range in audio perception. The ratio of the sound intensity that causes permanent damage during short exposure to the quietest sound that the ear can hear is greater than or equal to 1 trillion. Such large measurement ranges are conveniently expressed in logarithmic units: the base-10 logarithm of one trillion (10^{12}) is 12, which is expressed as an audio level of 120 dB. Since the human ear is not equally sensitive to all sound frequencies, noise levels at maximum human sensitivity—somewhere between 2 and 4 kHz—are factored more heavily into some measurements using frequency weighting.

Electronics

In electronics, the decibel is often used to express power or amplitude ratios (gains), in preference to arithmetic ratios or percentages. One advantage is that the total decibel gain of a series of components (such as amplifiers and attenuators) can be calculated simply by summing the decibel gains of the individual components. Similarly, in telecommunications, decibels are used to account for the gains and losses of a signal from a transmitter to a receiver through some medium (free space, wave guides, coax, fiber optics, etc.) using a link budget.

The decibel unit can also be combined with a suffix to create an absolute unit of electric power. For example, it can be combined with "m" for "milliwatt" to produce the "dBm". Zero dBm is the power level corresponding to a power of one milliwatt, and 1 dBm is one decibel greater (about 1.259 mW).

In professional audio, a popular unit is the dBu. The "u" stands for "unloaded", and was probably chosen to be similar to lowercase "v", as dBv was the older name for the same thing. It was changed to avoid confusion with dBV. This unit (dBu) is an RMS measurement of voltage which uses as its reference 0.775 V_{RMS}. Chosen for historical reasons, it is the voltage level which delivers 1 mW of power in a 600 ohm resistor, which used to be the standard reference impedance in telephone audio circuits.

Optics

In an optical link, if a known amount of optical power, in dBm (referenced to 1 mW), is launched into a fiber, and the losses, in dB (decibels), of each electronic component (e.g., connectors, splices, and lengths of fiber) are known, the overall link loss may be quickly calculated by addition and subtraction of decibel quantities.

In spectrometry and optics, the blocking unit used to measure optical density is equivalent to −1 B.

Video and digital imaging

In connection with digital and video image sensors, decibels generally represent ratios of video voltages or digitized light levels, using 20 log of the ratio, even when the represented optical power is directly proportional to the voltage or level, not to its square, as in a CCD imager where response voltage is linear in intensity. Thus, a camera signal-to-noise ratio or dynamic range of 40 dB represents a power ratio of 100:1 between signal power and noise power, not 10,000:1. Sometimes the 20 log ratio definition is applied to electron counts or photon counts directly, which are proportional to intensity without the need consider whether the voltage response is linear.

However, as mentioned above, the 10 log intensity convention prevails more generally in physical optics, including fiber optics, so the terminology can become murky between the conventions of digital photographic technology and physics. Most commonly, quantities called "dynamic range" or "signal-to-noise" (of the camera) would be specified in 20 log dBs, but in related contexts (e.g. attenuation, gain, intensifier SNR, or rejection ratio) the term should be interpreted cautiously, as confusion of the two units can result in very large misunderstandings of the value.

Photographers also often use an alternative base-2 log unit, the f-stop, and in software contexts these image level ratios, particularly dynamic range, are often loosely referred to by the number of bits needed to represent the quantity, such that 60 dB (digital photographic) is roughly equal to 10 f-stops or 10 bits, since 10^3 is nearly equal to 2^{10}.

Common reference levels and corresponding units

Although decibel measurements are always relative to a reference level, if the numerical value of that reference is explicitly and exactly stated, then the decibel measurement is called an "absolute" measurement, in the sense that the exact value of the measured quantity can be recovered using the formula given earlier. For example, since dBm indicates power measurement relative to 1 milliwatt,

- 0 dBm means no change from 1 mW. Thus, 0 dBm is the power level corresponding to a power of *exactly* 1 mW.
- 3 dBm means 3 dB greater than 0 dBm. Thus, 3 dBm is the power level corresponding to $10^{3/10} \times 1$ mW, or approximately 2 mW.
- −6 dBm means 6 dB less than 0 dBm. Thus, −6 dBm is the power level corresponding to $10^{-6/10} \times 1$ mW, or approximately 250 μW (0.25 mW).

If the numerical value of the reference is not explicitly stated, as in the dB gain of an amplifier, then the decibel measurement is purely relative. The practice of attaching a suffix to the basic dB unit, forming compound units such as dBm, dBu, dBA, etc., is not permitted for use with the SI. However, outside of documents adhering to SI units, the practice is very common as illustrated by the following examples.

Electric power

dBm or **dBmW**

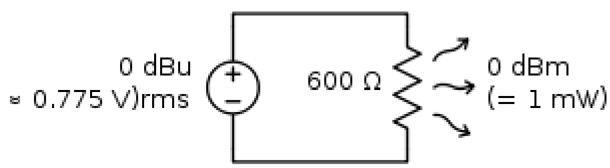
dB(1 mW) – power measurement relative to 1 milliwatt. $X_{dBm} = X_{dBW} + 30$.

dBW

dB(1 W) – similar to dBm, except the reference level is 1 watt. 0 dBW = +30 dBm; −30 dBW = 0 dBm; $X_{dBW} = X_{dBm} - 30$.

Voltage

Since the decibel is defined with respect to power, not amplitude, conversions of voltage ratios to decibels must square the amplitude, as discussed above.



A schematic showing the relationship between dBu (the voltage source) and dBm (the power dissipated as heat by the 600 Ω resistor)

dBV

dB(1 V_{RMS}) – voltage relative to 1 volt, regardless of impedance.

dBu or **dBv**

dB(0.775 V_{RMS}) – voltage relative to 0.775 volts. Originally dBv, it was changed to dBu to avoid confusion with dBV. The "v" comes from "volt", while "u" comes from "unloaded". dBu can be used regardless of impedance, but is derived from a 600 Ω load dissipating 0 dBm (1 mW). Reference voltage

$$V = \sqrt{600\,\Omega \cdot 0.001\,\mathrm{W}} \approx 0.7746\,\mathrm{V}$$

In professional audio, equipment may be calibrated to indicate a "0" on the VU meters some finite time after a signal has been applied at an amplitude of +4 dBu. Consumer equipment will more often use a much lower "nominal" signal level of -10 dBV.

Therefore, many devices offer dual voltage operation (with different gain or "trim" settings) for interoperability reasons. A switch or adjustment that covers at least the range between +4 dBu and -10 dBV is common in professional equipment.

dBmV

dB(1 mV_{RMS}) – voltage relative to 1 millivolt across 75 Ω. Widely used in cable television networks, where the nominal strength of a single TV signal at the receiver terminals is about 0 dBmV. Cable TV uses 75 Ω coaxial cable, so 0 dBmV corresponds to −78.75 dBW (−48.75 dBm) or ~13 nW.

dBμV or **dBuV**

dB(1 μV_{RMS}) – voltage relative to 1 microvolt. Widely used in television and aerial amplifier specifications. 60 dBμV = 0 dBmV.

Acoustics

Probably the most common usage of "decibels" in reference to sound loudness is dB SPL, sound pressure level referenced to the nominal threshold of human hearing:

dB(SPL)

dB (sound pressure level) – for sound in air and other gases, relative to 20 micropascals (μPa) = 2×10^{-5} Pa, the quietest sound a human can hear. This is roughly the sound of a mosquito flying 3 meters away. This is often abbreviated to just "dB", which gives some the erroneous notion that "dB" is an absolute unit by itself. For sound in water and other liquids, a reference pressure of 1 μPa is used.

One Pascal is equal to 94 dB(SPL). This level is used to specify microphone sensitivity. For example, a typical microphone may put out 20 mV at one pascal. For other sound pressure levels, the output voltage can be computed from this basis, except that noise and distortion will affect the extreme levels.

dB(PA)

dB – relative to 1 Pa, often used in telecommunications.

dB SIL

dB sound intensity level – relative to 10^{-12} W/m^2, which is roughly the threshold of human hearing in air.

dB SWL

dB sound power level – relative to 10^{-12} W.

dB(A), **dB(B)**, and **dB(C)**

These symbols are often used to denote the use of different weighting filters, used to approximate the human ear's response to sound, although the measurement is still in dB (SPL). These measurements usually refer to noise and noisome effects on humans and animals, and are in widespread use in the industry with regard to noise control issues, regulations and environmental standards. Other variations that may be seen are dB_A or dBA. According to ANSI standards, the preferred usage is to write $L_A = x$ dB. Nevertheless, the units dBA and dB(A) are still commonly used as a shorthand for A-weighted measurements. Compare dBc, used in telecommunications.

dB HL or dB hearing level is used in audiograms as a measure of hearing loss. The reference level varies with frequency according to a minimum audibility curve as defined in ANSI and other standards, such that the resulting audiogram shows deviation from what is regarded as 'normal' hearing.

dB Q is sometimes used to denote weighted noise level, commonly using the ITU-R 468 noise weighting

Audio electronics

dBFS

dB(full scale) – the amplitude of a signal compared with the maximum which a device can handle before clipping occurs. Full-scale may be defined as the power level of a full-scale sinusoid or alternatively a full-scale square wave.

dBTP

dB(true peak) - peak amplitude of a signal compared with the maximum which a device can handle before clipping occurs. In digital systems, 0 dBTP would equal the highest level (number) the processor is capable of representing. Measured values are always negative or zero, since they are less than or equal to full-scale.

Radar

dBZ

dB(Z) – energy of reflectivity (weather radar), related to the amount of transmitted power returned to the radar receiver; the reference level for Z is 1 $mm^6\ m^{-3}$. Values above 15–20 dBZ usually indicate falling precipitation.

dBsm

dBsm – decibel measure of the radar cross section (RCS) of a target relative one square meter. The power reflected by the target is proportional to its RCS. "Stealth" aircraft and insects have negative RCS measured in dBsm, large flat plates or non-stealthy aircraft have positive values.

Radio power, energy, and field strength

dBc

dBc – relative to carrier—in telecommunications, this indicates the relative levels of noise or sideband peak power, compared with the carrier power. Compare dBC, used in acoustics.

dBJ

dB(J) – energy relative to 1 joule. 1 joule = 1 watt per hertz, so power spectral density can be expressed in dBJ.

dBm

dB(mW) – power relative to 1 milliwatt. When used in audio work the milliwatt is referenced to a 600 ohm load, with the resultant voltage being 0.775 volts. When used in the 2-way radio field, the dB is referenced to a 50 ohm load, with the resultant voltage being 0.224 volts. There are times when spec sheets may show the voltage & power level e.g. −120 dBm = 0.224 microvolts.

dBμV/m or **dBuV/m**

dB(μV/m) – electric field strength relative to 1 microvolt per meter. Often used to specify the signal strength from a television broadcast at a receiving site (the signal measured *at the antenna output* will be in dBμV).

dBf

dB(fW) – power relative to 1 femtowatt.

dBW

dB(W) – power relative to 1 watt.

dBk

dB(kW) – power relative to 1 kilowatt.

Antenna measurements

dBi

dB(isotropic) – the forward gain of an antenna compared with the hypothetical isotropic antenna, which uniformly distributes energy in all directions. Linear polarization of the EM field is assumed unless noted otherwise.

dBd

dB(dipole) – the forward gain of an antenna compared with a half-wave dipole antenna. 0 dBd = 2.15 dBi

dBiC

dB(isotropic circular) – the forward gain of an antenna compared to a circularly polarized isotropic antenna. There is no fixed conversion rule between dBiC and dBi, as it depends on the receiving antenna and the field polarization.

dBq

dB(quarterwave) – the forward gain of an antenna compared to a quarter wavelength whip. Rarely used, except in some marketing material. 0 dBq = −0.85 dBi

Other measurements

dB-Hz

dB(hertz) – bandwidth relative to 1 Hz. E.g., 20 dB-Hz corresponds to a bandwidth of 100 Hz. Commonly used in link budget calculations. Also used in carrier-to-noise-density ratio (not to be confused with carrier-to-noise ratio, in dB).

dBov or **dBO**

dB(overload) – the amplitude of a signal (usually audio) compared with the maximum which a device can handle before clipping occurs. Similar to dBFS, but also applicable to analog systems.

dBr

dB(relative) – simply a relative difference from something else, which is made apparent in context. The difference of a filter's response to nominal levels, for instance.

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Chapter-4

Erlang

The **erlang** (symbol **E**) is a dimensionless unit that is used in telephony as a statistical measure of offered load or carried load on service-providing elements such as telephone circuits or telephone switching equipment. It is named after the Danish telephone engineer A. K. Erlang, the originator of traffic engineering and queueing theory.

