

Humid air - *psychrometry*

$$P_{\text{total}} = p_{N_2} + p_{O_2} + p_{H_2O}$$

$$P_{\text{total}} = p_{\text{dry air}} + p_{H_2O}$$

$$p_{\text{dry air}} = p_{N_2} + p_{O_2}$$

$$p_{\text{dry air}} \equiv p_{\text{bone dry air}} \equiv p_{\text{BDA}}$$

“Air” will now refer to humid air

“Bone dry air (BDA)” will refer to a 79% nitrogen (N₂)
21% oxygen (O₂) mixture

Relative humidity

$$0 \leq p_{H_2O} \leq p_{H_2O}^*$$

The partial pressure of water vapour can be anywhere from 0 to the saturation pressure

If there is no water around it is 0

If the air is contact with sufficient water in a closed container it will eventually be saturated

e.g. $p_{H_2O}^* = 2.62 \text{ kPa @ } 295 \text{ K}$ (from Antoine expression or steam tables)

If we normalize the partial pressure by using the vapour pressure:

$$0 \leq \frac{p_{H_2O}}{p_{H_2O}^*} \leq 1$$

$$0 \leq RH \leq 100\%$$

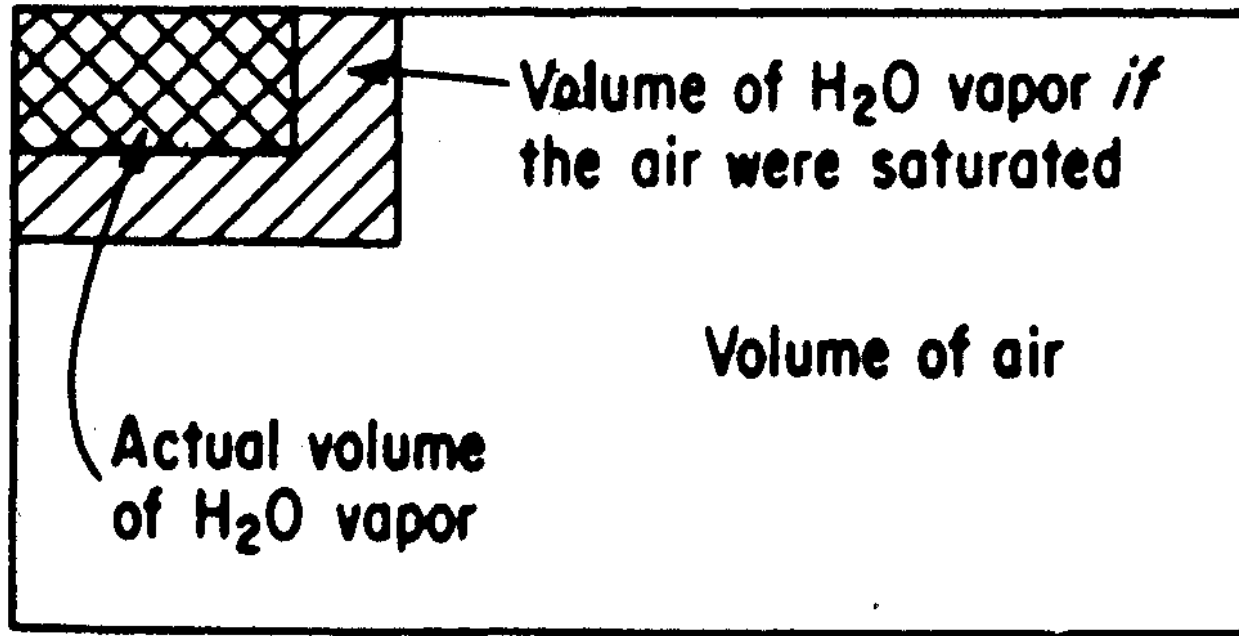


Figure 4.20 Partially saturated gas with the water and air separated conceptually.

