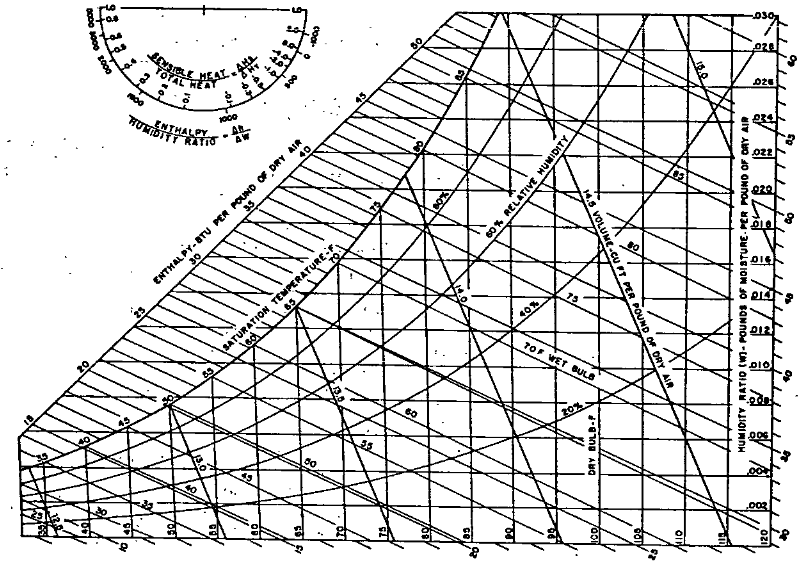

Fig. 1 .... Abridgment of Chart 1

2. The atmosphere consists of dry air which behaves as a perfect gas; thus

$$pv = RT \tag{24}$$

3. Gravity is constant at the standard value, namely 32.174 ft per (sec)².

4. At sea level, pressure (p_0) is 29.921 in. Hg; and temperature (T_0) is 518.67 F abs. (59 F).

Equations 23 and 24 may be combined to give a relation between p and Z. Table 6 shows values of pressure and temperature for altitudes in the standard atmosphere from − 1000 ft to 50,000 ft above sea level. Further explanation of the standard atmosphere is available in the literature.[6,7]

PSYCHROMETRIC CHARTS

A psychrometric chart is a graphical representation of the thermodynamic properties of moist air. Its distinctive features are selected to be of practical value in the solution of engineering problems.

The choice of coordinates for a psychrometric chart is arbitrary. Mollier[8] was the first to use coordinates of enthalpy and humidity ratio. An h, W chart provides for convenient graphical solutions of many types of moist air problems with a minimum of thermodynamic approximations.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers has developed four Mollier-type psychrometric charts.

Charts 1, 2 and 3 are for sea-level pressure. Chart 4 is for 5000 ft. altitude (24.89 in. Hg). All four charts (included at the back of this volume) use oblique-angle coordinates of enthalpy and humidity ratio and are consistent with the data of Table 1 and the properties computation methods of Goff and Gratch.[1,2] The geometry of chart construction applying specifically to Charts 1 and 4 has been made a matter of record.[9]

Fig. 1, which is an abridgment of Chart 1, shows the various properties which are represented on all four charts. These include the coordinates enthalpy and humidity ratio and lines of constant dry-bulb and thermodynamic wet-bulb temperature, relative humidity and volume.

The dry-bulb temperature ranges covered by the charts are as follows:

Charts 1 and 4	Normal Temperature	32 F to 120 F
Chart 2	Low Temperature	−40 F to 50 F
Chart 3	High Temperature	60 F to 250 F

Chart 1 and altitude Chart 4, included in the 1965 GUIDE AND DATA BOOK for the first time, are constructed on the identical system of coordinates. Psychrometric properties or charts for barometric pressures other than 29.921 and 24.89 in. Hg may be derived by interpolation. Alternatively, sufficiently exact values for most purposes may be derived by methods described earlier under Perfect Gas Relations. The construction of charts for altitude conditions has been treated by several authors.[10,11,12]

Comparison of Charts 1 and 4 by overlay will reveal the following:

1. The dry-bulb lines coincide.
2. Wet-bulb lines for a given temperature originate at the intersections of the corresponding dry-bulb line and the two saturation curves and they have the same slope.
3. The humidity ratio and enthalpy for a given dry-bulb and wet-bulb increase with altitude, but relative humidity changes little.
4. Volume changes rapidly, and for a given dry-bulb and humidity ratio, it is practically inversely proportional to barometric pressure.

The following table compares properties read from the Sea-Level (Chart No. 1) and 5000 ft (Chart No. 4) charts:

Chart No.	DB	WB	h	W	RH	V
1	100	81	44.6	.0186	45	14.5
4	100	81	49.8	.0234	46	17.6

The following discussion refers to Chart 1 which will hereafter be called the ASHRAE psychrometric chart. This chart shows humidity ratio lines (horizontal) for the range from zero (dry air) to 0.03 lb water per lb dry air. Enthalpy lines are oblique lines and are drawn across the chart in intervals of 5 Btu per lb dry air. The enthalpy lines are precisely parallel to each other. Edge scales for entalpy are shown above the saturation curve and at the bottom and right-hand margins for intervals of 0.2 Btu per lb dry air.