Traffic measurements of a telephone circuit

When used to represent **carried traffic**, a value (which can be a non-integer such as 43.5) followed by "erlangs" represents the average number of concurrent calls carried by the circuits (or other service-providing elements), where that average is calculated over some reasonable period of time. The period over which the average is calculated is often one hour, but shorter periods (e.g., 15 minutes) may be used where it is known that there are short spurts of demand and a traffic measurement is desired that does not mask these spurts. One erlang of carried traffic refers to a single resource being in continuous use, or two channels being in use fifty percent of the time, and so on. For example, if an office has two telephone operators who are both busy all the time, that would represent two erlangs (2 E) of traffic; or a radio channel that is occupied for one hour continuously is said to have a load of 1 Erlang.

When used to describe **offered traffic**, a value followed by "erlangs" represents the average number of concurrent calls that would have been carried if there were an unlimited number of circuits (that is, if the call-attempts that were made when all circuits were in use had not been rejected). The relationship between offered traffic and carried traffic depends on the design of the system and user behavior. Three common models are (a) callers whose call-attempts are rejected go away and never come back, (b) callers whose call-attempts are rejected try again within a fairly short space of time, and (c) the system allows users to wait in queue until a circuit becomes available.

A third measurement of traffic is **instantaneous traffic**, expressed as a certain number of erlangs, meaning the exact number of calls taking place at a point in time. In this case the number is an integer. Traffic-level-recording devices, such as moving-pen recorders, plot instantaneous traffic.

The concepts and mathematics introduced by A. K. Erlang have broad applicability beyond telephony. They apply wherever users arrive more or less at random to receive exclusive service from any one of a group of service-providing elements without prior reservation, for example, where the service-providing elements are ticket-sales windows, toilets on an airplane, or motel rooms. (Erlang's models do not apply where the server-providing elements are shared between several concurrent users or different amounts of service are consumed by different users, for instance, on circuits carrying data traffic.)

Offered traffic (in erlangs) is related to the **call arrival rate**, λ, and the **average call-holding time**, *h*, by:

$$E = \lambda h$$

provided that *h* and λ are expressed using the same units of time (seconds and calls per second, or minutes and calls per minute).

The practical measurement of traffic is typically based on continuous observations over several days or weeks, during which the instantaneous traffic is recorded at regular, short intervals (such as every few seconds). These measurements are then used to calculate a single result, most commonly the **busy hour traffic** (in erlangs). This is the average, over several days, of the average number of concurrent calls during the same one-hour period each day, where that period is selected to give the highest result. (This result is called the time-consistent busy hour traffic). An alternative is to calculate a busy hour traffic value separately for each day (which may correspond to slightly different times each day) and take the average of these values. This generally gives a slightly higher value than the time-consistent busy hour value.

The goal of Erlang's traffic theory is to determine exactly how many service-providing elements should be provided in order to satisfy users, without wasteful over-provisioning. To do this, a target is set for the grade of service (GoS) or quality of service (QoS). For example, in a system where there is no queuing, the GoS may be that no more than 1 call in 100 is blocked (i.e., rejected) due to all circuits being in use (a GoS of 0.01), which becomes the target probability of call blocking, P_b, when using the Erlang B formula.

There are several Erlang formulae, including Erlang B, Erlang C and the related Engset formula, based on different models of user behavior and system operation. These are discussed below, and may each be derived by means of a special case of continuous-time Markov processes known as a birth-death process.

Where the existing busy-hour carried traffic, E_c, is measured on an already-overloaded system, with a significant level of blocking, it is necessary to take account of the blocked calls in estimating the busy-hour offered traffic E_o (which is the traffic value to be used in the Erlang formula). The offered traffic can be estimated by $E_o = E_c/(1 - P_b)$. For this purpose, where the system includes a means of counting blocked calls and successful calls, P_b can be estimated directly from the proportion of calls that are blocked. Failing that, P_b can be estimated by using E_c in place of E_o in the Erlang formula and the resulting estimate of P_b can then be used in $E_o = E_c/(1 - P_b)$ to estimate E_o. Another method of estimating E_o in an overloaded system is to measure the busy-hour call arrival rate, λ (counting successful calls and blocked calls), and the average call-holding time (for successful calls), h, and then estimate E_o using the formula $E = \lambda h$.

For a situation where the traffic to be handled is completely new traffic, the only choice is to try to model expected user behavior, estimating active user population, N, expected level of use, U (number of calls/transactions per user per day), busy-hour concentration factor, C (proportion of daily activity that will fall in the busy hour), and average holding time/service time, h (expressed in minutes). A projection of busy-hour offered traffic would then be $E_o = (NUC/60)h$ erlangs. (The division by 60 translates the busy-hour call/transaction arrival rate into a per-minute value, to match the units in which h is expressed.)

Erlang B formula

Erlang-B (sometimes also written without the hyphen **Erlang B**), also known as the **Erlang loss formula**, is a formula for the **blocking probability** derived from the Erlang distribution to describe the probability of call loss on a group of circuits (in a circuit switched network, or equivalent). It is, for example, used in planning telephone networks. The formula was derived by Agner Krarup Erlang and is not limited to telephone networks, since it describes a probability in a queuing system (albeit a special case with a number of servers but no buffer spaces for incoming calls to wait for a free server). Hence, the formula is also used in certain inventory systems with lost sales.

The formula applies under the condition that an unsuccessful call, because the line is busy, is not queued or retried, but instead really lost forever. It is assumed that call attempts arrive following a Poisson process, so call arrivals are independent. Further it is assumed that message length (holding times) are exponentially distributed (Markovian system) although the formula turns out to apply under general holding time distributions.

Erlangs are a dimensionless quantity calculated as the average arrival rate, λ, multiplied by the average call length, h. The Erlang B formula assumes an infinite population of sources (such as telephone subscribers), which jointly offer traffic to N servers (such as links in a trunk group). The rate of arrival of new calls (birth rate) is equal to λ and is constant, *not* depending on the number of active sources, because the total number of sources is assumed to be infinite. The rate of call departure (death rate) is equal to the number of calls in progress divided by h, the mean call holding time. The formula calculates blocking probability in a loss system, where if a request is not served immediately when it tries to use a resource, it is aborted. Requests are therefore not queued. Blocking occurs when there is a new request from a source, but all the servers are already busy. The formula assumes that blocked traffic is immediately cleared.

The formula provides the GoS (grade of service) which is the probability P_b that a new call arriving at the circuit group is rejected because all servers (circuits) are busy: $B(E, m)$ when E Erlang of traffic are offered to m trunks (communication channels).

$$P_b = B(E,m) = \frac{\frac{E^m}{m!}}{\sum_{i=0}^{m} \frac{E^i}{i!}}$$

where:

- P_b is the probability of blocking
- m is the number of resources such as servers or circuits in a group
- $E = \lambda h$ is the total amount of traffic offered in erlangs

This may be expressed recursively as follows, in a form that is used to simplify the calculation of tables of the Erlang B formula:

$$B(E,0) = 1.$$
$$B(E,j) = \frac{EB(E,j-1)}{EB(E,j-1)+j} \; \forall j = 1,2,...,m$$

Typically, instead of $B(E, m)$ the inverse $1/B(E, m)$ is calculated in numerical computation in order to ensure numerical stability:

$$\frac{1}{B(E,0)} = 1$$
$$\frac{1}{B(E,j)} = 1 + \frac{j}{E}\frac{1}{B(E,j-1)} \; \forall j = 1,2,...,m$$

```
Function ErlangB (E as Double, m As Integer) As Double
Dim InvB As Double
Dim j As Integer

  InvB = 1.0
  For j = 1 To m
    InvB = 1.0 + j / E * InvB
  Next j
  ErlangB = 1.0 / InvB
End Function
```

The Erlang B formula applies to loss systems, such as telephone systems on both fixed and mobile networks, which do not provide traffic buffering, and are not intended to do so. It assumes that the call arrivals may be modeled by a Poisson process, but is valid for any statistical distribution of call holding times with finite mean. Erlang B is a trunk sizing tool for voice switch to voice switch traffic. The Erlang B formula is decreasing and convex in m.

Extended Erlang B

Extended Erlang B is an iterative calculation, rather than a formula, that adds an extra parameter, the Recall Factor, which defines the recall attempts.

The steps in the process are as follows:

1. Calculate

$$P_b = B(E, m)$$

as above for Erlang B.

2. Calculate the probable number of blocked calls

$$B_e = EP_b$$

3. Calculate the number of recalls, R assuming a Recall Factor, R_f:

$$R = B_e R_f$$

4. Calculate the new offered traffic

$$E_{i+1} = E_0 + R$$

where E_0 is the initial (baseline) level of traffic.

5. Return to step 1 and iterate until a stable value of E is obtained.

Erlang C formula

The **Erlang C formula** expresses the waiting probability in a queuing system. Just as the Erlang B formula, Erlang C assumes an infinite population of sources, which jointly offer traffic of A erlangs to N servers. However, if all the servers are busy when a request arrives from a source, the request is queued. An unlimited number of requests may be held in the queue in this way simultaneously. This formula calculates the probability of queuing offered traffic, assuming that blocked calls stay in the system until they can be handled. This formula is used to determine the number of agents or customer service representatives needed to staff a call centre, for a specified desired probability of queuing.

$$P_W = \frac{\frac{A^N}{N!}\frac{N}{N-A}}{\sum_{i=0}^{N-1}\frac{A^i}{i!} + \frac{A^N}{N!}\frac{N}{N-A}}$$

where:

- A is the total traffic offered in units of erlangs
- N is the number of servers
- P_W is the probability that a customer has to wait for service

It is assumed that the call arrivals can be modeled by a Poisson process and that call holding times are described by a negative exponential distribution. A common use for Erlang C is modeling and dimensioning call center agents in a call center environment.

Engset formula

The **Engset calculation** is a related formula, named after its developer, T. O. Engset, used to determine the probability of congestion occurring within a telephony circuit group. It deals with a finite population of S sources rather than the infinite population of sources that Erlang assumes. The formula requires that the user knows the expected peak traffic, the number of sources (callers) and the number of circuits in the network.

Example application

A business installing a PABX needs to know the minimum number of voice circuits it needs to have to and from the telephone network. An approximate approach is to use the Erlang-B formula. However, if the business has a small number of extensions, then it should instead use the more exact Engset calculation, which reflects the fact that extensions already in use will not make additional simultaneous calls. (For a large user population, the Engset and the Erlang-B calculations give the same result.)

Technical details

Engset's equation is similar to the Erlang-B formula; however it contains one major difference: Erlang's equation assumes an infinite source of calls, yielding a Poisson arrival process, while Engset specifies a finite number of callers . Thus Engset's equation should be used when the source population is small (say less than 200 users, extensions or customers).

$$P_b(N,A,S) = \frac{A^N \binom{S}{N}}{\sum_{i=0}^{N} A^i \binom{S}{i}}$$

where

A = offered traffic intensity in erlangs, from all sources
S = number of sources of traffic
N = number of circuits in group
P(*b*) = probability of blocking or congestion

In practice, like Erlang's equations, Engset's formula requires recursion to solve for the blocking or congestion probability. There are several recursions that could be used. One way to determine this probability, one first determines an initial estimate. This initial estimate is substituted into the equation and the equation then is solved. The answer to this initial calculation is then substituted back into the equation, resulting in a new answer which is again substituted. This iterative process continues until the equation converges to a stable result..

