Ideal Gas Law

Unit: Gases

MA Curriculum Frameworks (2016): HS-PS2-8(MA)

Mastery Objective(s): (Students will be able to…)

- Describe the relationship between any two variables in the ideal gas law.
- Apply the ideal gas law to problems involving a sample of gas.

Success Criteria:

- Solutions have the correct quantities substituted for the correct variables.
- Chosen value of the gas constant has the same units as the other quantities in the problem.
- Algebra and rounding to appropriate number of significant figures is correct.

Tier 2 Vocabulary: ideal, law

Language Objectives:

- Identify each quantity based on its units and assign the correct variable to it.
- Explain the placement of each quantity in the ideal gas law.

Notes:

<u>ideal gas</u>: a gas that behaves according to Kinetic-Molecular Theory (KMT).

When we developed the combined gas law, before we cancelled the number of moles, we had the equation:

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} = \text{constant}$$

Because *P*, *V*, *n* and *T* are all of the quantities needed to specify the conditions of an ideal gas, this expression must be true for *any ideal gas* under *any conditions*. If *V* is in liters, *P* is in kPa, *n* is in moles and *T* is in Kelvin, then the value of this constant is $8.31\,\frac{\text{L·kPa}}{\text{mol·K}}$. This number is called "the gas constant", and is denoted by the variable *R* in equations.

Therefore, we can rewrite the above expression as:

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} = R \quad \text{and therefore} \quad P_1V_1 = n_1RT_1 \quad \text{and} \quad P_2V_2 = n_2RT_2$$

Because this expression is true under any conditions, 1, 2, or whatever, we can drop the subscripts:

$$PV = nRT$$

Use this space for summary and/or additional notes:

Choosing a value of R

The purpose of the gas constant *R* is to convert the quantity *nT* from units of mol·K to units of pressure × volume. As we saw earlier in this chapter, the gas constant has different values, depending on the units it needs to cancel:

$$R = 0.0821\,\frac{\text{L·atm}}{\text{mol·K}}$$

$$R = 8.31\,\frac{\text{L·kPa}}{\text{mol·K}} = 8.31\,\frac{\text{J}}{\text{mol·K}} = 8.31\times 10^{-3}\,\frac{\text{kJ}}{\text{mol·K}}$$

$$R = 62.4\,\frac{\text{L·torr}}{\text{mol·K}} \qquad R = 1.987\,\frac{\text{cal}}{\text{mol·K}} \equiv 1.987\,\frac{\text{BTU}}{\text{lb-mol·°R}}$$

In order for the units in a problem to work out properly, ***R needs to have exactly the same units as the values in the problem***. In the problems we will be solving, this usually means you need to look at the pressure units and ***choose the value of R that has the same pressure unit as the pressure given in the problem***.

Amazing Fact:

In the metric system, the unit of pressure (the Pascal) is a combination of the S.I. units $\frac{\text{kg}}{\text{m}\cdot\text{s}^2}$, and volume has units of m^3. This means that pressure times volume (*PV*) has S.I. units of $\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$, which happens to equal Joules (the unit for energy). Dimensional analysis tells us that if the units work, the resulting formula must be correct.

So, if *PV* is equivalent to energy, *nRT* ***must also be*** equivalent to energy. In fact, *PV* is the energy that the gas expends in doing work on its surroundings (such as by expanding a balloon or pushing on a piston), and *nRT* is the kinetic energy of the individual gas molecules.

In other words, the ideal gas law *PV* = *nRT* is simply the law of conservation of energy, applied to gases!

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Solving Problems Using the Ideal Gas Law

If a gas behaves according to the ideal gas law, simply substitute the values for pressure, volume, number of moles (or particles), and temperature into the equation. Be sure your units are correct (especially that temperature is in Kelvin), and that you use the correct constant, depending on whether you know the number of particles or the number of moles of the gas.

Sample Problem:

n *P*

A 3.50 mol sample of an ideal gas has a pressure of 1.20 atm and a temperature of 35 °C. What is its volume?

$T \rightarrow K$ ⓥ

Answer:

First, we need to declare our variables and choose a value for *R* based on the units:

P = 1.20 atm

V = *V* (because we don't't know it yet)

n = 3.50 mol

$R = 0.0821\,\frac{\text{L·atm}}{\text{mol·K}}$ (Choose this one because *P* is in atm.)

T = 35 °C + 273 = 308 K

Then we substitute these numbers into the ideal gas law and solve:

$$PV = nRT$$

$$(1.20\,\text{atm})V = (3.50\,\text{mol})(0.0821\,\tfrac{\text{L·atm}}{\text{mol·K}})(308\,\text{K})$$

$$1.20V = 88.5$$

$$V = \frac{88.5}{1.20} = 73.75\,\text{L}$$

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Homework Problems

Use the ideal gas law to solve the following problems. Be sure to choose the appropriate value for the gas constant and to convert temperatures to Kelvin.

1. A sample of 1.00 moles of oxygen at 50.0 °C and 98.6 kPa occupies what volume?

   Answer: 27.2 L

2. If a steel cylinder with a volume of 1.50 L contains 10.0 moles of oxygen, under what pressure is the oxygen if the temperature is 27.0 °C?

   Answer: 164 atm = 125 000 torr = 16 600 kPa

3. In a gas thermometer, the pressure of 0.500 L of helium is 113.30 kPa at a temperature of −137 °C. How many moles of gas are in the sample?

   Answer: 0.050 mol

4. A sample of 4.25 mol of hydrogen at 20.0 °C occupies a volume of 25.0 L. Under what pressure is this sample?

   Answer: 4.09 atm = 3 108 torr = 414 kPa

Use this space for summary and/or additional notes: