NOTES AND CORRESPONDENCE

UNITS FOR COLUMN AMOUNTS OF OZONE AND OTHER ATMOSPHERIC GASES
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SUMMARY
This paper points out the unsatisfactory character of the units for expressing column amounts of atmospheric ozone (i.e., total ozone), it examines a number of alternative units suitable for column amounts of not only ozone but any gas in any planetary atmosphere, and it argues the case for using the SI derived unit of mole per square metre.

1. INTRODUCTION
A column amount of a specified gas is the amount of the gas in a vertical column of unit cross section extending from the Earth’s surface to the top of the atmosphere. It is a useful concept in atmospheric physics, and is defined as:

\[ \int_0^\infty \phi(z) \, dz \]  

where \( \phi(z) \) is a density function of the gas, usually concentration (number density) \( c(z) \), or mass density \( \rho(z) \). It is sometimes written as an integral of gas partial pressure increments \( dp = \rho(z)g(z) \, dz \), where \( g(z) \) is the gravitational acceleration constant which is taken to be constant with height. It is also possible to express a column amount as the equivalent layer of pure gas or liquid under specified conditions, or as a ratio of the column amount to the corresponding total air column amount.

The term ‘column amount’ has been used here in preference to other terms, in particular ‘column abundance’, which distorts the meaning of the word abundance, ‘column density’, with which there are possibilities of confusion between mass and number densities and areal and volume densities, and ‘total’, as used in total ozone, which is a poor description of the physical concept involved and is at present largely confined to use with ozone.

An earlier discussion of units for Earth atmospheric ozone quantities may be found in Godson (1962). The principal unit used for Earth ozone column amounts is the atmosphere centimetre, atm cm, which is equivalent to a pure layer of the gas one centimetre thick at NTP (0 °C and 760 mmHg). Since these column amounts are in the order of 0.3-30 atm cm, they are almost always expressed in milli atmosphere centimetres, m atm cm. Sometimes the milli atmosphere centimetre has been named the Dobson Unit, D.U., or the Dobson, D, in honour of G. M. B. Dobson’s contributions to the measurement and understanding of atmospheric ozone. The latter form, Dobson, D, was recommended by the International Ozone Commission of the International Association for Meteorology and Atmospheric Physics at its August 1980 meeting which the author attended.

From a present-day perspective however, the above units appear to be rather arbitrarily defined and inconvenient to use. In particular, they are not directly related to the base units of the Système Internationale d’Unités (SI), (see ISO, 1979 and McGlashan, 1971), they conceal the basic particle nature of gases, they are used with virtually only one atmospheric constituent (i.e. ozone), they are not very convenient for use with the growing numbers of measured gas species and measurement techniques, and the use of the Dobson label is inconsistent with the SI naming conventions. Needless to say none of the units is recognised as part of the SI system.

2. ALTERNATIVE UNITS
Possible alternative units for column amounts of any gas and in any planetary atmosphere are examined below. Conversion factors for one atmosphere centimetre are given, and the approximate mean Earth ozone column amount of 0.3 atm cm is expressed in the most convenient prefix and unit combination. Where necessary, the relative molecular mass (molecular weight) of the gas is written as Mr, in accord with ISO 1979 definitions. The unit the mole is defined and briefly discussed in the Appendix.

**Amount in moles:** mole per square metre, mol m\(^{-2}\)

- 1 atm cm = 0.4462 mol m\(^{-2}\)
- 0.3 atm cm = 134 mmol m\(^{-2}\)

Comments: Conforms to SI, is convenient to use, emphasises particle nature of gas. See Discussion.

**Molecular number:** molecules per square metre, molec m\(^{-2}\)
\[ 1\text{atm} \text{cm} = 2.687 \times 10^{20} \text{molec} \text{m}^{-2} \]
\[ 0.3 \text{atm} \text{cm} = 8.06 \times 10^{23} \text{molec} \text{m}^{-2} \]

Comments: Scientific notation is clumsy. Possible confusion between ‘molec’ and ‘mole’.

**Mass**: kilogram per square metre, kg m\(^{-2}\)

\[ 1\text{atm} \text{cm} = 4.462 \times 10^{-4} \times \text{Mr kg} \text{m}^{-2} \]
\[ 0.3 \text{atm} \text{cm} \text{ of ozone} = 6.42 \text{g} \text{m}^{-2} \]

Comments: Possibly useful for gas chemistries that involve phase changes. Otherwise inconvenient.

**Mean partial pressure**: pascal, Pa

\[ 1\text{atm} \text{cm} = 4.375 \times 10^{-3} \times \text{Mr Pa} \]
\[ 0.3 \text{atm} \text{cm} \text{ of ozone} = 63.0 \text{mPa} \]

Comments: Dependence on relative molecular mass inconvenient. See also comments below under Mean mixing ratio.

**Mean mixing ratio**: dimensionless. Ratio of gas column amount to total air column amount. If by volume, and if the air column amount is defined by a surface pressure of one atmosphere = 101325 Pa, then

\[ 1\text{atm} \text{cm} = 1.251 \text{ppmv} \]
\[ 0.3 \text{atm} \text{cm} = 375 \text{ppbv} \]

Comments: Dependence on a defined air column amount is unsatisfactory. Mixing ratio and partial pressure are useful concepts for expressing local concentrations but their use for column amounts is contrived and potentially confusing.

