Assignment 4

Ideal Gas Laws

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1 Ideal Gases

The concept of ideal gases is useful for understanding gas behavior. It is also useful for simplification and calculation of gas properties.

For a gas to be ideal, there are four main assumptions to be made [2]

- The gas molecules have negligible volume
- The gas particles are equally sized. They neither attract nor repel each other, i.e, they have no inter-molecular forces.
- The gas particles move in a random, straight-line motion, in agreement with Newton's Laws of Motion
- The gas particles collide elastically with the walls of the container and with each other. There is no energy loss

2 Gas Laws

2.1 Boyle's Law

In 1662, Boyle discovered that the relationship between Pressure(P) and Volume(V), assuming Temperature(T) and amount of gas(n) remains constant.

It is given by

$$P \propto \frac{1}{V} \tag{1}$$

2.2 Charles' Law

In 1787, French physicist Jacques Charles discovered that the relationship between Temperature(T) and Volume(V), assuming Pressure(P) and amount of gas(n) remains constant.

It is given by

$$V \propto T \tag{2}$$

2.3 Avogadro's Law

In 1811, Amedeo Avagadro discovered that the relationship between Amount of gas(n) and Volume(V), assuming Pressure(P) and Temperature(T) remains constant.

It is given by

$$V \propto n \tag{3}$$

3 Ideal Gas Law

The ideal gas law is the combination of of the three simple Gas Laws.

On combining the three equations we get:

$$V \propto \frac{nT}{P} \tag{4}$$

On replacing the proportionality sign we get the Ideal Gas Law: [1]

$$PV = nRT \tag{5}$$

where,

- P = Pressure,
- V = Volume,
- n = Amount of gas, i.e, number of moles,
- R = Universal Gas Constant,
- T = Absolute Temperature

In eq 5, the temperature value should be in absolute units so that the right hand side of eq 5 does not become zero.

3.1 Universal Gas Constant

R has different values and units and its value can be found in online databases. Figure 1, Figure 2 and Figure 3 present different values of R for various units of P, V, n and T. They are based on the values reported by Moldover *et al.* [3] Their value was determined from measurements of the speed of sound in argon as a function of pressure at the temperature of the triple point of water.

4 Ideal Gas Mixtures

The Ideal Gas Law, i.e. eq 5 also holds true for a system containing multiple ideal gases. An ideal gas mixture partitions the total pressure into the partial pressure contribution of each component.

Thus, the eq 5 can be rewritten as:

$$P_iV = n_iRT \tag{6}$$

where,

- P_i is Partial Pressure of the component
- n_i is number of moles of the component

5 Real gas as ideal gas

Ideal gases is a theoretical concept but real gases behave ideally under certain conditions. Systems with very low pressures or high temperature are said to show "ideal gas" behaviour. This is because at low pressure and high temperature, inter-molecular forces between the particles is low

6 Conclusion

The ideal gas equation is significant because it is a tool used for making predictions, doing calculations and understanding of gas behaviour under different conditions. It is used extensively in various scientific and engineering fields, including thermodynamics, chemistry, physics and material science.

TABLE 5.1A—GAS-CONSTANT VALUES BASED ON ENERGY UNITS				
	g mol Kelvin	lb mol Kelvin	g mol Rankine	lb mol Rankine
Btu	0.0078806	3.57458	0.00437811	1.98588
cal	1.98588	900.779	1.10327	500.433
Chu	0.00437811	1.98588	0.00243228	1.10327
erg	8.31447×10^{7}	3.77138×10^{10}	4.61915×10^{7}	2.09521×10^{10}
lbf-ft	6.13244	2781.63	3.40691	1545.35
hp-hr	3.09719×10^{-6}	0.00140486	1.72066×10^{-6}	0.000780479
J	8.31447	3771.38	4.61915	2095.21
kcal	0.00198588	0.900779	0.00110327	0.500433
kgf·m	0.847840	384.574	0.471022	213.652
kJ	0.00831447	3.77138	0.00461915	2.09521
kW-hr	$2.30958\ 10^{-6}$	0.00104761	$1.28310\ 10^{-6}$	0.000582003
N·m	8.31447	3771.38	4.61915	2095.21

Chu = Celsius heat unit (1 Chu = 1899.18 J); erg = a unit of energy (1 erg = 10^{-7} J); hp-hr = horsepower/hour.

Figure 1: Table 1A

TABLE 5.1B—GAS-CONSTANT VALUES BASED ON PRESSURE AND VOLUME UNITS					
	cm^3	L	m^3	ft^3	$in.^3$
atm	82.0575	0.0820575	8.20575×10^{-5}	0.00289783	5.00745
bar	83.1447	0.0831447	8.31447×10^{-5}	0.00293623	5.0738
ft H_2O	2781.63	2.78163	0.00278163	0.0982323	169.745
in. H_2O	33379.5	33.3795	0.0333795	1.17879	2036.94
in. Hg	2455.27	2.45527	0.00245527	0.086707	149.83
kgf/cm^2	84.784	0.084784	8.4784×10^{-5}	0.00299412	5.17384
kPa	8314.47	8.31447	0.00831447	0.293623	507.38
lbf/ft^2	173651	173.651	0.173651	6.13244	10596.9
mbar	83144.7	83.1447	0.0831447	2.93623	5073.8
m H_2O	847.84	0.84784	0.00084784	0.0299412	51.7384
mm H_2O	847840	847.84	0.84784	29.9412	51738.4
mm Hg	62363.8	62.3638	0.0623638	2.20236	3805.68
Pa	8.31447×10^6	8314.47	8.31447	293.623	507380
psi	1205.91	1.20591	0.00120591	0.0425864	73.5893

This table is based on g mol and Kelvin temperature units.

Figure 2: Table 1B

TABLE 5.1C—GAS-CONSTANT VALUES BASED ON PRESSURE AND VOLUME UNITS					
	cm^3	L	m^3	ft^3	$in.^3$
atm	20678.1	20.6781	0.0206781	0.730241	1261.86
bar	20952.1	20.9521	0.0209521	0.739917	1278.58
ft H_2O	700958	700.958	0.700958	24.7541	42775.1
in. H_2O	8.41150×10^6	8411.50	8.41150	297.049	513301
in. Hg	618717	618.717	0.618717	21.8498	37756.5
kgf/cm^2	21365.2	21.3652	0.0213652	0.754505	1303.79
kPa	2.09521×10^6	2095.21	2.09521	73.9917	127858
lbf/ft^2	4.37594×10^7	43759.4	43.7594	1545.35	2.67036×10^6
mbar	2.09521×10^7	20952.1	20.9521	739.917	1.27858×10^6
m H_2O	213652	213.652	0.213652	7.54505	13037.9
mm H_2O	2.13652×10^8	213652	213.652	7545.05	1.30379×10^7
mm Hg	1.57154×10^7	15715.4	15.7154	554.985	959014
Pa	2.09521×10^9	2.09521×10^6	2095.21	73991.7	1.27858×10^8
psi	303885	303.885	0.303885	10.7316	18544.2

This table is based on lb mol and Rankine temperature units.

Figure 3: Table 1C

References

[1] S. Levine. Derivation of the ideal gas law. *Journal of Chemical Education*, 62(5):399, 1985.

[2] W. F. Luder. Ideal gas definition. *Journal of Chemical Education*, 45(5):351, 1968.

[3] M. R. Moldover, J. P. M. Trusler, T. J. Edwards, J. B. Mehl, and R. S. Davis. Measurement of the universal gas constant r using a spherical acoustic resonator. *Phys. Rev. Lett.*, 60:249–252, Jan 1988.