water vapor varies considerably. To allow for this variation the specific properties of moist air are developed in terms of the relative amounts of water vapor and dry air. Accepted air-conditioning practice is to express this in terms of the amount of water vapor per pound of dry air.

Terms frequently used in describing the condition of a mixture of air and water vapor are *humidity ratio, relative humidity, degree of saturation, dry-bulb temperature, thermodynamic wet-bulb temperature,* and *dew-point temperature.* These terms are defined in following paragraphs.

Humidity Ratio. Weight of water vapor associated with unit weight of dry air, pounds of water vapor per pound of dry air. Humidity ratio has also been called *specific humidity,* and this term is still used in many places.

Relative Humidity. Ratio of the mol fraction of water vapor in the actual mixture to the mol fraction of water vapor in saturated air at the same dry-bulb temperature and barometric pressure.

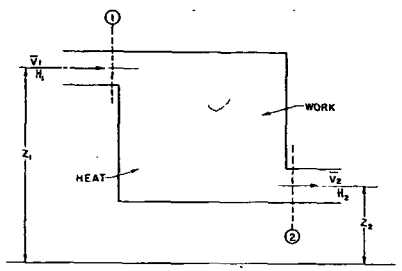

Fig. 1 . . . . Energy Change between Two Sections of a System

Degree of Saturation. Ratio of the actual humidity ratio to the humidity ratio of saturated air at the same dry-bulb temperature and barometric pressure.

Relative humidity and degree of saturation are related according to the identity:

$$\phi = \frac{\mu}{\left[1 - (1 - \mu)f_s\frac{P_s}{P_o}\right]} \tag{7}$$

where

ϕ = relative humidity, expressed as a decimal.
μ = degree of saturation, expressed as a decimal.
P_o = observed (or barometric) pressure of the moist air.
P_s = saturation pressure of pure water at the prevailing temperature, expressed in the same units as P_o.
f_s = a dimensionless factor which may be regarded as accounting for influences arising when air and water are intermixed. Magnitudes of f_s have been reported by Goff and Gratch[1] and by Goff.[2] Table 1 gives values of f_s for a limited range of conditions.

Dry-Bulb Temperature. The temperature indicated by any type of thermometer or thermocouple not affected by the water-vapor content of the air, or by radiation.

Table 1 . . . . Magnitudes of f_s for the Range 0 to 125 F
(Standard Barometric Pressure, 29.921 in. Hg)

Temp. F	f_s	Temp. F	f_s
0	1.0048	70	1.0045
10	1.0046	80	1.0047
20	1.0046	90	1.0048
30	1.0045	100	1.0050
40	1.0044	110	1.0053
50	1.0044	120	1.0055
60	1.0044	125	1.0057

Note: The original source gives f_s to seven significant figures over the temperature range −208 F to +202 F and over the pressure range 20 to 35 in. Hg.

Thermodynamic Wet-Bulb Temperature. The temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

Consider an adiabatic system as shown in Fig. 2. Unsaturated air at the state h_1, W_1, enters the system at Section 1, and saturated air at the state h,* W,* leaves the system at Section 2. Liquid water at the state h_w,* corresponding to the temperature of the saturated air leaving the system is supplied. Then, since no work is done and the system is strictly adiabatic, the energy equation becomes

$$h_1 + (W^* - W_1)h_w^* = h^* \tag{8}$$

where

* indicates condition at thermodynamic wet-bulb temperature.

The temperature corresponding to h^* for given values of h_1 and W_1 is called the thermodynamic wet-bulb temperature, or the temperature of adiabatic saturation.

The temperature indicated by an ordinary wet-bulb thermometer is affected by a number of factors not accounted for in Equation 8, and hence, may be quite different from the theoretical temperature obtained from its use. The measured wet-bulb temperature is influenced by (*a*) radiation from the surroundings to the wick; (*b*) conduction of heat along the stem of the thermometer; and (*c*) impact of the air on the wick or bulb of the thermometer. Arnold[3] has developed a theory which makes possible the calculation of the true thermodynamic wet-bulb temperature from observed data through the use of suitable corrections to be applied to the

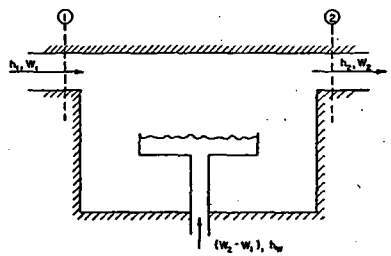

Fig. 2 . . . . Illustration of Adiabatic Saturation

readings of the wet-bulb thermometer. However, unless extreme precision is required, the observed temperature may be taken equal to the theoretical temperature for most engineering problems, if no attempt is made to shield the wick from radiation and the air velocity past the wick is about 1000 fpm.

Dew-Point Temperature. The saturation temperature corresponding to a given combination of humidity ratio W and barometric pressure is called the dew-point temperature. It is the lowest temperature at which the given humidity ratio can exist at the corresponding barometric pressure. At this temperature condensation will first start to form when moist air is cooled.

Perfect Gas Relationships

Hypotheses, based on experimental observation of the physical behavior of gases, which were advanced by Boyle, Charles, Gay-Lussac, Dalton, Gibbs, Joule, Kelvin, and others, were reduced to reasonably simple mathematical expressions and came to be regarded as physical laws. However, as scientific knowledge increased, and as more precise methods of measurement were developed, it became apparent that these simple equations did not describe the behavior of the mixtures of actual gases and vapors accurately.

The original statements have been found to be useful tools, nevertheless, in many cases. For example, the behavior of common diatomic and triatomic gases at low pressures follows these equations closely enough so that they may be used for some types of engineering problems. Many useful engineering works have been constructed through the use of approximations. The degree of approximation, however, which may be tolerated in engineering design must be decided by the engineer, based upon his study and experience in the field.

Boyle's Law. One of the original observations of the physical behavior of gases was made by Robert Boyle who noted that, if a constant weight of gas is compressed with the temperature held constant, the volume V varied inversely as the absolute pressure P. Stated mathematically,

$$PV = \text{constant} \quad \text{(temperature constant)} \tag{9}$$

Charles' Law. Experiments made independently by Charles and Gay-Lussac led to the formulation of what is now known as Charles' Law: If a constant weight of gas is heated or cooled at constant volume, the absolute pressure P varies as the absolute temperature T; if a constant weight of gas is heated or cooled at constant pressure, the volume V varies as the absolute temperature T. Stated mathematically,

$$\frac{P}{T} = \text{constant} \quad \text{(volume constant)} \tag{10}$$

$$\frac{V}{T} = \text{constant} \quad \text{(pressure constant)} \tag{11}$$

Boyle's Law and Charles' Law may be combined to form the equation of state for the ideal or perfect gas,

$$PV = RT \tag{12}$$

where

R is a constant whose value depends on the units selected for P, V, and T.

Dalton's Rule. Dalton stated that each gas in a mixture occupies the total volume of the mixture just as though the other gases were not present. Gibbs later expanded this statement for perfect gases into the following principles:

1. The pressure of a mixture of gases is the sum of the partial pressures of the individual gases when they exist at the total volume and temperature of the mixture.

2. The internal energy, enthalpy, and entropy of a mixture of gases are respectively equal to the sums of the individual internal energies, enthalpies, and entropies of the components when they exist at the total volume and temperature of the mixture.

While these relationships do not hold exactly for all systems of real gases, they may be used with a good degree of precision for many engineering applications at low pressures. Moreover, since water vapor very closely follows the perfect gas relationships in the range usually encountered in air conditioning, the Gibbs-Dalton Rule may frequently be applied to mixtures of dry air and water vapor.

Thus,
$$V_m = V_a = V_w \tag{13}$$

$$T_m = T_a = T_w \tag{14}$$

$$p_m = p_a + p_w \tag{15}$$

$$m_m h = m_a h_a + m_w h_w \tag{16}$$

where

Subscript m denotes mixture; subscript a denotes dry air; subscript w denotes water vapor.
Symbol m = weight of dry air crossing any duct section, pounds per minute.

Using Equations 12, 13, 14, and 15, the relation is obtained as follows:

$$v_T = \frac{n_a RT}{p_a} = \frac{n_w RT}{p_w} = \frac{(n_a + n_w)RT}{p} \tag{17}$$

where

v_T = total volume, cubic feet.
n_a = number of mols of dry air.
n_w = number of mols of water vapor.
R = universal gas constant, 1545 foot-pounds per (Fahrenheit degree) (mol).
p_a = partial pressure of dry air.
p_w = partial pressure of water vapor.
T = absolute temperature, Fahrenheit degrees.

The partial pressure of water vapor in the mixture is then

$$p_w = \frac{n_w}{n_a + n_w} p \tag{18}$$

or, the partial pressure of the water vapor in moist air is equal to the product of the mol fraction of the water vapor and the observed pressure of the mixture. A similar expression is obtained for the dry air.

Assuming that the perfect gas laws can be applied to water vapor at saturation at low pressures, the partial pressure of water vapor in a *saturated* mixture may be written as

$$p_s = \frac{n_s}{n_a + n_s} p \tag{19}$$

where

n_s = number of mols of water vapor at saturation.

The relative humidity may be obtained by combining