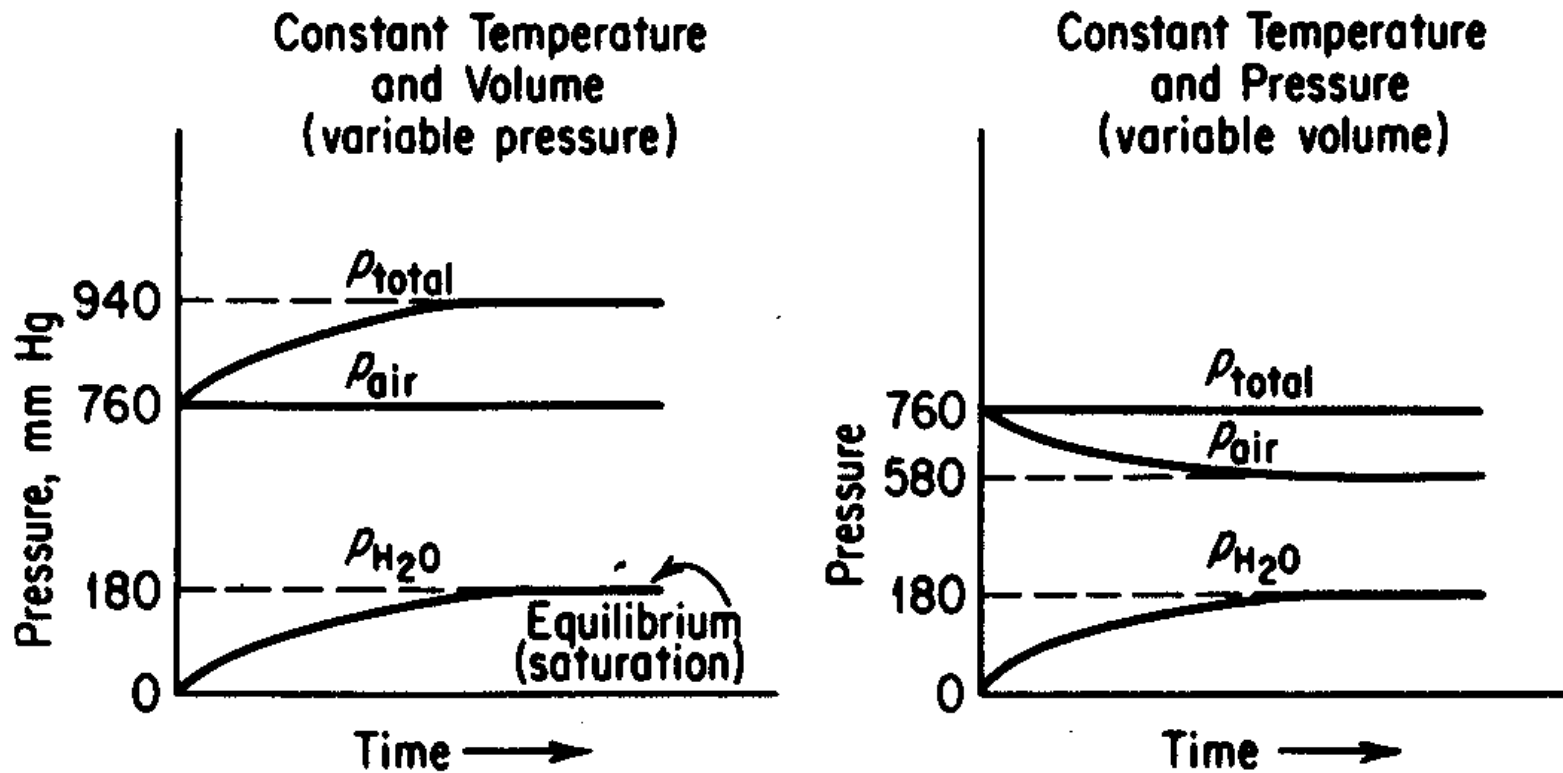


Fig. 3.16. Change of partial and total pressures on vaporization of water into air at constant temperature. @ 150 F, $p^* = 180$ mm Hg

