The Ideal Gas Constant

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Students are often confused by the units of the ideal gas constant. This confusion is compounded by the fact that there are two forms of the gas constant: the ***universal gas constant*** and the ***specific gas constant***. To avoid confusion and error, these are defined below, along with their relationships with ***mol*** and ***molecular weight***. For completeness, numerical values are given in both S.I. and English units.

Mol, Atomic weight, and Molecular weight

- A ***mol*** (sometimes gmol, g-mol, or mole, not to be confused with the rodent) denotes an *amount of matter*. Specifically one mol is 6.0251×10^{23} molecules of a substance, a standard number of molecules known as ***Avogadro's number***. Strictly speaking, mol does not have dimensions of mass; rather, mol is a primary dimension in and of itself, i.e. the amount of matter. Note that some authors, however, treat mol as a unit of mass. The number of mols of a substance is denoted by the letter n.
- ***Molecular weight*** (M) is defined as the number of grams (g) per mol of the molecular form of a substance. Do not confuse this with ***Atomic wight*** (A_r), which is the number of grams per mol of an *atom* of the substance. Atomic weight is obtained from standard periodic charts of the elements. For example, the atomic weight of nitrogen is listed on periodic charts as $A_{r,nitrogen}$ = 14.0067 g/mol. However, nitrogen in its gaseous or vapor state occurs as a diatomic molecule, N_2; thus, $M_{gaseous\ nitrogen}$ = 28.0134 g/mol. Since air is made up predominantly of nitrogen gas, the molecular weight of air is very close to that of nitrogen, i.e.
  $$M_{air} = 28.97\frac{g}{mol}$$
- In S.I. units, the kilogram (kg) is preferred over the gram; thus the ***kilogram-mol*** (kmol, sometimes kg-mol or kg-mole) is often used instead of the mol. By definition, a kmol is defined as 1000 mol, or 6.0251×10^{26} molecules of the substance. The molecular weight of air in terms of kg and kmol is then
  $$M_{air} = \left(\frac{28.97\ g}{mol}\right)\left(\frac{1000\ mol}{kmol}\right)\left(\frac{kg}{1000\ g}\right) = 28.97\frac{kg}{kmol}$$
- In English units, the ***pound-mass*** (lbm) is the standard unit of mass. In order to use the same atomic weights as those listed on the periodic chart, the ***pound-mol***, (lbmol, sometimes lb-mol, lbm-mol, or lbm-mole) is defined. The atomic weight of elemental nitrogen, for example, in English units is $A_{r,nitrogen}$ = 14.0067 lbm/lbmol, and the molecular weight of air is
  $$M_{air} = 28.97\frac{lbm}{lbmol}$$

Universal gas constant and ideal gas law

- The ***universal gas constant*** (R_u) is, as its name implies, *universal*, i.e. the same regardless of the gas being considered.
- The ***ideal gas law*** in terms of R_u is
  $$P V = n R_u T$$
  where P is the absolute pressure of the gas, V is the volume occupied by the gas, n is the number of mols of the gas, and T is the absolute temperature of the gas.
- In S.I. units,
  $$R_u = 8.3143 \frac{kJ}{kmol \cdot K} = 8314.3 \frac{J}{kmol \cdot K}$$
  In the above form of the ideal gas law, since R_u is given in terms of kmol, n must represent the number of kmols of the substance. The mass, m, of the substance in kg is equal to n times the molecular weight, i.e. m = nM.
- In English units,
  $$R_u = 1545.4 \frac{ft \cdot lbf}{lbmol \cdot R}$$
  In the ideal gas law above, since R_u is given in terms of lbmol, n must represent the number of lbmols of the substance. The mass, m, of the substance in lbm is equal to n times the molecular weight, i.e. m = nM.

Specific gas constant

- The ***specific gas constant*** (R, sometimes R_{gas}) is *not* universal, and its value depends on the specific gas being considered. R is defined as the universal gas constant divided by the molecular weight of the substance, i.e.
  $$R = \frac{R_u}{M}$$
  The dimensions of R are not the same as those of R_u, since molecular weight is a not a dimensionless quantity, although some authors treat it as such.
- The ideal gas law in terms of R is
  $$P V = mRT$$
  where P is the absolute pressure of the gas, V is the volume occupied by the gas, m is the mass of the gas, and T is the absolute temperature of the gas.
- For air in S.I. units,
  $$R_{air} = \frac{R_u}{M} = \frac{8.3143 \frac{kJ}{kmol \cdot K}}{28.97 \frac{kg}{kmol}} = 0.2870 \frac{kJ}{kg \cdot K} = 287.0 \frac{J}{kg \cdot K}$$
- For air in English units,
  $$R_{air} = \frac{R_u}{M} = \frac{1545.4 \frac{ft \cdot lbf}{lbmol \cdot R}}{28.97 \frac{lbm}{lbmol}} = 53.34 \frac{ft \cdot lbf}{lbm \cdot R}$$
- As a check, one can convert from S. I. to English units, i.e.
  $$R_{air} = \left(0.2870 \frac{kJ}{kg \cdot K}\right)\left(\frac{1\ Btu}{1.055\ kJ}\right)\left(\frac{5\ K}{9\ R}\right)\left(\frac{778.17\ ft \cdot lbf}{Btu}\right)\left(\frac{0.4536\ kg}{lbm}\right) = 53.35 \frac{ft \cdot lbf}{lbm \cdot R}$$
  The disagreement in the last digit is due to round-off errors in the conversion factors.