Dry-bulb temperature lines are shown in 1 F deg intervals. The dry-bulb temperature lines are drawn straight, are not precisely parallel to each other, and are inclined slightly from the vertical position. Thermodynamic wet-bulb temperature lines are oblique lines shown in intervals of 1 deg F. Their directions differ but slightly from that of enthalpy lines. The thermodynamic wet-bulb temperature lines are identically straight but are not precisely parallel to each other.

Relative humidity lines are shown in intervals of 10 percent. The saturation curve is the line of 100 percent relative humidity while the horizontal line for $W = 0$ (dry air) is the line for zero relative humidity.

Volume lines are oblique lines and are shown in intervals of 0.5 cu ft per lb dry air. The volume lines are drawn straight and are not precisely parallel to each other.

A narrow region above the saturation curve has been developed for fog conditions of moist air. This two-phase region represents a mechanical mixture of saturated moist air and liquid water with the two components in thermal equilibrium. Isothermal lines in the fog region are coincident with extensions of thermodynamic wet-bulb temperature lines. If required, a user of the chart may further expand the fog region by extension of humidity ratio, enthalpy, and thermodynamic wet-bulb temperature lines.

A protractor and a nomograph are shown to the left of the chart. The protractor shows two scales—one for sensible-total heat ratio and one for the ratio of enthalpy difference to humidity ratio difference. The protractor is useful in establishing the direction of a condition line on the psychrometric chart. The nomograph provides an alternate method for determining enthalpy from the psychrometric chart and also allows a direct reading of the enthalpy ($\Delta W h_w$) of liquid water added or rejected in a process in Btu per lb dry air.

Example 3 illustrates the use of the ASHRAE psychrometric chart in determination of moist-air properties.

Example 3: Moist air exists at a condition of 100 F dry-bulb temperature, 65 F thermodynamic wet-bulb temperature, and 29.921 in. Hg pressure. Determine the humidity ratio, enthalpy, dew-point temperature, relative humidity, and the volume.

Solution: The state-point may be located on the chart at the intersection of the 100 F dry-bulb temperature line and the 65 F thermodynamic wet-bulb temperature line. Read $W = 0.00523$ lb water/lb dry air.

The enthalpy may be found by two methods. Through use of two triangles, draw a line parallel to nearest enthalpy line (30 Btu/lb dry air) through the state-point to the nearest edge scale. Read $h = 29.80$ Btu/lb dry air.

An alternate method for determining enthalpy will now be described. From Equation 9

$$h = h_s^* - (W_s^* - W)h_w^* = h_s^* + D$$

where h_s^* is the enthalpy of saturated moist air at the thermodynamic wet-bulb temperature and D is the enthalpy deviation given by the nomograph. At 65 F, read $h_s^* = 30.06$ Btu/lb dry air. By the nomograph, at $W = 0.00523$ lb water/lb dry air and $t^* = 65$ F, read $D = -0.26$ Btu/lb dry air. Thus, $h = 30.06 - 0.26 = 29.80$ Btu/lb dry air.

The dew-point temperature may be read at the intersection of $W = 0.00523$ lb water/lb dry air with the saturation curve. Thus, $t_d = 40$ F.

The relative humidity may be estimated directly. Thus, $\phi = 13$ percent.

The volume may be accurately found by linear interpolation between the volume lines for 14.0 and 14.5 cu ft/lb dry air. Thus, $v = 14.22$ cu ft/lb dry air.

TYPICAL AIR CONDITIONING PROCESSES

The ASHRAE psychrometric chart may be used conveniently in the solution of numerous process problems with moist air. The best explanation of its use is through illustrative examples. In each of the following examples, it is to be understood that the process in question takes place at a constant pressure of 29.921 in. Hg.

Heating of Moist Air

The process of adding heat alone to moist air is represented by a horizontal line on the ASHRAE chart since the humidity ratio remains unchanged.

Fig. 2 shows a device which may add heat to a stream of moist air. For steady-flow conditions, the required rate of heat addition is

$$_1q_2 = m_a(h_2 - h_1) \tag{25}$$

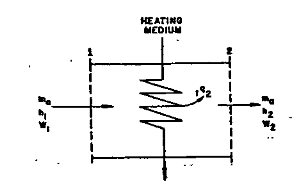

Fig. 2 .... Schematic Device for Heating Moist Air

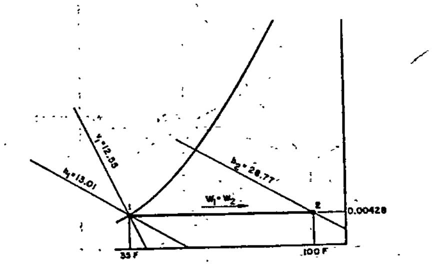

Fig. 3 .... Schematic Solution for *Example 4*