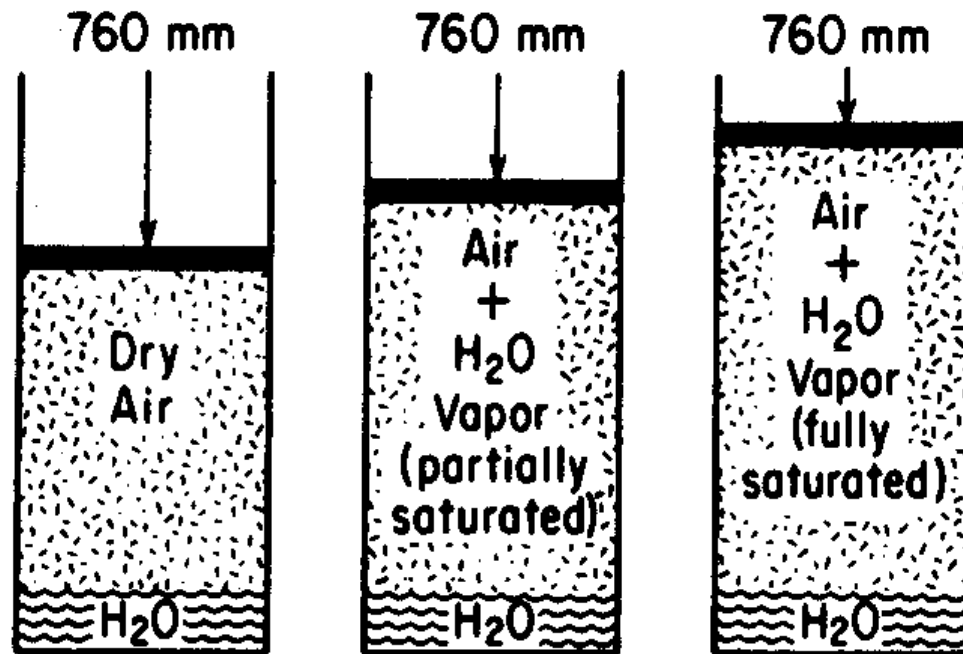


Fig. 3.17. Evaporation of water at constant pressure and temperature.

Humidity, ω , the mass ratio of H₂O to BDA

$$\text{Mol ratio : } \frac{N_{H_2O}}{N_{BDA}} = \frac{P_{H_2O}}{P_{BDA}}$$

Mass = (mols)(MW)

What is the MW of BDA?

Average MW = total mass / total mols

Basis: 1 mol of BDA

$$\text{MW} = (0.79)(28) + (0.21)(32) = 28.84 \sim 29$$

$$\text{Mass ratio : } \omega = \frac{P_{H_2O}}{P_{BDA}} \frac{18}{29} \quad \frac{\text{kg } H_2O}{\text{kg } BDA}$$

Properties of humid air

expressed per unit mass of BDA

	BDA	H ₂ O	Total
Mass (Kg)	1	w	1+w
Moles (kg-moles)	1/28.84	w/18	1/28.84+w/18
Volume (m ³)	Use PV=NRT to find volume for given P, T		

Note that you can also use the following line calculation for volumes from the ideal gas law without needing a value for R,

e.g.

$$\left(22.4 \frac{m^3}{kg - mole} \text{ at STP} \right) \left(\frac{T}{273K} \right) \left(\frac{1 atm}{P} \right) \left(\frac{1}{28.84} kg - mole \right)$$

Comparing volumes at different states

$$P_1V_1 = nRT_1$$

$$P_2V_2 = nRT_2$$

$$\frac{P_2V_2}{P_1V_1} = \frac{T_2}{T_1}$$

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{P_1}{P_2} \right)$$

This form is convenient to use:

- No need for R
- The temperature and pressure ratios are dimensionless
- No need to memorize which temperature or pressure is on top: If temperature increases volume should increase, if pressure increases volume should decrease.