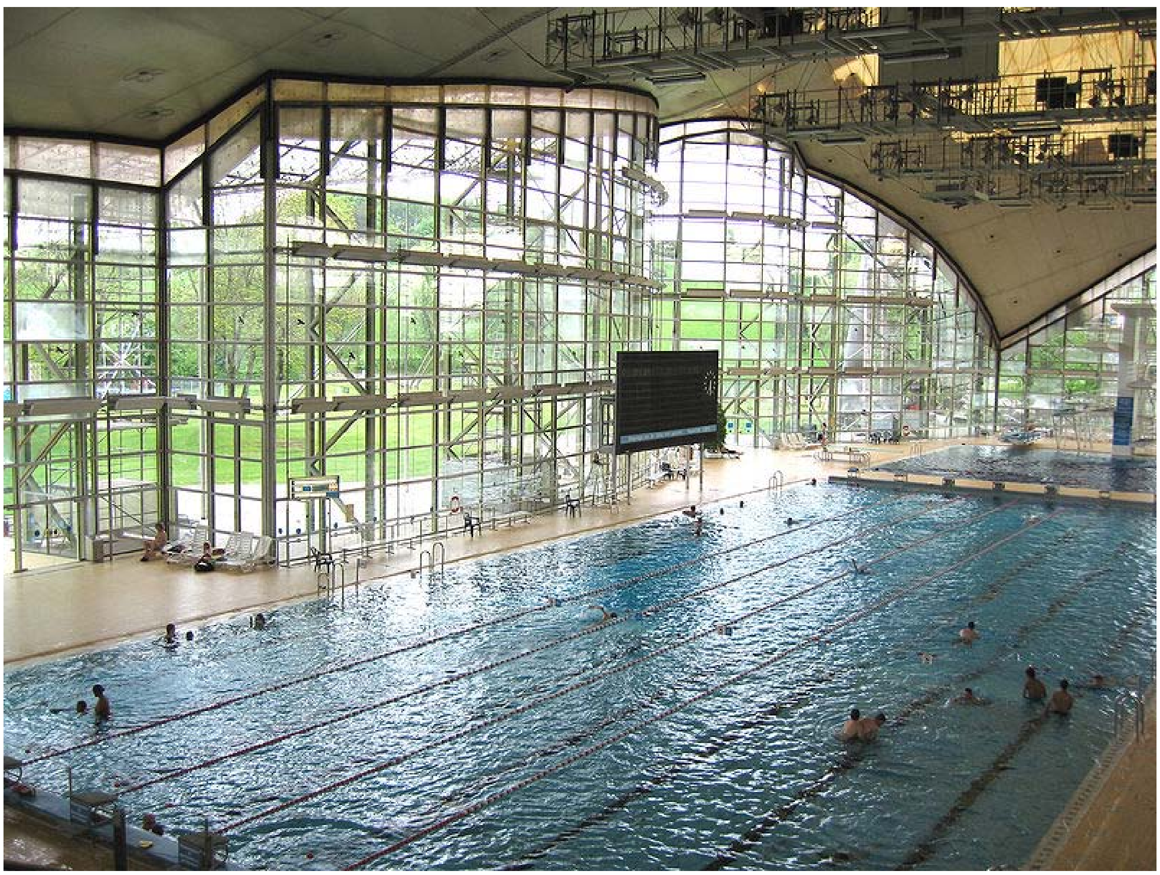
Engset's equation follows:

$$P(b) = \frac{\left[\frac{(S-1)!}{N!\cdot(S-1-N)!}\right]\cdot M^N}{\sum_{X=1}^{N}\left[\frac{(S-1)!}{X!\cdot(S-1-X)!}\right]\cdot M^X}$$

$$M = \frac{A}{S - A\cdot(1-P(b))}$$

Chapter-5

Parts-per Notation



One part per trillion (1 ppt) is a proportion equivalent to one-twentieth of a drop of water diluted into an Olympic-size swimming pool.

In science and engineering, the **parts-per notation** is a set of pseudo units to describe small values of miscellaneous dimensionless quantities, e.g. mole fraction or mass fraction. Since these fractions are quantity-per-quantity measures, they are pure numbers with no associated units of measurement. Commonly used are **ppm** (parts-per-million, 10^{-6}), **ppb** (parts-per-billion, 10^{-9}), **ppt** (parts-per-trillion, 10^{-12}) and **ppq** (parts-per-quadrillion, 10^{-15}).

Overview

Parts-per notation is often used describing dilute solutions in chemistry, for instance, the relative abundance of dissolved minerals or pollutants in water. The unit "1 ppm" can be used for a mass fraction if a water-borne pollutant is present at one-millionth of a gram per gram of sample solution.

Similarly, parts-per notation is used also in physics and engineering to express the value of various proportional phenomena. For instance, a special metal alloy might expand 1.2 micrometers per meter of length for every degree Celsius and this would be expressed as "α = 1.2 ppm/°C." Parts-per notation is also employed to denote the change, stability, or uncertainty in measurements. For instance, the accuracy of land-survey distance measurements when using a laser rangefinder might be 1 millimeter per kilometer of distance; this could be expressed as "Accuracy = 1 ppm."

Parts-per notations are all dimensionless quantities: in mathematical expressions, the units of measurement always cancel. In fractions like "2 nanometers per meter" ($2\ \text{n}\cancel{\text{m}}/\cancel{\text{m}} = 2\ \text{nano} = 2 \times 10^{-9} = 2\ \text{ppb} = 2 \times 0.000000001$) so the quotients are pure-number coefficients with positive values less than 1. When parts-per notations, including the percent symbol (%), are used in regular prose (as opposed to mathematical expressions), they are still pure-number dimensionless quantities. However, they generally take the literal "parts per" meaning of a comparative ratio (e.g., "2 ppb" would generally be interpreted as "two parts in a billion parts").

Parts-per notations may be expressed in terms of any unit of the same measure. For instance, the coefficient of thermal expansion of a certain brass alloy, α = 18.7 ppm/°C, may be expressed as 18.7 (µm/m)/°C, or as 18.7 (µin/in)/°C; the numeric value representing a relative proportion does not change with the adoption of a different unit of measure. Similarly, a metering pump that injects a trace chemical into the main process line at the proportional flow rate Q_p = 125 ppm, is doing so at a rate that may be expressed in a variety of volumetric units, including 125 µL/L, 125 µgal/gal, 125 µ(m^3)/m^3, etc.

Parts-per expressions

- *One part per hundred* is generally represented by the percent (%) symbol and denotes one part per 100 parts, one part in 10^2, and a value of 1×10^{-2}. This is equivalent to one drop of water diluted into 5 milliliters (one spoon-full), or about fifteen minutes out of one day.

- *One part per thousand* should generally spelled out in full and **not** as "ppt" (which is usually understood to represent "parts per trillion"). It may also be denoted by the permille (‰) symbol. Note however, that specific disciplines such as the analysis of ocean water salt concentration and educational exercises occasionally use the "ppt" abbreviation. "One part per thousand" denotes one part per 1000 parts, one part in 10^3, and a value of 1×10^{-3}. This is equivalent to one drop of water diluted into 50 milliliters (ten spoon-fulls), or about one and a half minutes out of one day.

- *One part per ten thousand* is denoted by the permyriad (‱) symbol. It is used almost exclusively in finance, where it is known as the basis point and is typically used to denote fractional changes in percentages. For instance, a change in an interest rate from 5.15% to 5.35% would be denoted as a change of 20 basis points or 20 ‱. Although rarely used in science (ppm is typically used instead), one permyriad has an unambiguous value of one part per 10,000 parts, one part in 10^4, and a value of 1×10^{-4}. This is equivalent to one drop of water diluted into half a liter, or about nine seconds out of one day.

- *One part per million* (**ppm**) denotes one part per 1,000,000 parts, one part in 10^6, and a value of 1×10^{-6}. This is equivalent to one drop of water diluted into 50 liters (roughly the fuel tank capacity of a compact car), or about thirty seconds out of a year.

- *One part per billion* (**ppb**) denotes one part per 1,000,000,000 parts, one part in 10^9, and a value of 1×10^{-9}. This is equivalent to one drop of water diluted into 250 chemical drums (50 m^3), or about three seconds out of a century.

- *One part per trillion* (**ppt**) denotes one part per 1,000,000,000,000 parts, one part in 10^{12}, and a value of 1×10^{-12}. This is equivalent to one drop of water diluted into 20 Olympic-size swimming pools (50,000 m^3), or about three seconds out of every hundred thousand years.

- *One part per quadrillion* (**ppq**) denotes one part per 1,000,000,000,000,000 parts, one part in 10^{15}, and a value of 1×10^{-15}. This is equivalent to 1 drop of water diluted into a cube of water measuring approximately 368 meters on a side (fifty million cubic meters, which is a cube about as tall as the roof of the Empire State Building), or two and a half minutes out of the age of the Earth (4.5 billion years). Although relatively uncommon in analytic chemistry, measurements at the ppq level *are* performed.

Criticism

Although the International Bureau of Weights and Measures (an international standards organization known also by its French-language initials BIPM) recognizes the use of parts-per notation, it is not formally part of the International System of Units (SI). Note, that although "percent" (%) is not formally part of the SI, both the BIPM and the ISO, take the position that *"in mathematical expressions, the internationally recognized symbol % (percent) may be used with the SI to represent the number 0.01"* for dimensionless quantities. According to IUPAP, *"a continued source of annoyance to unit purists has been the continued use of percent, ppm, ppb, and ppt."*. Clearly, this admonition would also apply to "parts per quadrillion" (ppq). Although SI-compliant expressions should be used as an alternative, the parts-per notation remains nevertheless widely used in technical disciplines. The main problems with the parts-per notation are:

Long and short scales

Because the named numbers starting with a "billion" have different values in different countries, the BIPM suggests avoiding the use of "ppb" and "ppt" to prevent misunderstanding. In the English language, named numbers have a consistent meaning only up to "million". Starting with "billion", there are *two* numbering conventions: the "long" and "short" scales, and "billion" can mean either 10^9 or 10^{12}. The U.S. National Institute of Standards and Technology (NIST) takes the stringent position, stating that *"the language-dependent terms 'part per million,' 'part per billion,' and 'part per trillion'…are not acceptable for use with the SI to express the values of quantities."*

Thousand vs trillion

Although "ppt" usually means "parts per trillion", it occasionally means "parts per thousand". Unless the meaning of "ppt" is defined explicitly, it has to be guessed from the context.

Mass fraction vs mole fraction

Another problem of the parts-per notation is that it may refer to either a mass fraction or a mole fraction. Since it is usually not stated which quantity is used, it is better to write the unit as kg/kg, or mol/mol (even though they are all dimensionless). For example, the conversion factor between a mass fraction of 1 ppb and a mole fraction of 1 ppb is about 4.7 for the greenhouse gas CFC-11 in air. The usage is generally quite fixed inside most specific branches of science, leading some researchers to draw the conclusion that their own usage (mass/mass, mol/mol or others) is the only correct one. This, in turn, leads them to not specify their usage in their publications, and others may therefore misinterpret their results. For example, electrochemists often use volume/volume, while chemical engineers may use mass/mass as well as volume/volume. Many academic papers of otherwise excellent level fail to specify their usage of the part-per notation. The difference between expressing concentrations as mass/mass or volume/volume is quite significant when dealing with gases and it is very important to specify which is being used.

SI-compliant expressions

SI-compliant units that can be used as alternatives are shown in the chart below. Expressions that the BIPM does not explicitly recognize as being suitable for denoting dimensionless quantities with the SI are shown in underlined green text.

NOTATIONS FOR DIMENSIONLESS QUANTITIES				
Measure	**SI units**	**Named parts-per ratio**	**Parts-per abbreviation or symbol**	**Value in scientific notation**
A strain of…	2 cm/m	2 parts per hundred	2%	2×10^{-2}
A sensitivity of…	2 mV/V	2 parts per thousand	2 ‰	2×10^{-3}
A sensitivity of…	0.2 mV/V	2 parts per ten thousand	2 ‱	2×10^{-4}
A sensitivity of…	2 µV/V	2 parts per million	2 ppm	2×10^{-6}
A sensitivity of…	2 nV/V	2 parts per billion	2 ppb	2×10^{-9}
A sensitivity of…	2 pV/V	2 parts per trillion	2 ppt	2×10^{-12}
A mass fraction of…	2 mg/kg	2 parts per million	2 ppm	2×10^{-6}
A mass fraction of…	2 µg/kg	2 parts per billion	2 ppb	2×10^{-9}
A mass fraction of…	2 ng/kg	2 parts per trillion	2 ppt	2×10^{-12}

A mass fraction of…	2 pg/kg	2 parts per quadrillion	2 ppq	2×10^{-15}
A volume fraction of…	5.2 µL/L	5.2 parts per million	5.2 ppm	5.2×10^{-6}
A mole fraction of…	5.24 µmol/mol	5.24 parts per million	5.24 ppm	5.24×10^{-6}
A mole fraction of…	5.24 nmol/mol	5.24 parts per billion	5.24 ppb	5.24×10^{-9}
A mole fraction of…	5.24 pmol/mol	5.24 parts per trillion	5.24 ppt	5.24×10^{-12}
A stability of…	1 (µA/A)/min.	1 part per million per min.	1 ppm/min.	1×10^{-6}/min.
A change of…	5 nΩ/Ω	5 parts per billion	5 ppb	5×10^{-9}
An uncertainty of…	9 µg/kg	9 parts per billion	9 ppb	9×10^{-9}
A shift of…	1 nm/m	1 part per billion	1 ppb	1×10^{-9}
A strain of…	1 µm/m	1 part per million	1 ppm	1×10^{-6}
A temperature coefficient of…	0.3 (µHz/Hz)/°C	0.3 part per million per °C	0.3 ppm/°C	0.3×10^{-6}/°C

A frequency change of…	$0.35 \times 10^{-9} f$	0.35 part per billion	0.35 ppb	0.35×10^{-9}

Note that the notations in the “SI units” column above are all dimensionless quantities; that is, the units of measurement cancel in expressions like “1 nm/m” (1 n~~m~~/~~m~~ = 1 nano = 1×10^{-9}) so the quotients are pure-number coefficients with values less than 1.