3. **Discussion**

The mole per square metre stands out as the best available unit. It is the properly derived SI unit for column amount. It relates directly to number of molecules, which for any gas is the amount in moles times Avogadro’s number. The conversion from the atmosphere centimetre does not require the use of relative molecular mass. With the aid of the standard SI prefixes it conveniently covers the range of column amounts encountered in the Earth’s atmosphere, from trace constituents such as CCIF at about 55 \(\mu\text{mol m}^{-2}\) and \(O_3\) at about 150 mmol m\(^{-2}\), through to \(CO_2\) at about 118 mol m\(^{-2}\) and \(N_2\) at 278.6 kmol m\(^{-2}\). It is also suitable for other planetary atmospheres. For example the column amount of \(CO_2\) on Venus is about 20 Mmol m\(^{-2}\).

The column amount of Earth atmospheric water is called the total precipitable water and along with rainfall is usually expressed as the height in millimetres of an equivalent layer of pure liquid water. Both can be expressed in moles per square metre, where 1.0 mm \(H_2O\) is equal to 55.51 mol m\(^{-2}\), but it is likely that a very strong case would be needed to successfully overturn the entrenched millimetre convention.

Earth ozone column amounts are best represented in whole milli moles per square metre. Values then range between about 100 and 200 mmol m\(^{-2}\) and data archived in whole milli atmosphere centimetres can be converted without need for extra character space. The resolution of data expressed in milli moles per square metre is less but is still quite acceptable bearing in mind the accuracy of the measurement methods. The appropriate values of the relative ozone absorption coefficients for the Dobson instrument standard wavelength bandpairs labelled A, B, C and D are 3.918, 2.555, 1.793 and 0.807 m\(^2\) mol\(^{-1}\) respectively.

It would be convenient to have the mole per square metre named after a distinguished atmospheric scientist and thus abbreviated to a symbol, but this is unlikely to happen since international weights and measures organisations are reluctant to allow the proliferation of named units and there are a number of more fundamental quantities, such as concentration, whose units so far are not named.

4. **Conclusion**

The unit for column amount that is derived from the SI base units is the mole per square metre. This unit has several advantages over the most commonly used unit, the atmosphere centimetre. The author urges the International Ozone Commission and others to support the use of the mole per square metre.

**Appendix**

**The unit of amount, the mole**

The mole is now defined as ‘the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg (exactly) of \(^{12}\text{C}\)’ (ISO 1979). The entities of the
substance, e.g. ions, atoms, or molecules must be specified. It thus represents a fixed but imperfectly known number of elementary entities. Avogadro’s number is equal to this fixed number, whose estimated value is currently set at \((6.02252 \pm 0.00028) \times 10^{20}\) per mole (ISO 1979). The mole is not widely used in atmospheric science, possibly owing to the availability of more familiar alternatives and to confusion over its definition and over the exact meaning of the word ‘amount’. One of its main virtues lies in its relating and scaling of the world of atomic entities to the more accessible world of macroscopic amounts.

**REFERENCES**


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I was quite interested in the survey of thunderstorm electrification by Latham (1981). The discussion of material published after the address was delivered was a welcome update. I agree that the material related to the negative charge accumulation between \(-10^\circ C\) and \(-20^\circ C\) and given in his Fig. 7, is very important (Krehbiel et al 1979).

I am somewhat amused, however, at the conclusion he was able to reach from these facts; that the ice-ice collision process was compatible with these data, and, that the ‘strongest reason for concluding that this convective process is unlikely to be of primary importance in thunderstorm electrification is its incompatibility with Fig. 7’, since I have reached the opposite conclusions (see Telford and Wagner 1979, and Wagner and Telford 1981).

While the discussion of the convective mechanism is somewhat vague there is a clear reference to ‘penetrative downdraughts’, and readers could well assume the author had seriously considered the problem. In Telford and Wagner (1979) it is explained why the downdraughts carrying the negative charge will tend to come into equilibrium between \(-10^\circ C\) and \(-20^\circ C\). The parcels descending from higher regions will be ice filled and so will have the advantage of the latent heat of freezing in increasing their buoyancy relative to the rising air currents, which will often contain mostly supercooled liquid water, and hence will be biased towards a greater density because in them the latent heat of freezing has not yet been released.

Thus the descending downdraughts with the negative charge will tend to accumulate at the observed level. On the other hand it is not explained how the falling negatively charged particles stop falling at the \(-10^\circ C\) level. I submit that this fact, that the negative charges do not fall lower than the \(-10^\circ C\) level, should be considered a major problem for falling particles charge generation (separation) theories.

The reference to Wornell (1953) apparently refers to a comment in that paper (page 25) in regard to the Wilson capture process ..., charge production would correspond to the 10ion cm\(^{-3}\) s\(^{-1}\) which normally appear in the lower atmosphere. This is equivalent to 6Ckm\(^{-3}\) h\(^{-1}\).

Since, further, the process is far from being of such perfect efficiency, it is impossible therefore that of itself it can separate the observed charges during the lifetime of a typical cell.

Now at 10km altitude we have 125 ions cm\(^{-3}\) s\(^{-1}\) (Israel, 1973). If we use 30 ion-pairs cm\(^{-3}\) s\(^{-1}\), as found at 6km, as an average, and the charge on the electron is \(1.6 \times 10^{-19}\) C, and if this charge is separated, we have a current,