Determination of humidity in air

- We measure the temperature recorded by two thermometers:
 - One with a bulb covered by a wet wick: $T_{wet\ bulb}$
 - One without a wet wick: $T_{dry\ bulb}$
- If the air is saturated with water vapour there will be no evaporation of water from the wet wick, the temperatures will be the same.
- If the air is less than saturated with water vapour, there will be evaporation which cools the wick, resulting in a $T_{wet\ bulb}$ lower than $T_{dry\ bulb}$

Wet bulb temperature

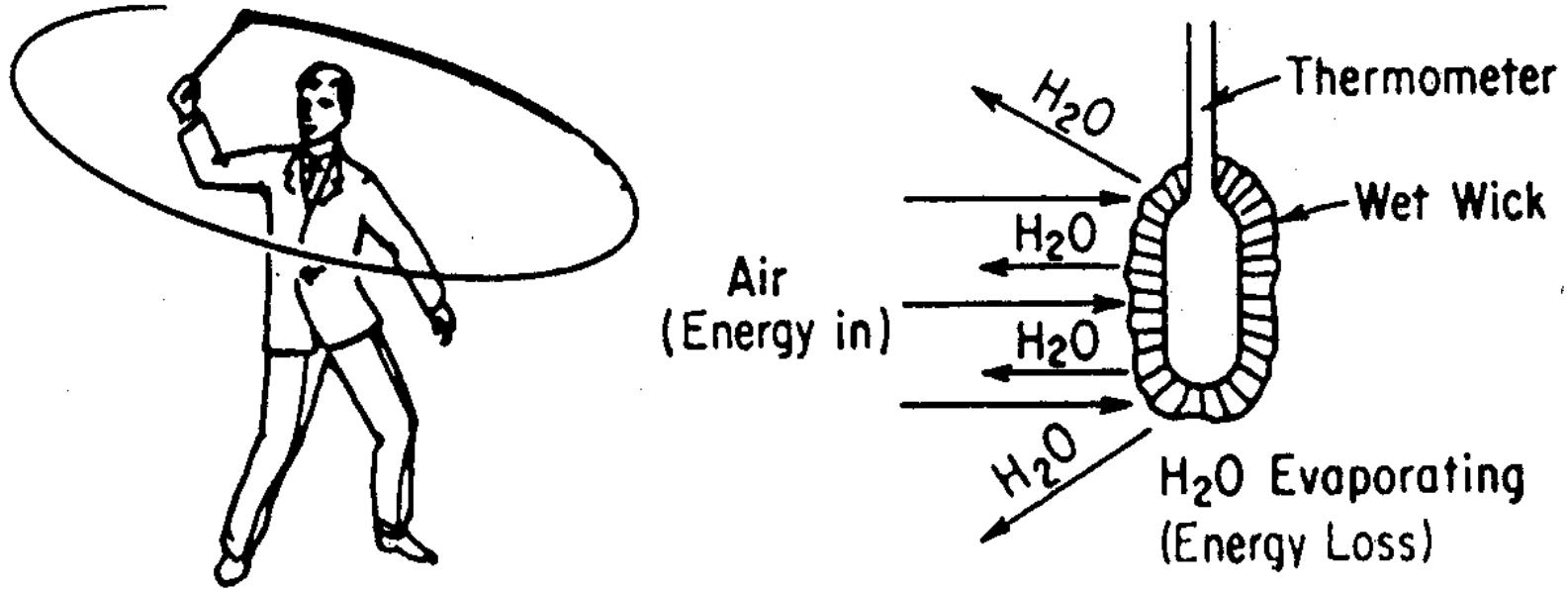
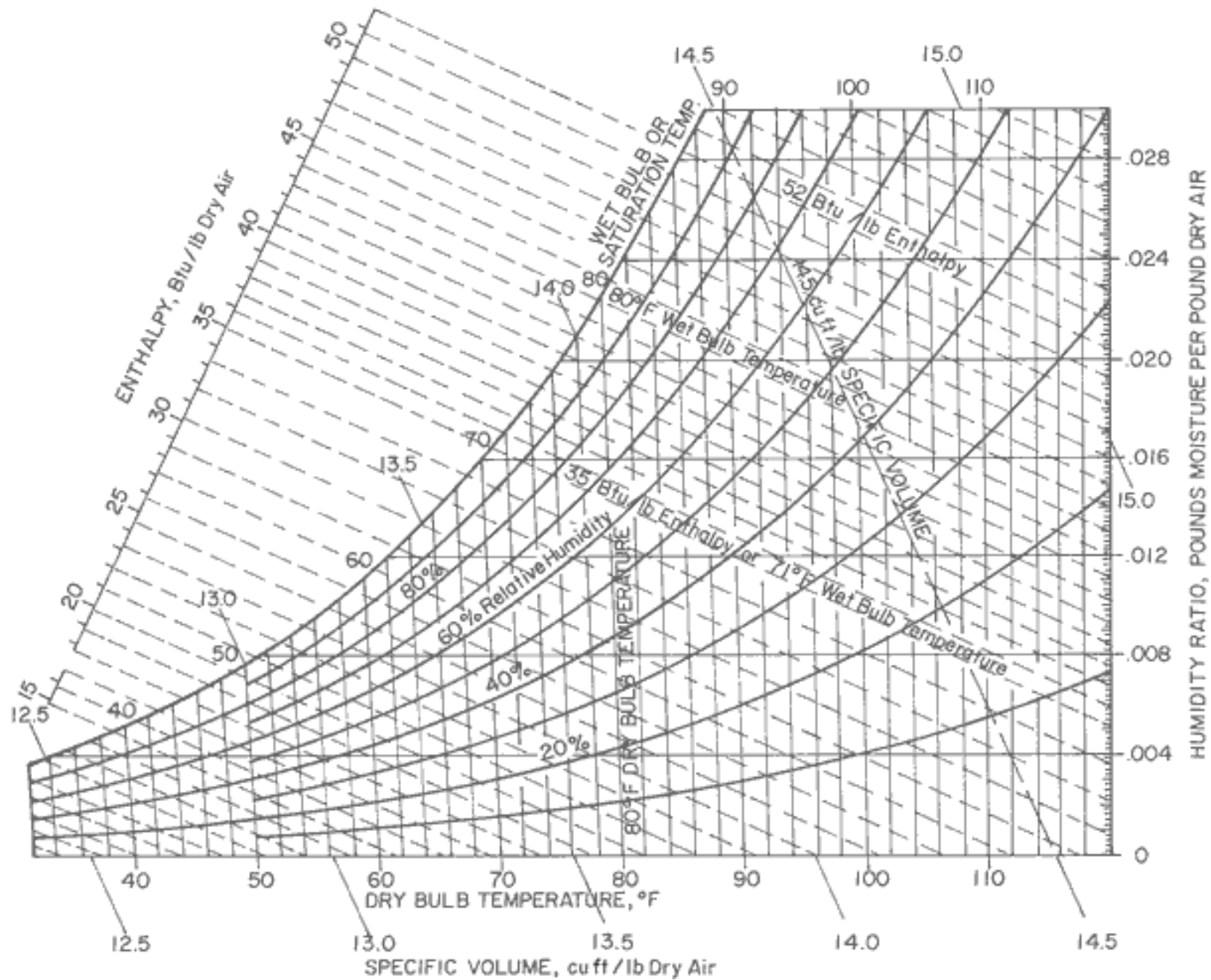