Uno

Because of the cumbersome nature of expressing certain dimensionless quantities per SI guidelines, the International Union of Pure and Applied Physics (IUPAP) in 1999 proposed the adoption of the special name “uno” (symbol: U) to represent the number 1 in dimensionless quantities. This symbol is not to be confused with the always-italicized symbol for the variable ‘uncertainty’ (symbol: *U).* This unit name uno and its symbol could be used in combination with the SI prefixes to express the values of dimensionless quantities which are much less—or even *greater*—than one.

Common parts-per notations in terms of the uno are given in the table below.

IUPAP’s “uno” proposal

Coefficient	**Parts-per example**	**Uno equiv.**	**Symbol form**	**Value of quantity**
10^{-2}	2%	2 centiuno	2 cU	2×10^{-2}
10^{-3}	2 ‰	2 milliuno	2 mU	2×10^{-3}
10^{-6}	2 ppm	2 microuno	2 µU	2×10^{-6}
10^{-9}	2 ppb	2 nanouno	2 nU	2×10^{-9}
10^{-12}	2 ppt	2 picouno	2 pU	2×10^{-12}

In 2004, a report to the International Committee for Weights and Measures (known also by its French-language initials CIPM) stated that response to the proposal of the uno *“had been almost entirely negative”* and the principal proponent *“recommended dropping the idea.”* To date, the uno has not been adopted by any standards organization and it appears unlikely it will ever become an officially sanctioned way to express low-value (high-ratio) dimensionless quantities. The proposal was instructive, however, as to the perceived shortcomings of the current options for denoting dimensionless quantities.

Improper applications of parts-per notation

Parts-per notation may properly be used only to express true dimensionless quantities; that is, the units of measurement *must* cancel in expressions like “1 mg/kg” so that the quotients are pure numbers with values less than 1. Mixed-unit quantities such as “a radon concentration of 15 pCi/L” are not dimensionless quantities and may not be expressed using any form of parts-per notation, such as “15 ppt”. Other examples of measures that are not dimensionless quantities are as follows:

- Particulate matter in the air: 50 $\mu g/m^3$ ***but not***: 50 ppb.
- A stepper motor/gear system that produces a motion of 1 µm/pulse ***but not***: 1 ppm
- Mercury vapor concentration in air: 0.6 ng/L ***but not***: 0.6 ppt

Note however, that it is not uncommon to express aqueous concentrations—particularly in drinking-water reports intended for the general public—using parts-per notation (2.1 ppm, 0.8 ppb, etc.) and further, for those reports to state that the notations denote milligrams per liter or micrograms per liter. Whereas “2.1 mg/L” is technically not a dimensionless quantity on the face of it, it is well understood in scientific circles that one liter of water has a mass of one kilogram and that “2.1 mg/kg” (2.1 ppm) is the true measure. The goal in all technical writing (including drinking-water reports for the general public) is to clearly communicate to the intended audience with minimal confusion. Drinking water is intuitively a volumetric quantity in the public’s mind so measures of contamination expressed on a per-liter basis are considered to be easier to grasp. Still, it is technically possible, for example, to "dissolve" more than one liter of a very hydrophilic chemical in 1 liter of water; parts-per notation would be confusing when describing its solubility in water (greater than a million parts per million), so one would simply state the volume (or mass) that will dissolve into a liter, instead.

When reporting air-borne rather than water-borne densities, a slightly different convention is used since air is approximately 1000 times less dense than water. In water, 1 $\mu g/m^3$ is roughly equivalent to parts-per-trillion whereas in air, it is roughly equivalent to parts-per-billion. Note also, that in the case of air, this convention is much less accurate. Whereas one liter of water is almost exactly 1 kg, one cubic meter of air is often taken as 1.143 kg—much less accurate, but still close enough for many practical uses.

Chapter-6

pH

In chemistry, **pH** is a measure of the acidity or basicity of an aqueous solution. Pure water is said to be neutral, with a pH close to 7.0 at 25 °C (77 °F). Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline. pH measurements are important in medicine, biology, chemistry, food science, environmental science, oceanography, civil engineering and many other applications.

In a solution pH approximates but is not equal to p[H], the negative logarithm (base 10) of the molar concentration of dissolved hydronium ions (H_3O^+); a low pH indicates a high concentration of hydronium ions, while a high pH indicates a low concentration. This negative of the logarithm matches the number of places behind the decimal point, so, for example, 0.1 molar hydrochloric acid should be near pH 1 and 0.0001 molar HCl should be near pH 4 (the base 10 logarithms of 0.1 and 0.0001 being −1, and −4, respectively). Pure (de-ionized) water is neutral, and can be considered either a very weak acid or a very weak base (center of the 0 to 14 pH scale), giving it a pH of 7 (at 25 °C (77 °F)), or 0.0000001 M H^+. For an aqueous solution to have a higher pH, a base must be dissolved in it, which binds away many of these rare hydrogen ions. Hydrogen ions in water can be written simply as H^+ or as hydronium (H_3O^+) or higher species (e.g., $H_9O_4^+$) to account for solvation, but all describe the same entity. Most of the Earth's freshwater surface bodies are slightly acidic due to the abundance and absorption of carbon dioxide; in fact, for millennia in the past, most fresh water bodies have long existed at a slightly acidic pH level.

However, pH is not precisely p[H], but takes into account an activity factor. This represents the tendency of hydrogen ions to interact with other components of the solution, which affects among other things the electrical potential read using a pH meter. As a result, pH can be affected by the ionic strength of a solution – for example, the pH of a 0.05 M potassium hydrogen phthalate solution can vary by as much as 0.5 pH units as a function of added potassium chloride, even though the added salt is neither acidic nor basic.

Hydrogen ion activity coefficients cannot be measured directly by any thermodynamically sound method, so they are based on theoretical calculations. Therefore, the pH scale is defined in practice as traceable to a set of standard solutions whose pH is established by international agreement. Primary pH standard values are determined by the Harned cell, a hydrogen gas electrode, using the Bates–Guggenheim Convention.

History

The concept of p[H] was first introduced by Danish chemist Søren Peder Lauritz Sørensen at the Carlsberg Laboratory in 1909 and revised to the modern pH in 1924 after it became apparent that electromotive force in cells depends on activity rather than concentration of hydrogen ions. In the first papers, the notation had the H as a subscript to the lowercase p, like so: p_H.

It is unknown what the exact definition of 'p' in pH is. A common definition often used in schools is "percentage". However some references suggest the p stands for “Power”, others refer to the German word “Potenz” (meaning power in German), still others refer to “potential”. Jens Norby published a paper in 2000 arguing that p is a constant and stands for “negative logarithm”; H then stands for Hydrogen. According to the Carlsberg Foundation pH stands for "power of hydrogen". Other suggestions that have surfaced over the years are that the p stands for *puissance* (also meaning *power*, but, then, the Carlsberg Laboratory was French-speaking) or that pH stands for the Latin terms *pondus Hydrogenii* or *potentia hydrogenii*. It is also suggested that Sørensen used the letters p and q (commonly paired letters in mathematics) simply to label the test solution (p) and the reference solution (q).

Definitions

Mathematical definition

pH is defined as a negative decimal logarithm of the hydrogen ion activity in a solution.

$$\mathrm{pH} = -\log_{10}(a_{\mathrm{H}^+}) = \log_{10}\left(\frac{1}{a_{\mathrm{H}^+}}\right)$$

where a_H is the activity of hydrogen ions in units of Mol/L (molar concentration). Activity has a sense of concentration, however activity is always less than the concentration and is defined as a concentration (Mol/L) of an ion multiplied by activity coefficient. The activity coefficient for diluted solutions is a real number between 0 and 1 (for concentrated solutions may be greater than 1) and it depends on many parameters of a solution, such as nature of ion, ion force, temperature, etc. For a strong electrolyte, activity of an ion approaches its concentration in diluted solutions. Activity can be measured experimentally by means of an ion-selective electrode that responds, according to the Nernst equation, to hydrogen ion activity. pH is commonly measured by means of a glass electrode connected to a milli-voltmeter with very high input impedance, which measures the potential difference, or electromotive force, E, between an electrode sensitive to the hydrogen ion activity and a reference electrode, such as a calomel electrode or a silver chloride electrode. Quite often, glass electrode is combined with the reference electrode and a temperature sensor in one body. The glass electrode can be described (to 95–99.9% accuracy) by the Nernst equation:

$$E = E^0 + \frac{RT}{nF}\ln(a_{\mathrm{H}^+}); \qquad \mathrm{pH} = \frac{E^0 - E}{2.303RT/F}$$

where E is a measured potential , E^0 is the standard electrode potential, that is, the electrode potential for the standard state in which the activity is one. R is the gas constant, T is the temperature in kelvins, F is the Faraday constant, and n is the number of electrons transferred (ion charge), one in this instance. The electrode potential, E, is proportional to the logarithm of the hydrogen ion activity.

This definition, by itself, is wholly impractical, because the hydrogen ion activity is the product of the concentration and an activity coefficient. To get proper results, the electrode must be calibrated using standard solutions of known activity.

The operational definition of pH is officially defined by International Standard ISO 31-8 as follows: For a solution X, first measure the electromotive force E_X of the galvanic cell

reference electrode|concentrated solution of KCl || solution X|H_2|Pt

and then also measure the electromotive force E_S of a galvanic cell that differs from the above one only by the replacement of the solution X of unknown pH, pH(X), by a solution S of a known standard pH, pH(S). The pH of X is then

$$\mathrm{pH(X)} - \mathrm{pH(S)} = \frac{E_\mathrm{S} - E_\mathrm{X}}{2.303RT/F}$$

The difference between the pH of solution X and the pH of the standard solution depends only on the difference between two measured potentials. Thus, pH is obtained from a potential measured with an electrode calibrated against one or more pH standards; a pH meter setting is adjusted such that the meter reading for a solution of a standard is equal to the value pH(S). Values pH(S) for a range of standard solutions S, along with further details, are given in the IUPAC recommendations. The standard solutions are often described as standard buffer solution. In practice, it is better to use two or more standard buffers to allow for small deviations from Nernst-law ideality in real electrodes. Note that, because the temperature occurs in the defining equations, the pH of a solution is temperature-dependent.

Measurement of extremely low pH values, such as some very acidic mine waters, requires special procedures. Calibration of the electrode in such cases can be done with standard solutions of concentrated sulfuric acid, whose pH values can be calculated with using Pitzer parameters to calculate activity coefficients.

pH is an example of an acidity function. Hydrogen ion concentrations can be measured in non-aqueous solvents, but this leads, in effect, to a different acidity function, because the standard state for a non-aqueous solvent is different from the standard state for water. Superacids are a class of non-aqueous acids for which the Hammett acidity function, H_0, has been developed.

p[H]

This was the original definition of Sørensen, which was superseded in favour of pH in 1924. However, it is possible to measure the concentration of hydrogen ions directly, if the electrode is calibrated in terms of hydrogen ion concentrations. One way to do this, which has been used extensively, is to titrate a solution of known concentration of a strong acid with a solution of known concentration of strong alkali in the presence of a relatively high concentration of background electrolyte. Since the concentrations of acid and alkali are known, it is easy to calculate the concentration of hydrogen ions so that the measured potential can be correlated with concentrations. The calibration is usually carried out using a Gran plot. The calibration yieds a value for the standard electrode potential, E^0, and a slope factor, f, so that the Nernst equation in the form

$$E = E^0 + f\frac{RT}{nF}\log_e[\mathrm{H}^+]$$

can be used to derive hydrogen ion concentrations from experimental measurements of E. The slope factor is usually slightly less than one. A slope factor of less than 0.95 indicates that the electrode is not functioning correctly. The presence of background electrolyte ensures that the hydrogen ion activity coefficient is effectively constant during the titration. As it is constant, its value can be set to one by defining the standard state as being the solution containing the background electrolyte. Thus, the effect of using this procedure is to make activity equal to the numerical value of concentration.

