7 N nitrogen [14.00, 14.01]	8 O oxygen [15.99, 16.00]	52 Te tellurium 127.6	16 S sulfur [32.05, 32.08]
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Memos and tips compiled by the IUPAC Interdivisional Committee on Terminology, Nomenclature and Symbols. See also iupac.org

The Units ppm, ppb, and ppt

by Ian Mills

Dimensionless quantities, which are also sometimes called quantities of dimension one, are generally defined as the ratio of two quantities of the same kind. Examples are refractive index n (defined as the ratio of the speed of light in vacuum to the speed in a medium, $n = c_0/c$); and mole fraction x_i – more properly called amount of substance fraction (defined as the ratio of the amount of a particular substance i in a mixture to the total amount of substance j , $x_i = n_i/\sum_j n_j$). Thus the value of a dimensionless quantity is simply a number, and it would seem that no unit is required. The International System of units, the SI, includes no units for dimensionless quantities as it is at present defined.

However important situations arise where the value of a dimensionless quantity is a number, which is very small compared to one, small by many powers of ten, or sometimes very large compared to one. For example the mole fraction of a minor constituent in a mixture may be of the order 10^{-6} or 10^{-9} or even smaller. When there is a unit in the value of a quantity it is customary and convenient to make use of the SI prefixes, so that instead of writing a small mass as, for

example, 2.6×10^{-6} g or 2.6×10^{-9} g, we would write 2.6 μ g or 2.6 ng, using the SI prefixes micro- or nano- for 10^{-6} or 10^{-9} . The convenience of the SI prefixes avoids the need to use powers of ten with large negative (or positive) exponents, which are clumsy to say and to type. However they are not available for dimensionless quantities, because there is no unit to which they may be prefixed.

The symbols ppm, ppb, and ppt are used to escape this problem. They are best thought of as non-SI units for dimensionless quantities with the meanings 10^{-6} , 10^{-9} , and 10^{-12} respectively. They are abbreviations for the words parts-per-million, parts-per-billion, and parts-per-trillion. These symbols have become commonplace in everyday use, in the media for example, as well as in scientific and technical contexts. If we regard them as units it is important to note that they are not part of the SI. SI units have an unambiguous definition provided by the BIPM, which is accepted for use worldwide. It follows that if we accept the use of symbols like ppm then we have to ensure that they are unambiguously defined. Advice on the use of these symbols is provided by the SI Brochure,¹ the ISO 80000 series of standards,² the IUPAC Green book,³ and the NIST Special Publication 330,⁴ in addition to a number of other similar sources. There is also useful advice in a paper by Cvitas.⁵

It is sometimes argued that the use of non-SI units

Name	Symbol	Value	Examples of use	Possible replacement
Percent, or part percent, or parts per hundred	% or pph	10^{-2}	The degree of dissociation was 1.5 %	Use % rather than pph
part per million	ppm	10^{-6}	The mole fraction of CO ₂ in the atmosphere is about $x(\text{CO}_2) = 300$ ppm	$\mu\text{mol/mol}$
part per billion	ppb	10^{-9}	The air quality standard for ozone is a volume fraction of $\phi = 120$ ppb	nmol/mol for mole fraction, or nL/L for volume fraction
part per trillion	ppt	10^{-12}	The volume fraction of NO in air is $\phi = 140$ ppt	pmol/mol or pL/L
part per quadrillion	ppq	10^{-15}		rarely used
part per thousand, or permille	ppt, or ‰	10^{-3}	The mole fraction of CO ₂ in the atmosphere is 0.3 ‰, or 0.3 ppt	Use percent or ppm with a power of ten. Avoid using ppt which is clearly ambiguous.
part per hundred million	pphm	10^{-8}	The mass fraction of impurity in the metal was less than 5 pphm	rarely used

Table 1. Some commonly used symbols for dimensionless numbers, with their commonly accepted meanings and examples of their use. The last three entries in this table are rarely seen, and are best not used. See also comments in the text concerning the meaning of billion and trillion.

should always be deprecated. However there is little point in deprecating their use if almost everyone continues to use them, which is the situation at present regarding ppm, ppb, and ppt. Because there is no official authority for defining their meaning, users of these units must consider these problems for themselves, and if necessary add extra words to ensure that their meaning is unambiguous. A particular problem arises in the meaning of a billion and a trillion: the usual meaning of these words today is 10^9 and 10^{12} respectively, but there are still a few countries (notably Scandinavia) where a billion and a trillion are taken to mean 10^{12} and 10^{18} respectively, with corresponding changes to the meaning of ppb and ppt. For this reason ISO and the SI Brochure recommend that the symbols ppb and ppt should never be used at all, but nonetheless they are still in common use.

Table 1 gives a number of examples of symbols for dimensionless units of the kind discussed here which are to be found in published literature. There are also a few other rules to note. The SI Brochure advises that none of these non-SI symbols should ever be combined with SI units. It is also a general rule that in specifying the value of a quantity, the definition of the quantity should always be specified—if possible by giving the recommended symbol in addition to the name. Never assume that the unit alone provides sufficient information to specify the quantity involved. The quantity should be clearly distinguished from the definition of the unit, which should preferably not be

decorated with information on the quantity involved. Thus symbols such as ppm-V (intended to imply that the quantity is a volume fraction) should not be used; instead specify the quantity involved explicitly (see the examples in the table).

Some of the views expressed in this note are my personal views, with which others may not always agree. Different authors have different levels of tolerance towards the use of non-SI units, and it is a characteristic of the units discussed here that there is not really any general authority to advise on these units.

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References

1. The International System of Units (the SI Brochure), published by the BIPM, www.bipm.org; see particularly Chapter 4 on units outside the SI.
2. The International Organisation for Standardisation; see particularly ISO TC12 and ISO TC25, www.iso.org.
3. Quantities, Units and Symbols in Physical Chemistry (the IUPAC Green Book), 3rd edition, the Royal Society of Chemistry, 2007.
4. The International System of Units, NIST Special publication 330, 2008 edition.
5. T. Cvitaš, Quantities describing the compositions of mixtures, *Metrologia*, 33, 35-39 (1996).

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by Ron Weir

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