Figure 5.16 Wet-bulb temperature obtained with a sling psychrometer.

Psychrometric (humidity) chart

- The difference between $T_{wet\ bulb}$ and $T_{dry\ bulb}$ can be used to determine the relative saturation of the air
- This is done via the psychrometric chart where we will find wet bulb temperature lines to locate us on the chart.
- The wet bulb lines are also “*adiabatic saturation*” lines and we will return to this after we have seen energy balances.
- All the relevant properties of humid air are displayed on the psychrometric chart



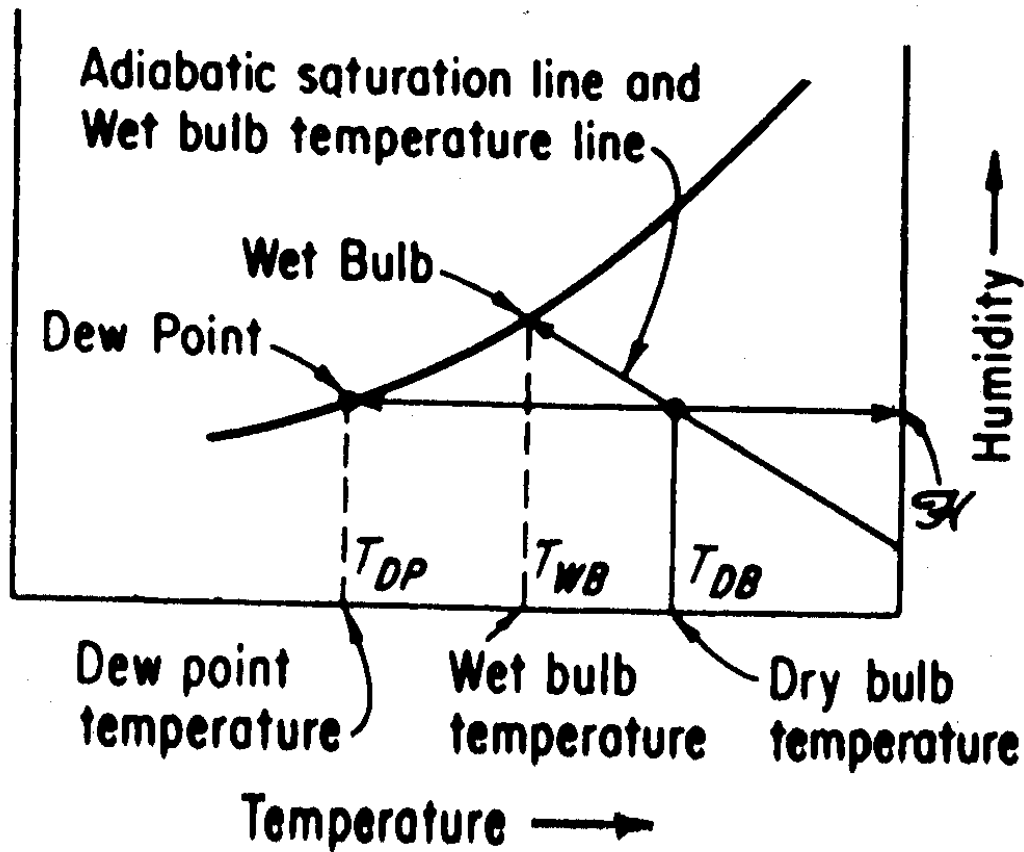


Figure 5.17 General layout of the humidity chart showing the location of the wet-bulb and dry-bulb temperatures, the dew point and dew point temperature, and the adiabatic saturation line and wet-bulb line.

The Phase Rule

- If we have pure H₂O liquid and vapour in a container, we can determine P, given T, and vice versa.
- To calculate all the properties of humid air, we need T, P, and RH
- How many properties (such as T, P) have to be specified to definitely fix all the remaining properties?

The Phase Rule

Applied to systems at equilibrium

$$F = C - P + 2$$

F : number of “degrees of freedom” (the number of intensive properties that can be specified independently)

C : number of components

P : number of phases

Phase Rule applications

- Vapour-liquid mixture of Water:
 $C=1, P = 2, F=1-2+2=1$ Specify T or P (or any other intensive property) and everything else is fixed
- Subcooled H₂O liquid:
 $C=1, P=1, F=1-1+2=2$ Both T and P (or any 2 intensive properties need to be specified.
- Superheated vapour: $F=2$

Phase Rule applications

- Humid air:
 $C=2$, $P=1$, $F=2-1+2=3$ Specify T , P , and RH (or any other intensive property) and everything else is fixed
- Dry air:
 $C=1$, $P=1$, $F=1-1+2=2$ Specifying T and P fixes everything else
- How can we apply this rule to dry air as a mixture of 2 components?