The difference between p[H] and pH is quite small. It has been stated that pH = p[H] + 0.04. It is common practice to use the term "pH" for both types of measurement.

pOH

pOH is sometimes used as a measure of the concentration of hydroxide ions, OH^-, or alkalinity. pOH is not measured independently, but is derived from pH. The concentration of hydroxide ions in water is related to the concentration of hydrogen ions by

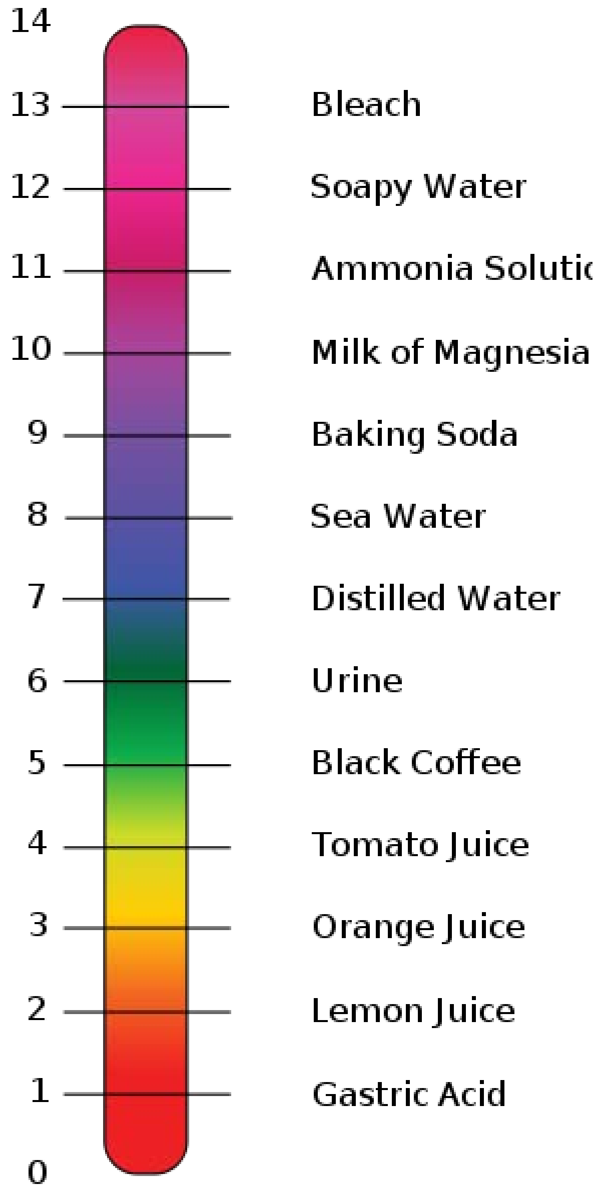
$$[\mathrm{OH}^-] = K_\mathrm{W} / [\mathrm{H}^+]$$

where K_W is the self-ionisation constant of water. Taking cologarithms

$$\mathrm{pOH} = \mathrm{p}K_\mathrm{W} - \mathrm{pH}.$$

So, at room temperature pOH ≈ 14 − pH. However this relationship is not strictly valid in other circumstances, such as in measurements of soil alkalinity.

Applications



Some typical pH values

Pure (neutral) water has a pH around 7 at 25 °C (77 °F); this value varies with temperature. When an acid is dissolved in water, the pH will be less than 7 (if at 25 °C (77 °F)). When a base, or alkali, is dissolved in water, the pH will be greater than 7 (if at 25 °C (77 °F)). A solution of a strong acid, such as hydrochloric acid, at concentration 1 mol dm^{-3} has a pH of 0. A solution of a strong alkali, such as sodium hydroxide, at concentration 1 mol dm^{-3}, has a pH of 14. Thus, measured pH values will lie mostly in the range 0 to 14. Since pH is a logarithmic scale, a difference of one pH unit is equivalent to a tenfold difference in hydrogen ion concentration.

Because the glass electrode (and other ion selective electrodes) responds to activity, the electrode should be calibrated in a medium similar to the one being investigated. For instance, if one wishes to measure the pH of a seawater sample, the electrode should be calibrated in a solution resembling seawater in its chemical composition, as detailed below.

An approximate measure of pH may be obtained by using a pH indicator. A pH indicator is a substance that changes color around a particular pH value. It is a weak acid or weak base and the color change occurs around 1 pH unit either side of its acid dissociation constant, or pK_a, value. For example, the naturally occurring indicator litmus is red in acidic solutions (pH<7 at 25 °C (77 °F)) and blue in alkaline (pH>7 at 25 °C (77 °F)) solutions. Universal indicator consists of a mixture of indicators such that there is a continuous color change from about pH 2 to pH 10. Universal indicator paper is simple paper that has been impregnated with universal indicator.

Universal indicator components

Indicator	Low pH color	Transition pH range	High pH color
Thymol blue (first transition)	Red	1.2 – 2.8	Yellow
Methyl red	Red	4.4 – 6.2	Yellow
Bromothymol blue	Yellow	6.0 – 7.6	Blue
Thymol blue (second transition)	Yellow	8.0 – 9.6	Blue
Phenolphthalein	Colorless	8.3 – 10.0	Fuchsia

A solution whose pH is 7 (at 25 °C (77 °F)) is said to be neutral, that is, it is neither acidic nor basic. Water is subject to a self-ionization process.

$$H_2O \rightleftharpoons H^+ + OH^-$$

The dissociation constant, K_W, has a value of about 10^{-14}, so, in neutral solution of a salt, both the hydrogen ion concentration and hydroxide ion concentration are about 10^{-7} mol dm^{-3}. The pH of pure water decreases with increasing temperatures. For example, the pH of pure water at 50 °C is 6.55. Note, however, that water that has been exposed to air is mildly acidic. This is because water absorbs carbon dioxide from the air, which is then slowly converted into carbonic acid, which dissociates to liberate hydrogen ions:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Examples

Substance	pH
Lead-battery acid	< 1
Vinegar	2.4–3.4

Baking soda 8.0

Calculations of pH

Strong acids and bases

Strong acids and bases are those that, for practical purposes, completely dissociated (ionize) in water. Hydrochloric acid (HCl) is a good example of a strong acid.

A commonly encountered problem is to calculate the pH of a solution of a given concentration of a strong acid. Normally, the concentration of the acid will be very high compared to the baseline concentration of H^+ ions in pure water, which is 10^{-7} molar. Under these conditions, the H^+ ion concentration is very nearly that of the acid concentration, and the pH is calculated simply by taking the negative logarithm of that value

For example, for a 0.01M solution of HCl, the H^+ concentration can be taken as 0.01M, and the pH is −log(0.01). That is, pH = 2.

For very weak concentrations, i.e. concentrations around 10^{-6}M or less, the baseline concentration of H^+ ions in pure water becomes significant, and must be taken into account. A method of solution is as follows. At equilibrium, any aqueous solution must satisfy the dissociation equilibrium equation for water,

$$[H^+][OH^-] = K_w = 10^{-14}$$

Another constraint is that the *nominal concentration* of the acid must be preserved. The nominal concentration is designated C_a, and is equivalent to the amount of acid that is initially added to the reaction. This is known as the mass balance equation, and can be written,

$$C_a = [HA] + [A^-]$$

Where "HA" refers to the protonated form of the acid, and "A^-" to the conjugate base anion.

Note that for a given reaction, C_a is constant. This equation is merely saying that the molecules of acid can either be protonated or ionized, but that the total number will stay the same.

For a strong acid which is completely dissociated, $[A^-] >> [HA]$, and the [HA] term can be dropped:

$$C_a = [A^-]$$

Another relationship that must be satisfied is known as the *electroneutrality principle*, or the *charge balance equation*, and is the statement that the total charge of the solution must be zero. So the sum of all the negative ion charges must equal the sum of the positive ion charges. This can be written,

$$[H^+] = [A^-] + [OH^-]$$

For a strong acid, one can use C_a in place of $[A^-]$, and eliminate $[OH^-]$ from this equation by substituting the value derived from the equilibrium equation for water, $[OH^-] = K_w / [H^+]$. Thus,

$$[H^+] = C_a + \frac{K_w}{[H^+]}$$

Putting this into the form of a quadratic equation,

$$[H^+]^2 - C_a[H^+] - K_w = 0$$

Which is readily solved for $[H^+]$.

For example, to find the pH of a solution of 5×10^{-8}M of HCl, first note that this concentration is small compared to the baseline concentration of $[H^+]$ in water (10^{-7}). So the quadratic equation derived above should be used.

$$[H^+]^2 - 5 \times 10^{-8}[H^+] - 10^{-14} = 0$$
$$[H^+] = 1.28 \times 10^{-7}$$
$$pH = 6.89$$

Weak acids and bases

The problem in this case would be to determine the pH of a solution of a specific concentration of an acid, when that acid's pK_a or K_a (acid dissociation constant) is given.

In this case, the acid is not completely dissociated, but the degree of dissociation is given by the equilibrium equation for that acid:

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

The *mass balance* and *charge balance* equations can be applied here as well, but in the case of a weak acid, the acid is not completely dissociated, and thus the assumption $[A^-] >> [HA]$ is not valid. Therefore the mass balance equation is

$$C_a = [HA] + [A^-]$$

Unless the acid is very weak, or the concentration is very dilute, it it reasonable to assume that the concentration of $[H^+]$ is much greater than the concentration of $[OH^-]$. This assumption simplifies the calculation and can be verified after the result is found. Note that this is equivalent to the assumption that the pH value is lower than about 6. With this assumption, the charge balance equation is

$$[H^+] = [A^-]$$

There are three equations with three unknowns ($[H^+]$, $[A^-]$, and [HA]), which need to be solved for $[H^+]$. The mass balance equation allows to solve for [HA] in terms of $[H^+]$:

$$[HA] = C_a - [A^-] = C_a - [H^+]$$

And then plug these into the equilibrium equation for the acid

$$K_a = \frac{[H^+]^2}{C_a - [H^+]}$$

Rearrange this to put it in the form of a quadratic equation,

$$[H^+]^2 + K_a[H^+] - K_a C_a = 0$$

The ICE table allows to evaluate the differences in concentrations before and after the reaction – basically, it is a mnemonic device for implementing the mass balance and charge balance equations for a given reaction, by accounting for the movements of the acid molecules and the charges. The equation derived by using the ICE table is the same as the quadratic equation given above.

For example, consider a problem of finding the pH of a 0.01M solution of benzoic acid, given that, for this acid, $K_a = 6.5\times10^{-5}$ ($pK_a = 4.19$).

The equilibrium equation for this reaction is

$$6.5 \times 10^{-5} = \frac{[H^+][A^-]}{[HA]}$$

One can neglect the $[OH^-]$ concentration, hoping that the final answer will by pH < 6. Then $[H^+] = [A^-]$, and the equilibrium equation becomes

$$6.5 \times 10^{-5} = \frac{[H^+]^2}{[HA]}$$

The mass balance equation is

$$0.01M = [HA] + [A^-] = [HA] + [H^+]$$

Solving for [HA] yields

$$[HA] = 0.01M - [H^+]$$

and plugging that into the equilbrium equation, results in the quadratic equation

$$6.5 \times 10^{-5} = \frac{[H^+]^2}{0.01 - [H^+]}$$
$$[H^+]^2 + 6.5 \times 10^{-5}[H^+] - 6.5 \times 10^{-5} \times 0.01 = 0$$

Which gives the answer

$$[H^+] = 7.74 \times 10^{-4}$$
$$pH = -\log[H^+] = 3.11$$

Thus the assumption that pH < 6 was valid, and the [OH^-] concentration might well be ignored.

pH in nature

Hydrangea macrophylla blossoms are either pink or blue, depending on a pH-dependent mobilization and uptake of soil aluminium into the plants.

pH-dependent plant pigments that can be used as pH indicators occur in many plants, including hibiscus, marigold, red cabbage (anthocyanin), and red wine.

Seawater

The pH of seawater plays an important role in the ocean's carbon cycle, and there is evidence of ongoing ocean acidification caused by carbon dioxide emissions. However, pH measurement is complicated by the chemical properties of seawater, and several distinct pH scales exist in chemical oceanography.

As part of its operational definition of the pH scale, the IUPAC defines a series of buffer solutions across a range of pH values (often denoted with NBS or NIST designation). These solutions have a relatively low ionic strength (~0.1) compared to that of seawater (~0.7), and, as a consequence, are not recommended for use in characterising the pH of seawater, since the ionic strength differences cause changes in electrode potential. To resolve this problem, an alternative series of buffers based on artificial seawater was developed. This new series resolves the problem of ionic strength differences between samples and the buffers, and the new pH scale is referred to as the **total scale**, often denoted as **pH_T**.

The total scale was defined using a medium containing sulfate ions. These ions experience protonation, $H^+ + SO_4^{2-} \rightleftharpoons HSO_4^-$, such that the total scale includes the effect of both protons (free hydrogen ions) and hydrogen sulfate ions:

$$[H^+]_T = [H^+]_F + [HSO_4^-]$$

An alternative scale, the **free scale**, often denoted **pH_F**, omits this consideration and focuses solely on $[H^+]_F$, in principle making it a simpler representation of hydrogen ion concentration. Only $[H^+]_T$ can be determined, therefore $[H^+]_F$ must be estimated using the $[SO_4^{2-}]$ and the stability constant of HSO_4^-, K_S^*:

$$[H^+]_F = [H^+]_T - [HSO_4^-] = [H^+]_T \left(1 + [SO_4^{2-}] / K_S^* \right)^{-1}$$

However, it is difficult to estimate K_S^* in seawater, limiting the utility of the otherwise more straightforward free scale.

