SVC Topics

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Ideal Gas Law

The Ideal Gas Law applies to low-pressure gases and is of concern to all doing vacuum or plasma processing. The Ideal Gas Law states that the pressure (P) times the volume (V) divided by the absolute temperature (T) (°K*) equals a constant.

PV/T = constant

The constant in the Ideal Gas Law is equal to nR, where n is the number of moles** of gas and R is the Universal Gas Constant equal to:

R = 6.2364 x 10^4 Torr-cm^3/K-mole

Gas pressure is the force exerted on a surface by the energetic gas molecules impinging on the surface. The kinetic energy of a particle is given by 1/2 MV^2, where M is the mass of the particle and V is the velocity of the particle, which is determined by the temperature. The pressure is the sum of the forces exerted by all particles impinging on the surface, and is a function of the particle density of the gas. The gas pressure is, therefore, dependent on the temperature, mass of the gas particles, and the particle density. If there is a mixture of gases, or of gases and vapors, then each gas or vapor will exert a partial pressure, and the total pressure will be the sum of the partial pressures. A process performed at a constant pressure is called an isobaric process. A process performed at constant temperature is called an isothermal process.

An adiabatic process is one in which there is not energy lost or gained by the gas from external sources, including the container walls. The Ideal Gas Law states that in an adiabatic process, if the temperature remains constant, any change in the volume will result in a change in the pressure, or $P_1V_1 = P_2V_2$ (Boyles' Law). If the volume is doubled, for example, the pressure will be decreased by one half. Because the temperature is constant and the particle energy is unchanged, this means that the particle density has been reduced by half. The Ideal Gal Law also says that in an adiabatic process, if the volume is held constant and the temperature is increased, the pressure will increase (Charles' Law). For example, if the temperature is doubled (say from 273 °K or 0 °C to 546 °K or 273 °C) the pressure will double.

Of course, no process is completely adiabatic, so when the pressure in a volume (vacuum chamber) is decreased rapidly, the gas and vapors will cool. This, in turn, will cool the chamber walls by taking up heat from the surfaces, and prevents the gas temperature from going as low as the Ideal Gas Law predicts. This cooling, however, can be important. If the water vapor in the chamber is near saturation (high relative humidity), for example, the cooling can raise the relative humidity above saturation, and water vapor will condense on ions and airborne particles in the system, producing water droplets that will deposit on surfaces causing a residue.

Conversely, if the gas/vapor is compressed the gas and vapor temperature will increase, and the partial pressure of the vapor will be increased. If the vapor pressure exceeds the saturation, the vapor will condense. For example, water has a saturation vapor pressure of about 18 Torr at room temperature, and if the water vapor pressure exceeds this value at room temperature the water will condense.

Several types of vacuum pumps compress gases and vapors. These types of pumps are susceptible to condensing vapors and losing there effectiveness. If an oil-sealed mechanical pump condenses water during compression, for example, the water will mix with the oil and the oil-seal will not be effective. Just changing the oil in the pump will often restore the pumping efficiency of the machine. To prevent liquification by compression in such a pump, the vapor flowing into the pump is diluted with a dry gas (ballasted) to the extend that its partial pressure never exceeds the saturation vapor pressure during compression. This increases the pumping load on the system and should be avoided if possible. The table shows the saturation vapor pressure of water at several temperatures.

Saturation Vapor Pressure of Water

-10 °C	0 °C	10 °C	20 °C	30 °C	40 °C	50 °C
2.1 Torr	4.6 Torr	9.2 Torr	17.5 Torr	32.8 Torr	55.3 Torr	92.5 Torr

Heating gas by compression can also pose problems. Blower pumps, for example, compress large amounts of gas and generate a lot of heat. If the blower pump is exhausted to atmospheric pressure, the pump will overheat and the bearings will suffer. Generally, a blower pump is "backed" by an oil sealed, mechanical pump so that it exhausts to a pressure lower than atmospheric pressure.

A plasma system has a constant mass flow of gas through the system. When plasma is first established the pressure will rise because of the heating of the gas. This means that in order to maintain a given pressure in the system, the mass flow or pumping conductance must be adjusted. Changes in the plasma parameters, such as power input, may require further adjustments. In the plasma, heating of the gas can generate gas particle density variations in the plasma chamber. Because many plasma-based PVD processes, such as reactive sputter deposition, are sensitive to the density of reactive particles, this can lead to variations in the film properties as a function of location in the deposition chamber. o

*The Absolute or Kelvin temperature scale is based on the absolute zero, the temperature at which all molecular motion ceases and there is no heat energy present. The Kelvin temperature scale uses 100 °K as the temperature difference between the freezing and boiling points of water under standard conditions of 760 Torr. Zero degrees Kelvin (0 °K) equals -273.16 °C and -459.69 °F.

**A mole is the gram-molecular-weight of a material. For example, argon has a molecular weight of 39.944 and 39.944 grams of argon will be one mole of gas. A mole of a gas will contain 6.032 x 1023 molecules (Avogadros' number) and will occupy 22.4 liters under standard conditions of 760 Torr and 0 °C.