changed to approach equality with that of the air touching the wick, even if this requires the liquid to freeze on the wick. Then the liquid (or solid) will continue for a time to evaporate into the air stream at such temperature as will bring a portion of the air stream to saturation at this same temperature. This equilibrium temperature is called *wet-bulb temperature*.

It is clear that the readings of an actual wet-bulb thermometer cannot be regarded as values of a thermodynamic property of moist air; for these readings are importantly affected by a number of non-thermodynamic factors including design, construction, installation, and technique of using the instrument. Thus, unless the wet-bulb is effectively shielded against radiation from relatively warm surfaces the process will not be strictly adiabatic as tacitly assumed in writing Equation 7. Also, partial drying of the wick will prevent the air immediately adjacent to it from reaching complete saturation as assumed in Equation 7. A working theory developed by Arnold[5] enables the calculation of corrections to be applied to the readings of the actual instrument in order to make them agree with the values of temperature calculated from Equation 7. Fortunately, and indeed fortuitously, these corrections can be made small, but to emphasize the necessity of making them in accurate experimentation, the temperature defined by Equation 7 is called *thermodynamic wet-bulb temperature*.

Example 2. Find the degree of saturation of moist air at 90 F dry-bulb, 63 F thermodynamic wet-bulb, atmospheric pressure.

Solution. Inserting numerical data from Table 1 into Equation 7 gives

$$(21.625 + 34.31\mu) + (0.01235 - 0.03118\mu) \times 31.12 = 28.57$$

The solution of this equation is direct and the final answer is

$$\mu = 19.67 \text{ per cent}$$

The per cent saturation may also be read directly at intersection of 90 F dry-bulb and 63 F thermodynamic wet-bulb lines on the Goff Diagram.

Example 3. Find the temperature to which moist air initially saturated at 40 F and at standard atmospheric pressure must be heated in order to have a thermodynamic wet-bulb temperature of 60 F.

Solution. On the Goff Diagram follow a horizontal line from the saturation curve at 40 F to its intersection with the 60 F thermodynamic wet-bulb line and read the corresponding temperature directly.

Inserting numerical data from Table 1 into Equation 7, this becomes

$$h_a + 0.005213h_{as}/W_s = 26.46 - (0.01108 - 0.005213) \times 28.12 = 26.295$$

At 85 F the left-hand member of this equation has the value 26.147; at 86 F its value is 26.389; by linear interpolation the answer is: $t = 85.61$ F.

Dew-Point Temperature. Corresponding to any given state of moist air there exists another state on the saturation curve having the same humidity ratio W and same pressure p as the given state. The temperature at this other state on the saturation curve is called the *dew-point temperature* of the given state. Obviously, if moist air is cooled at constant pressure and constant humidity ratio it will reach saturation when its temperature falls to a value equal to its dew-point temperature. This will usually be marked by the first appearance of a coexisting condensed phase. In one type of dew-point apparatus a continuous sample of air is passed over a mirror which can be cooled by external refrigeration and whose temperature can be accurately measured. The measured temperature at which the intensity of light reflected from the mirror is abruptly diminished by condensation is taken to be the dew-point temperature

of the air sample. Examples 4 and 5 illustrate the relation between the dew-point, degree of saturation and dry-bulb temperature.

Example 4. Find the dew-point temperature of moist air at 80 F, 50 per cent saturation, atmospheric pressure.

Solution. On the Goff Diagram follow a horizontal line from a given state point (80 F, 50 per cent) to the saturation curve and read the temperature at the intersection.

To solve from Table 1:

From the data in Table 1, the humidity ratio of the air is $W = 0.50 \times 0.02233 = 0.01117$ lb_w/lb_a. By interpolation this is found to be the humidity ratio at saturation at 60.22 F which is therefore the required answer.

Example 5. Find the degree of saturation of moist air at 90 F dry-bulb, 40 F (dew-point), atmospheric pressure.

Solution. On the Goff Diagram follow a horizontal line from 40 F on the saturation curve to the 90 F isotherm (dry-bulb) and read the degree of saturation directly.

To solve from Table 1:

From the data in Table 1, the humidity ratio of the air must be $W = 0.005213$. But the humidity ratio at saturation at 90 F is 0.03118; hence the degree of saturation is

$$\mu = 0.005213/0.03118 = 16.72 \text{ per cent}$$

TYPICAL AIR CONDITIONING PROCESSES

The use of Table 1 and the Goff Diagram in analyzing typical air conditioning processes is best explained by means of illustrative examples. In each of the following, it is to be understood that the process in question takes place at a constant pressure of 29.921 in. Hg, or standard atmospheric pressure.

Heating

The process of adding heat to moist air is represented by a horizontal line on the Goff Diagram. The length of the line between the initial and final state points is the increase of reduced enthalpy; but, since the humidity ratio is constant, it is also the increase of enthalpy itself and therefore the quantity of heat added per pound of dry air.

Example 6. Air initially at 20 F, 80 per cent saturation is heated to 120 F. Find the quantity of heat required to process 20,000 cfm of heated air.

Solution. From the data in Table 1: the initial humidity ratio is $0.80 \times 0.002152 = 0.001722$ lb_w/lb_a; the initial enthalpy is $4.804 + 0.80 \times 2.302 = 6.646$ Btu/lb_a; the final degree of saturation is $0.001722/0.08149 = 2.113$ per cent; the final enthalpy is $28.841 + 0.02113 \times 90.70 = 30.757$ Btu/lb_a.

It may be supposed that the air is heated between two sections of a duct. The quantities of energy convected across the two sections per pound of dry air crossing them are the two enthalpies calculated. Conservation of energy requires that the difference between these two enthalpies be the quantity of heat added; thus,

$${}_{A}q_{B} = 30.757 - 6.646 = 24.111 \text{ Btu/lb}_a.$$

The final volume is $14.611 + 0.02113 \times 1.905 = 14.651$ cu ft/lb_a. Since 20,000 cfm of heated air is to be processed, the total quantity of heat required is

$${}_{A}Q_{B} = 24.111 \times 20{,}000/14.651 = 32{,}914 \text{ Btu per minute.}$$

On the Goff Diagram the process is represented by the horizontal line AB, Fig. 2, whose length is the quantity of heat added per pound of dry air. The reduced enthalpy at A is 4.92 while that at B is 29.03, both being read directly from the chart. Since humidity ratio is constant the difference between these reduced enthalpies is also the difference between the enthalpies themselves, namely, 24.11 Btu/lb_a.