Another scale, known as the **seawater scale**, often denoted **pH_{SWS}**, takes account of a further protonation relationship between hydrogen ions and fluoride ions, $H^+ + F^- \rightleftharpoons HF$. Resulting in the following expression for $[H^+]_{SWS}$:

$$[H^+]_{SWS} = [H^+]_F + [HSO_4^-] + [HF]$$

However, the advantage of considering this additional complexity is dependent upon the abundance of fluoride in the medium. In seawater, for instance, sulfate ions occur at much greater concentrations (> 400 times) than those of fluoride. As a consequence, for most practical purposes, the difference between the total and seawater scales is very small.

The following three equations summarise the three scales of pH:

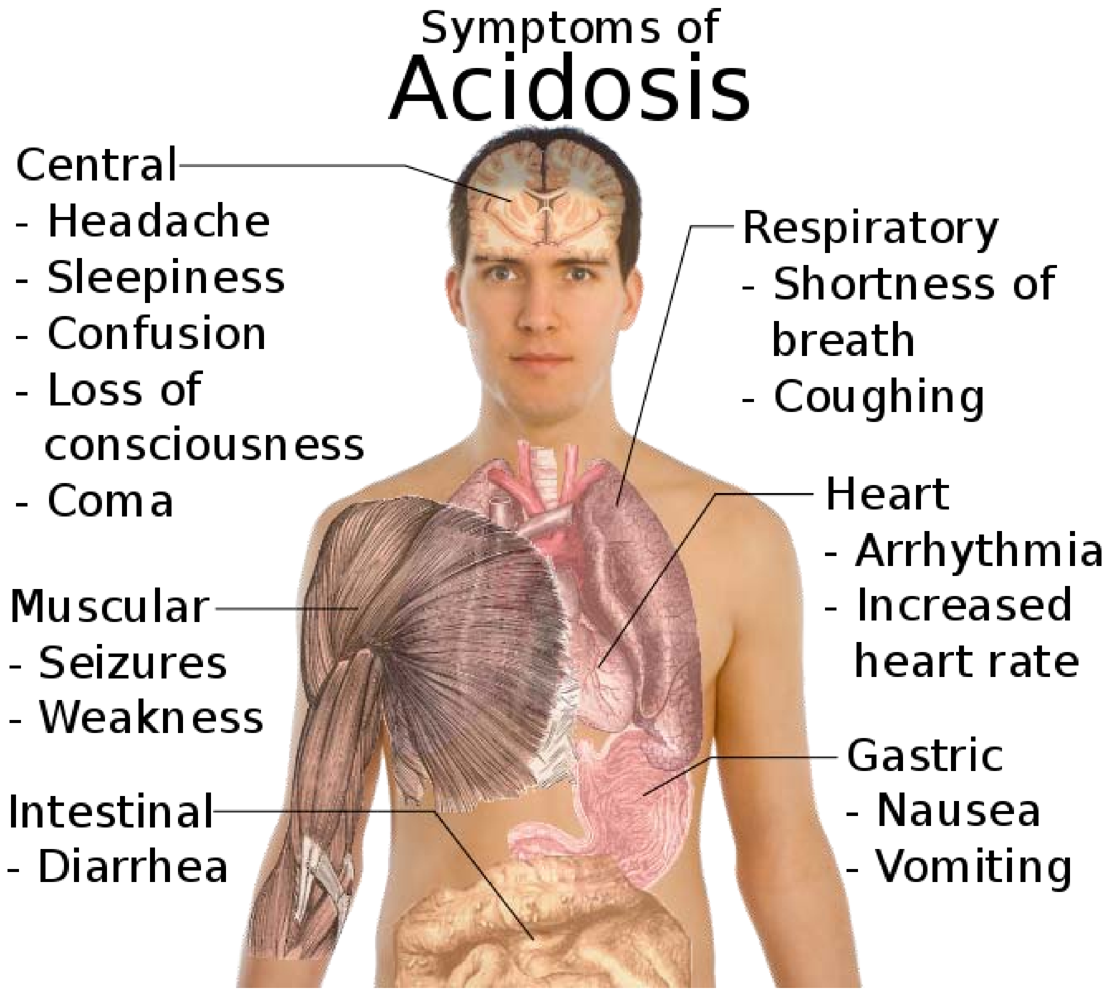
$$pH_F = -\log [H^+]_F$$
$$pH_T = -\log ([H^+]_F + [HSO_4^-]) = -\log [H^+]_T$$
$$pH_{SWS} = -\log ([H^+]_F + [HSO_4^-] + [HF]) = -\log [H^+]_{SWS}$$

In practical terms, the three seawater pH scales differ in their values by up to 0.12 pH units, differences that are much larger than the accuracy of pH measurements typically required, in particular, in relation to the ocean's carbonate system. Since it omits consideration of sulfate and fluoride ions, the free scale is significantly different from both the total and seawater scales. Because of the relative unimportance of the fluoride ion, the total and seawater scales differ only very slightly.

Living systems

pH in living systems

Compartment	pH
Gastric acid	1
Lysosomes	4.5
Granules of chromaffin cells	5.5
Human skin	5.5
Urine	6.0
Neutral H_2O at 37 °C	6.81
Cytosol	7.2
Cerebrospinal fluid (CSF)	7.3
Blood	7.34–7.45
Mitochondrial matrix	7.5
Pancreas secretions	8.1



General symptoms of acidosis, resulting from decrease in body pH.

The pH of different cellular compartments, body fluids, and organs is usually tightly regulated in a process called acid-base homeostasis.

The pH of blood is usually slightly basic with a value of pH 7.365. This value is often referred to as physiological pH in biology and medicine.

Plaque can create a local acidic environment that can result in tooth decay by demineralisation.

Enzymes and other proteins have an optimum pH range and can become inactivated or denatured outside this range.

The most common disorder in acid-base homeostasis is acidosis, which means an acid overload in the body, generally defined by pH falling below 7.35.

In the blood, pH can be estimated from known base excess (be) and bicarbonate concentration (HCO_3) by the following equation:

$$\mathrm{pH} = \frac{be - 0.93\mathrm{HCO_3} + 124}{13.77}$$

Chapter-7

Units of Measure in Science

Dioptre

A **dioptre**, or **diopter**, is a unit of measurement of the optical power of a lens or curved mirror, which is equal to the reciprocal of the focal length measured in metres (that is, 1/metres). It is thus a unit of reciprocal length. For example, a 3-dioptre lens brings parallel rays of light to focus at $\frac{1}{3}$ metre. The same unit is also sometimes used for other reciprocals of distance, particularly radii of curvature and the vergence of optical beams. The term was proposed by French ophthalmologist Felix Monoyer in 1872.

One benefit of quantifying a lens in terms of its optical power rather than its focal length is that when relatively thin lenses are placed close together their powers approximately add. Thus a thin 2-dioptre lens placed close to a thin 0.5-dioptre lens yields almost the same focal length as a 2.5-dioptre lens would have.

Though the dioptre is based on the SI-metric system it has not been included in the standard so that there is no international name or abbreviation for this unit of measurement—within the international system of units this unit for optical power would need to be specified explicitly as the inverse metre (m^{-1}). However most languages have borrowed the original name and some national standardization bodies like DIN specify a unit name (dioptrie, dioptria, ..) and derived unit symbol "dpt".

In optometry

The fact that optical powers are approximately additive enables an optometrist to prescribe corrective lenses as a simple correction to the eye's optical power, rather than doing a detailed analysis of the entire optical system (the eye and the lens). Optical power can also be used to adjust a basic prescription for reading. Thus an optometrist, having determined that a myopic (nearsighted) person requires a basic correction of, say, −2 dioptres to restore normal distance vision, might then make a further prescription of 'add 1' for reading, to make up for lack of accommodation (ability to alter focus). This is the same as saying that −1 dioptre lenses are prescribed for reading.

In humans, the total optical power of the relaxed eye is approximately 60 dioptres. The cornea accounts for approximately two-thirds of this refractive power and the crystalline lens (in conjunction with the aqueous and vitreous humors) contributes the remaining third. In focusing, the ciliary muscle contracts to reduce the tension or stress transferred to the lens by the suspensory ligaments. This results in increased convexity of the lens which in turn increases the optical power of the eye. As humans age, the amplitude of accommodation reduces from approximately 15 to 20 dioptres in the very young, to about 10 dioptres at age 25, to around 1 dioptre at 50 and over.

Convex lenses have positive dioptric value and are generally used to correct hyperopia (farsightedness) or to allow people with presbyopia (the limited accommodation of advancing age) to read at close range. Concave lenses have negative dioptric value and generally correct myopia (nearsightedness). Typical glasses for mild myopia will have a power of −1.00 to −3.00 dioptres, while over the counter reading glasses will be rated at +1.00 to +3.00 dioptres. Optometrists usually measure refractive error using lenses graded in steps of 0.25 dioptres.

Curvature

The dioptre can also be used as a measurement of curvature equal to the reciprocal of the radius measured in metres. For example, a circle with a radius of 1/2 metre has a curvature of 2 dioptres. If the curvature of a surface of a lens is C and the index of refraction is n, the optical power is $\varphi = (n - 1)C$. If both surfaces of the lens are curved, consider their curvatures as positive toward the lens and add them. This will give approximately the right result, as long as the thickness of the lens is much less than the radius of curvature of one of the surfaces. For a mirror the optical power is $\varphi = 2C$.

Savart

The **savart** is a unit of measurement for musical intervals. One savart is equal to one thousandth of a decade. Today the savart has largely been replaced by the cent and the millioctave. Another name for the savart is the **eptaméride**.

Definition

If $\frac{f_2}{f_1}$ is the ratio of frequencies of a given interval, the corresponding measure in savarts is given by:

$$s = 1000 \log_{10} \frac{f_2}{f_1}$$

or

$$\frac{f_2}{f_1} = 10^{s/1000}$$

Like the more common cent, the savart is a logarithmic measure, and thus intervals can be added by simply adding their savart values, instead of multiplying them as you would frequencies. The number of savarts in an octave is 1000 times the base-10 logarithm of 2, or nearly 301.03. Sometimes this is rounded to 300, which makes the unit more useful for equal temperament.

Conversion

The conversion from savarts into cents or millioctaves is rather simple:

$$1 \text{ savart} = \frac{1200}{1000 \log_{10} 2} \text{ cent} \approx 3.986 \text{ cent}$$

$$1 \text{ savart} = \frac{1}{\log_{10} 2} \text{ millioctave} \approx 3.3219 \text{ millioctave}$$

History

The savart is named after the French physicist and doctor Félix Savart (1791–1841), but it was devised earlier by the French acoustician Joseph Sauveur (1653–1716), who named it the *eptaméride* or *heptaméride*, as one seventh of a *méride*, the earliest logarithmic interval measure. The name was changed to savart in the 20th century.

Thermal dose unit

A **Thermal Dose Unit** (**TDU**) is a unit of measurement used in the Oil and Gas Industry to measure exposure to thermal radiation. It is a function of intensity (power per unit area) and exposure time .

1 TDU = 1 $(kW/m^2)^{4/3}s$.

Results of Exposure

Level of Exposure		Result
Mean	Range	
92	86-103	Pain
105	80-130	Threshold First Degree Burn

290	240-350	Threshold Second Degree Burn
1000	870-2600	Threshold Third Degree Burn

Bubnoff unit

The **Bubnoff unit** (abbreviated **B**) is a unit of speed equal to 1 m / 10^6 a. In other words, 1 B is equal to 1 meter in 1,000,000 years, 1 millimeter in 1,000 years, or one micrometer per year. The Bubnoff unit is employed in geology to measure rates of lowering of earth surfaces due to erosion and is named after the Russian (German-Baltic) geologist Serge von Bubnoff (1888–1957). An erosion speed of 1 B also means that 1 m^3 of earth is being removed from an area of 1 km^2 in 1 year (Kearey 2001).

Compared to everyday phenomena, erosion is under most circumstances (excluding rapid events like landslides) an extremely slow process, calling for such a specialized unit. For instance, the current average rate of erosion over the Earth's landmasses has been estimated at 30 B (30 m in a million years). There are, however, great regional differences in erosion speed. As an extreme example the watershed area of the Semani River in Albania is eroding at a rate of almost 3000 B (3 millimeters per year), the river having been estimated to transport about 4600 tons of earth per year from the average square kilometer in its watershed (Hall 1993).

Cent

A **cent** is a one-hundredth of a unit of measurement, as in "12 cents of an inch". In some cases the base unit is understood, and the cent is used as a unit itself.

In India, a cent is a measure of area and equals $^1⁄_{100}$ acre (40.468 m^2).

In music, a cent is $^1⁄_{100}$ of a semitone, i.e. $^1⁄_{1200}$ of an octave.

In diamonds, a cent is $^1⁄_{100}$ carat; this is also known as a *point*.

