The Ideal Gas Constant

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Introduction

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 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 x 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 a substance. *M* is obtained from standard periodic charts or periodic tables of the elements. For example, the molecular weight of nitrogen is M_{nitrogen} = 14.0067 g/mol. Nitrogen in its gaseous or vapor state occurs as a diatomic molecule, N_2; thus, $M_{gaseous\ \text{nitrogen}}$ = 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,

$$M_{\text{air}} = 28.97\frac{\text{g}}{\text{mol}}.$$

- 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 x 10^{26} molecules of the substance. The molecular weight of air in terms of kg and kmol is then

$$M_{\text{air}} = \left(\frac{28.97\ \text{g}}{\text{mol}}\right)\left(\frac{1000\ \text{mol}}{\text{kmol}}\right)\left(\frac{\text{kg}}{1000\ \text{g}}\right) = 28.97\frac{\text{kg}}{\text{kmol}}.$$

- In English units, the ***pound-mass*** (lbm) is the standard unit of mass. In order to use the same molecular weights as those listed on the periodic chart, the ***pound-mol***, (lbmol, sometimes lb-mol, lbm-mol, or lbm-mole) is defined. The molecular weight of elemental (atomic) nitrogen, for example, in English units is

M_{nitrogen} = 14.0067 lbm/lbmol, and the molecular weight of air is $M_{\text{air}} = 28.97\frac{\text{lbm}}{\text{lbmol}}$.

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 $\boxed{PV = nR_uT}$, 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. [Note that we use the font *V* for volume to distinguish from *V* for velocity or speed.]
- In S.I. units,

$$R_u = 8.3143\frac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 8314.3\frac{\text{J}}{\text{kmol}\cdot\text{K}}.$$

  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,

$$\text{R}_\text{u} = 1545.4\frac{\text{ft}\cdot\text{lbf}}{\text{lbmol}\cdot\text{R}}.$$

  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,
$$\boxed{R = \frac{R_u}{M}}.$$
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 $\boxed{PV = mRT}$, 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,
$$R_{\text{air}} = \frac{R_u}{M} = \frac{8.3143 \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}}{28.97 \frac{\text{kg}}{\text{kmol}}} = 0.2870 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} = 287.0 \frac{\text{J}}{\text{kg}\cdot\text{K}}.$$
- For air in English units,
$$R_{\text{air}} = \frac{R_u}{M} = \frac{1545.4 \frac{\text{ft}\cdot\text{lbf}}{\text{lbmol}\cdot\text{R}}}{28.97 \frac{\text{lbm}}{\text{lbmol}}} = 53.34 \frac{\text{ft}\cdot\text{lbf}}{\text{lbm}\cdot\text{R}}.$$
- As a check, one can convert from S. I. to English units, i.e.,
$$R_{air} = \left(0.2870 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}\right)\left(\frac{1\ \text{Btu}}{1.055\ \text{kJ}}\right)\left(\frac{5\ \text{K}}{9\ \text{R}}\right)\left(\frac{778.17\ \text{ft}\cdot\text{lbf}}{\text{Btu}}\right)\left(\frac{0.4536\ \text{kg}}{\text{lbm}}\right) = 53.35 \frac{\text{ft}\cdot\text{lbf}}{\text{lbm}\cdot\text{R}}$$
The disagreement in the last digit is due to round-off errors in the conversion factors.