Darcy

A **darcy** (or **darcy unit**) and **millidarcies** (mD) are units of permeability, named after Henry Darcy. They are not SI units, but they are widely used in petroleum engineering and geology. Like other measures of permeability, a darcy has the same units as area.

Definition

Permeability measures the ability of fluids to flow through rock (or other porous media). The darcy is defined using Darcy's law, which can be written as:

$$v = \frac{\kappa \, \Delta P}{\mu \, \Delta x}$$

where:

v	is the superficial (or bulk) fluid flow rate through the medium
κ	is the permeability of a medium
μ	is the dynamic viscosity of the fluid
ΔP	is the applied pressure difference
Δx	is the thickness of the medium

The darcy is referenced to a mixture of unit systems. A medium with a permeability of 1 darcy permits a flow of 1 cm^3/s of a fluid with viscosity 1 cP (1 mPa·s) under a pressure gradient of 1 atm/cm acting across an area of 1 cm^2. A millidarcy (mD) is equal to 0.001 darcy and a microdarcy (µD) equals 0.000001 darcy.

Origin

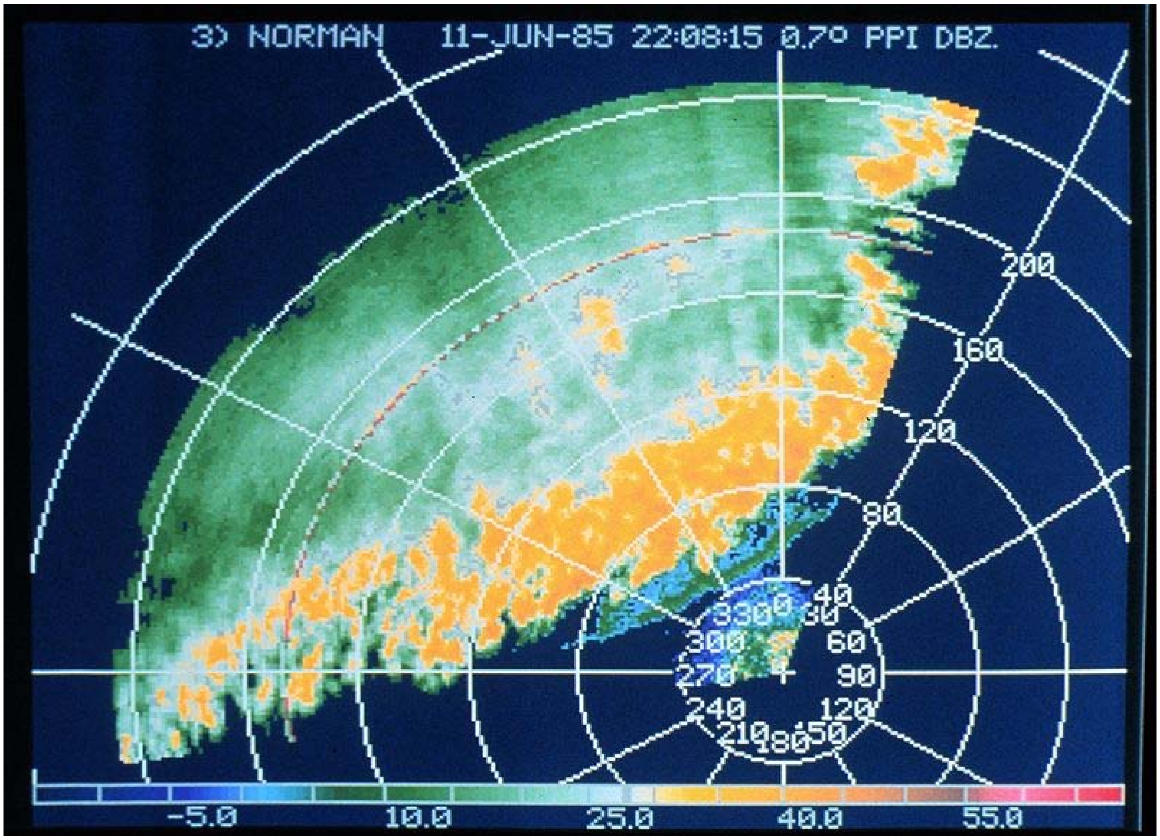
The darcy is named after Henry Darcy. Rock permeability is usually expressed in millidarcies (mD) because rocks found in oil and water reservoirs typically have permeabilities in the range of 5 to 500 mD, just a fraction of a whole darcy.

The odd combination of units comes from Darcy's original studies of water flow through columns of sand. Water has a viscosity of 1.0019 cP at about room temperature.

Conversions

Converted to SI units, 1 darcy is equivalent to 9.869233×10^{-13} m^2 or 0.9869233 $(\mu m)^2$. This conversion is usually approximated as 1 $(\mu m)^2$. Note that this is the reciprocal of 1.013250—the conversion factor from atmospheres to bars.

dBZ (meteorology)



The scale of dBZ values can be seen along the bottom of the image.

dBZ stands for decibels of Z. It is a meteorological measure of equivalent reflectivity (Z) of a radar signal reflected off a remote object. The reference level for Z is 1 $mm^6\ m^{-3}$, which is equal to 1 μm^3. It is related to the number of drops per unit volume and the sixth power of drop diameter.

Reflectivity of a cloud is dependent on the number and type of hydrometeors, which includes rain, snow, and hail, and the hydrometeors' size. A large number of small hydrometeors will reflect the same as one large hydrometeor. The signal returned to the radar will be equivalent in both situations, so a group of small hydrometeors is virtually indistinguishable from one large hydrometeor on the resulting radar image.

A meteorologist can determine the difference between one large hydrometeor and a group of small hydrometeors as well as the type of hydrometeor through knowledge of local weather condition contexts.

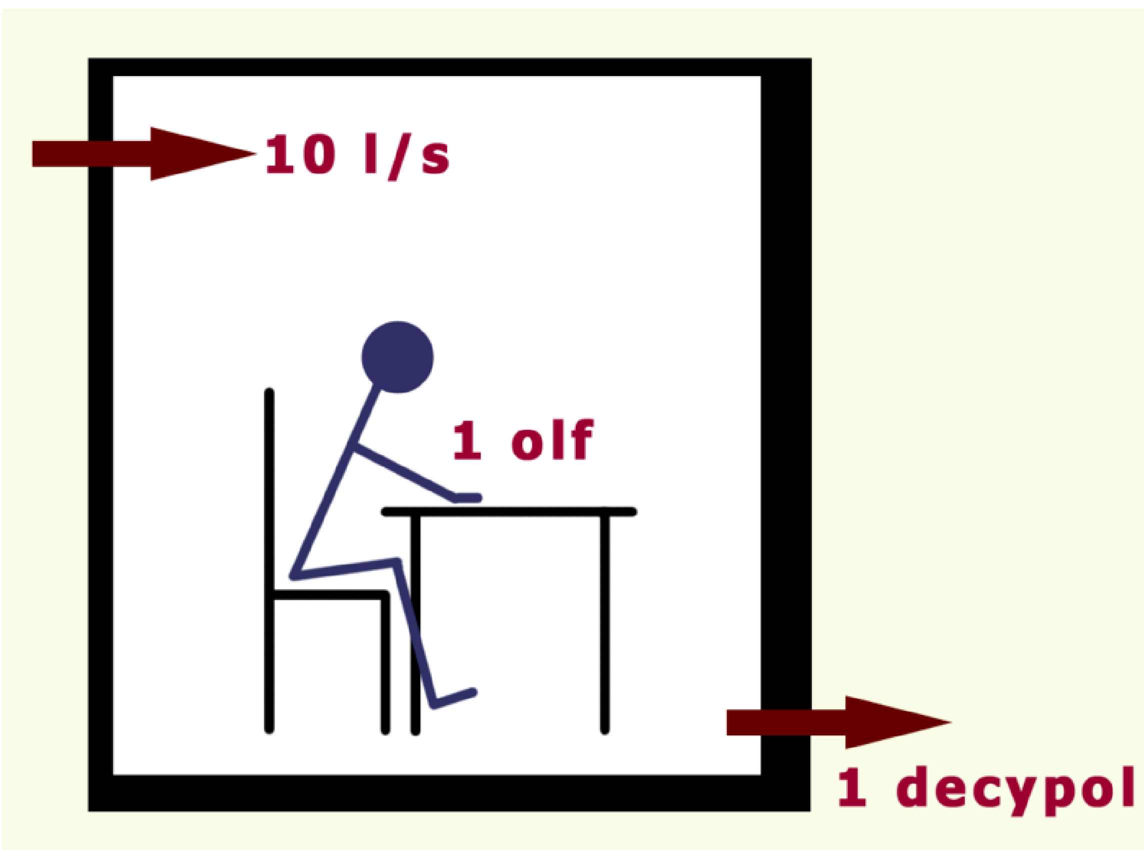
One dBZ-scale of rain:

- 40 heavy
- 24-39 moderate
- 8-23 light
- 0-8 Barely anything

dBZ values can be converted to rainfall rates in millimetres per hour using this formula:

- $$\frac{\text{mm}}{\text{hr}} = \left(\frac{10^{(dBZ/10)}}{200}\right)^{\frac{5}{8}}$$

Decipol



The **Decipol** is a unit used to measure the perceived air quality. It was introduced by Danish professor P. Ole Fanger;

One decipol (dp) is the perceived air quality (PAQ) in a space with a sensory load of one olf (one standard person) ventilated by 10 L/s. It was developed to quantify how the strength of indoor pollution sources indoors influence air quality as it is perceived by humans.

International unit

In pharmacology, **international unit** measures biological activity, or effect, of a substance. It is abbreviated as **IU**, as **UI** (French *unité internationale* or Italian *unità internazionale*), or as **IE** (German *Internationale Einheit*). It is used to quantify vitamins, hormones, some medications, vaccines, blood products, and similar biologically active substances. IU has the advantage over a measure of mass, as milligram (mg), in being consistent in nominal quantity across various forms of a biological agent (as vitamin A in the form of retinol or *beta*-carotene). Despite its name, IU is not part of the International System of Units used in physics and chemistry.

In order to remove the possibility of having the letter: "I" confused with the digit: "1", some hospitals have it as a stated policy to omit the "I", that is: to only use **U** or **E** when talking and writing about dosages.

Equality and equivalency of IU for different substances

To define an IU of a substance, the WHO Expert Committee on Biological Standardization provides a reference preparation of the substance, arbitrarily sets the number of IUs contained in that preparation, and specifies a biological procedure to compare similar substances to the reference preparation. The goal in setting the standard is that different substances with the same biological effect will contain the same number of IUs. For example, rather than specifying the precise types and masses of vitamin E in a mixture, it is sufficient to simply specify the number of IUs of vitamin E.

For some substances, the mass equivalent to one IU is later established. If that happens, the former IU mass for that substance is officially abandoned in favor of a newly established mass. The unit count often will still remain in use.

Since the number of IUs contained in a new substance is arbitrarily set, there is no equivalence between an IU measurement between two dissimilar biological agents. For instance, one IU of vitamin E cannot be equated with one IU of vitamin A in any way, including mass and efficacy.

Mass equivalents of 1 IU

- **Insulin**: 1 IU is the biological equivalent of about 45.5 μg pure crystalline insulin (1/22 mg exactly).

This corresponds to the old USP insulin unit, first suggested by Frederick Banting et.al. in 1922, where one unit (U) of insulin is equal to the amount required to reduce the concentration of blood glucose in a fasting rabbit to 0.045 per cent (≈47.7 mg/dl or 2.65 mmol/L) within 4 hours.

- **Vitamin A**: 1 IU is the biological equivalent of 0.3 μg retinol, or of 0.6 μg beta-carotene in the USA , and in Canada

- **Vitamin C**: 1 IU is 50 μg L-ascorbic acid
- **Vitamin D**: 1 IU is the biological equivalent of 0.025 μg cholecalciferol/ergocalciferol
- **Vitamin E**: 1 IU is the biological equivalent of about 0.667 mg d-alpha-tocopherol (2/3 mg exactly), or of 1 mg of dl-alpha-tocopherol acetate

Difference from unit of enzyme activity

The IU should not be confused with the enzyme unit, also known as the *International unit of enzyme activity* and abbreviated as **U**.

Millioctave

The **millioctave** (**mO**) is a unit of measurement for musical intervals. As is expected from the prefix milli-, an octave is defined as 1000 millioctaves. From this it follows that one millioctave is equal to the ratio $2^{1/1000}$, the 1000th root of 2, or approximately 1.0006934.

Given two frequencies *a* and *b*, the measurement of the interval between them in millioctaves can be calculated by

$$n = 1000 \log_2 \left(\frac{a}{b}\right) \approx 3322 \log_{10} \left(\frac{a}{b}\right)$$

Likewise, if you know a note *b* and the number *n* of millioctaves in the interval, then the other note *a* may be calculated by:

$$a = b \times 2^{\frac{n}{1000}}$$

Like the more common cent, the millioctave is a linear measure of intervals, and thus the size of intervals can be calculated by adding their millioctave values, instead of multiplication, which is necessary for calculations of frequencies.

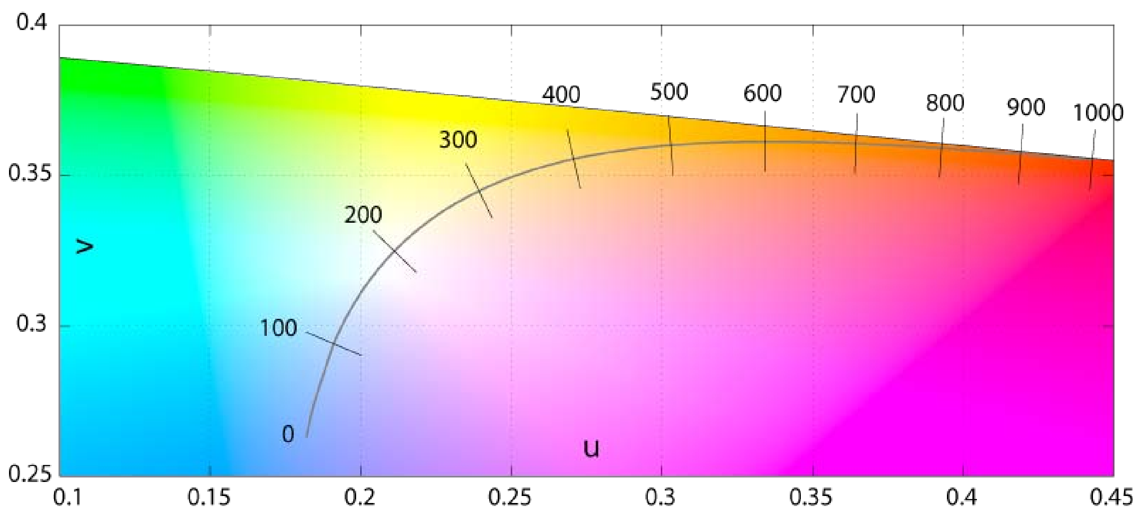
A millioctave is exactly 1.2 cents.

History and use

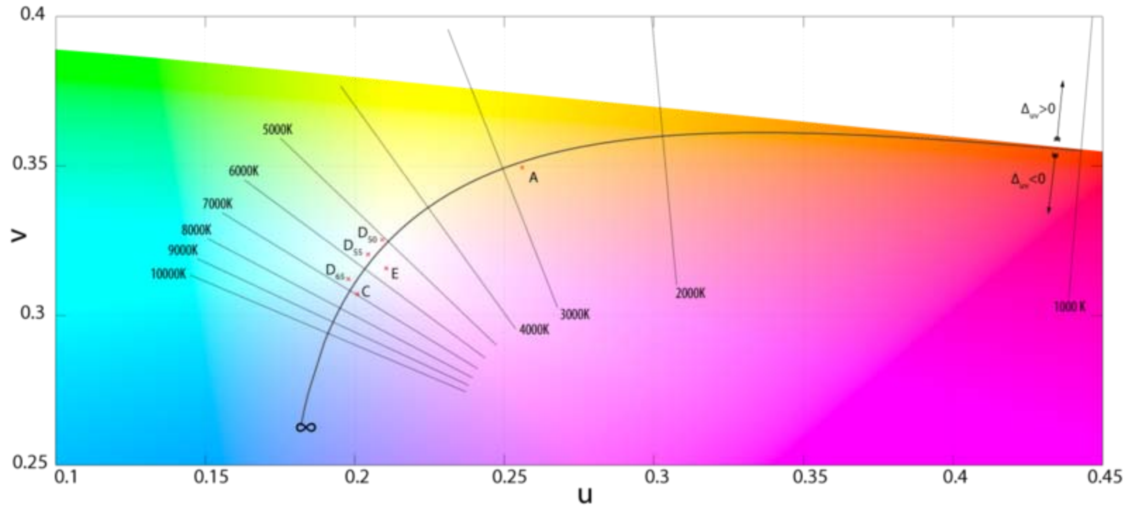
The millioctave was introduced by the German physicist Arthur von Oettingen in his book *Das duale Harmoniesystem* (1913). The invention goes back to John Herschel, who proposed a division of the octave into 1000 parts, which was published (with appropriate credit to Herschel) in George Biddell Airy's book on musical acoustics.

Compared to the cent, the millioctave has not been as popular. It is, however, occasionally used by authors who wish to avoid the close association between the cent and equal temperament. However, it has been criticized that it introduces a bias for the less familiar 10-tone equal temperament.

Mired



Close up of the Planckian locus in the CIE 1960 color space, with the isotherms in mireds. Note the even spacing of the isotherms when using the reciprocal temperature scale. The even spacing of the isotherms on the locus implies that the mired scale is a better measure of perceptual color difference than the temperature scale.



Close up of the Planckian locus in the CIE 1960 color space, with the isotherms in kelvins. The range of isothermal color temperatures, as in the previous diagram, is from 1000 K (1000 MK^{-1}) to 10,000 K (100 MK^{-1}).

Contracted from the term *micro reciprocal degree*, the **mired** is a unit of measurement used to express color temperature. It is given by the formula:

$$M = \frac{1000000}{T}$$

where M is the mired value desired, and T is the color temperature in kelvins.

For convenience, *decamireds* are sometimes used, each decamired containing 10 mireds. The SI unit is the **reciprocal megakelvin** (MK^{-1}), shortened to **mirek**, but this term has not gained traction.

Its use dates back to Irwin G. Priest's observation in 1932 that the just noticeable difference between two illuminants is based on the difference of their reciprocal temperatures, rather than the difference in the temperatures themselves.

Examples

A blue sky, which has a color temperature T of about 25,000 K, has a mired value of M=40 mireds, while a standard electronic photography flash, having a color temperature T of 5000 K, has a mired value of M=200 mireds.

In photography, mireds are used to indicate the color temperature shift provided by a filter or gel for a given film and light source. For instance, to use a tungsten light (3200 K) in natural light (say, 5700 K) without introducing a color cast, one would need a corrective filter or gel providing a mired shift of

$$\frac{10^6}{5700} - \frac{10^6}{3200} \approx -137\ \mathrm{MK}^{-1}$$

This corresponds to a CTB (color temperature blue) filter.

Neper

The **neper** is a dimensionless logarithmic unit for ratios of measurements of physical field and power quantities, such as gain and loss of electronic signals. It has the unit symbol **Np**. The unit's name is derived from the name of John Napier, the inventor of logarithms. As is the case for the decibel and bel, the neper is not a unit in the International System of Units (SI), but it is accepted for use alongside the SI.

Definition

Like the decibel, the neper is a unit in a logarithmic scale. While the bel uses the decadic (base-10) logarithm to compute ratios, the neper uses the natural logarithm, based on Euler's number ($e \approx 2.71828$). The value of a ratio in nepers is given by

$$L_{Np} = \ln \frac{x_1}{x_2} = \ln x_1 - \ln x_2.$$

where x_1 and x_2 are the values of interest, and *ln* is the natural logarithm.

The neper is used, albeit not frequently, to express ratios of voltage and current amplitudes in electrical circuits, or pressure in acoustics, whereas the decibel is used to express power ratios. One kind of ratio may be converted into the other. Wave power is proportional to the square (Joule's laws) of the amplitude:

$$1\ \mathrm{Np} = \frac{20}{\ln 10}\ \mathrm{dB} = 20 \log_{10} e\ \mathrm{dB} \approx 8.685889638\ \mathrm{dB}$$

and

$$1\ \mathrm{dB} = \frac{\ln 10}{20}\ \mathrm{Np} = \frac{1}{20 \log_{10} e}\ \mathrm{Np} \approx 0.115129254\ \mathrm{Np}.$$

The decibel and the neper have a fixed ratio to each other. The (voltage) level is

$$L = 10\log_{10}\frac{x_1^2}{x_2^2} \qquad \text{dB}$$
$$= 10\log_{10}\left(\frac{x_1}{x_2}\right)^2 \qquad \text{dB}$$
$$= 20\log_{10}\frac{x_1}{x_2} \qquad \text{dB}$$
$$= \ln\frac{x_1}{x_2} \qquad \text{Np.}$$

Like the decibel, the neper is a dimensionless unit. The International Telecommunication Union (ITU) recognizes both units.

Olf

The **Olf** is a unit used to measure the strength of a pollution source. It was introduced by Danish professor P. Ole Fanger; the name "Olf" is derived from the Latin word *olfactus*, meaning "smelled".

One Olf is the sensory pollution strength from a standard person defined as an average adult working in an office or similar non–industrial workplace, sedentary and in thermal comfort, with a hygienic standard equivalent of 0.7 baths per day and whose skin has a total area of 1.8 square metres. It was defined to quantify the strength of pollution sources which can be perceived by humans.

The perceived air quality is measured in Decipol.

Examples of typical scent emissions

Person/object	Scent emission
Sitting person	1 olf
Heavy smoker	25 olf
Athlete	30 olf
Marble	0.01 olf/m²
Linoleum	0.2 olf/m²
Synthetic fibre	0.4 olf/m²
Rubber gasket	0.6 olf/m²

Perm

A **perm** is a unit of permeance or "water vapor transmission" given a certain differential in partial pressures on either side of a material or membrane.

Definitions

US perm

The US perm is defined as 1 grain of water vapor per hour, per square foot, per inch of mercury.

1 US perm = 0.659045 metric perms
$\approx 57.2135\ \mathrm{ng{\cdot}s^{-1}{\cdot}m^{-2}{\cdot}Pa^{-1}}$

Metric perm

The metric perm (not an SI unit) is defined as 1 gram of water vapor per day, per square meter, per millimeter of mercury.

1 metric perm = 1.51735 US perms
$\approx 86.8127\ \mathrm{ng{\cdot}s^{-1}{\cdot}m^{-2}{\cdot}Pa^{-1}}$

Equivalent SI unit

The equivalent SI measure is the nanogram per second per square meter per pascal.

$1\ \mathrm{ng{\cdot}s^{-1}{\cdot}m^{-2}{\cdot}Pa^{-1}} \approx 0.0174784$ US perms
≈ 0.0115191 metric perms

The base normal SI unit for permeance is the kilogram per second per square meter per pascal.

$1\ \mathrm{kg{\cdot}s^{-1}{\cdot}m^{-2}{\cdot}Pa^{-1}} \approx 1.74784\text{x}10^{+10}$ US perms
$\approx 1.15191\text{x}10^{+10}$ metric perms

German Institute for Standardization unit

A variant of the metric perm is used in DIN Standard 53122, where permeance is also expressed in grams per square meter per day, but at a fixed, "standard" vapor-pressure difference of 17.918 mmHg. This unit is thus 17.918 times smaller than a metric perm, corresponding to about 0.084683 of a US perm.

Thomson

	thomson
Unit of...	Mass-to-charge ratio
Symbol:	Th
Named after:	J. J. Thomson

The **thomson** (symbol: **Th**) is a unit that has appeared infrequently in scientific literature relating to the field of mass spectrometry as a unit of mass-to-charge ratio. The unit was proposed by Cooks and Rockwood naming it in honour of J. J. Thomson who measured the mass-to-charge ratio of electrons and ions.

Definition

The thomson is defined as

$$1\ \mathrm{Th} = 1\ \frac{\mathrm{u}}{e} = 1\ \frac{\mathrm{Da}}{e} = 1.036426 \times 10^{-8}\, kg\, C^{-1}$$

where **u** represents the unified atomic mass unit, Da represents the unit dalton, and *e* represents the elementary charge which is the electric charge unit in the atomic unit system.

For example, for the ion $C_7H_7^{2+}$ has an exact mass of 91.0 Da. Its charge number is +2, and hence its charge is 2*e*. The ion will be observed at 45.5 Th in a mass spectrum.

The thomson allows for negative values for negatively charged ions. For example, the benzoate anion would be observed at *m/z* 121, but at −121 Th since the charge is −e.

Use

The thomson has been used by some mass spectrometrists, for example Alexander Makarov—the inventor of the Orbitrap—in a scientific poster, papers, and (notably) one book. The journal Rapid Communications in Mass Spectrometry (in which the original article appeared) states that "the Thomson (Th) may be used for such purposes as a unit of mass-to-charge ratio although it is not currently approved by IUPAP or IUPAC." Even so, the term has been called "controversial" by RCM's former Editor-in Chief (in a review the Hoffman text cited above). The book, *Mass Spectrometry Desk Reference*, argues against the use of the thomson. However, the editor-in-chief of the Journal of the Mass Spectrometry Society of Japan has written an editorial in support of the thomson unit.