

CHAPTER-2: GAS–VAPOR MIXTURES

Introduction

- At temperatures **below the critical temperature**, the gas phase of a substance is frequently referred to as a **vapor**.
- The term **vapor implies** a gaseous state that is close to **the saturation region** of the substance, raising the possibility of condensation during a process.
- In Chapter 1, we discussed mixtures of gases that are usually **above their critical temperatures**.
- Therefore, we were not concerned about any of the gases condensing during a process.
 - That means, Not having to deal with two phases greatly simplified the analysis.
- When we are dealing with **a gas–vapor mixture**, however, the **vapor may condense out of the mixture** during a process, forming **a two-phase mixture**
 - This may complicate the analysis considerably.
- Therefore, a gas–vapor mixture needs to be treated differently from an ordinary gas mixture.
- **Several gas–vapor mixtures** are encountered in engineering.
 - In this chapter, we consider **the air–water-vapor mixture**, which is the most commonly encountered gas–vapor mixture in practice.

DRY AND ATMOSPHERIC AIR

Air is a mixture of nitrogen, oxygen, and small amounts of some other gases.

Air in the atmosphere normally contains some water vapor (or *moisture*) and is referred to as **atmospheric air**.

By contrast, air that contains **no water vapor** is called **dry air**.

It is often convenient to **treat air as a mixture** of water vapor and dry air since the composition of **dry air remains relatively constant**, but the amount of **water vapor changes** as a result of **condensation and evaporation** from oceans, lakes, rivers, showers, and even the human body.

Although the amount of water vapor in the air is small, it **plays a major role in human comfort**.

Therefore, it is an important consideration in air-conditioning applications.

DRY AND ATMOSPHERIC AIR

Air is a mixture of nitrogen, oxygen, and small amounts of some other gases.

Air in the atmosphere normally contains some water vapor (or *moisture*) and is referred to as **atmospheric air**.

By contrast, air that contains **no water vapor** is called **dry air**.

It is often convenient to **treat air as a mixture** of water vapor and dry air since the composition of **dry air remains relatively constant**, but the amount of **water vapor changes** as a result of **condensation and evaporation** from oceans, lakes, rivers, showers, and even the human body.

Although the amount of water vapor in the air is small, it **plays a major role in human comfort**.

Therefore, it is an important consideration in air-conditioning applications.

DRY AND ATMOSPHERIC AIR

The temperature of air in air-conditioning applications ranges from about -10 to about 50°C.

In this range, dry air can be treated as an ideal gas with constant C_p value of 1.005 kJ/kg · K [0.240 Btu/lbm · R] with negligible error (under 0.2 percent).

The enthalpy and enthalpy change of dry air can be determined from:

DRY AIR	
$T, ^\circ\text{C}$	$c_p, \text{kJ/kg} \cdot ^\circ\text{C}$
-10	1.0038
0	1.0041
10	1.0045
20	1.0049
30	1.0054
40	1.0059
50	1.0065

$$h_{\text{dry air}} = c_p T = (1.005 \text{ kJ/kg} \cdot ^\circ\text{C}) T \quad (\text{kJ/kg})$$

$$\Delta h_{\text{dry air}} = c_p \Delta T = (1.005 \text{ kJ/kg} \cdot ^\circ\text{C}) \Delta T \quad (\text{kJ/kg})$$

NOTICE:

T in °C

DRY AND ATMOSPHERIC AIR

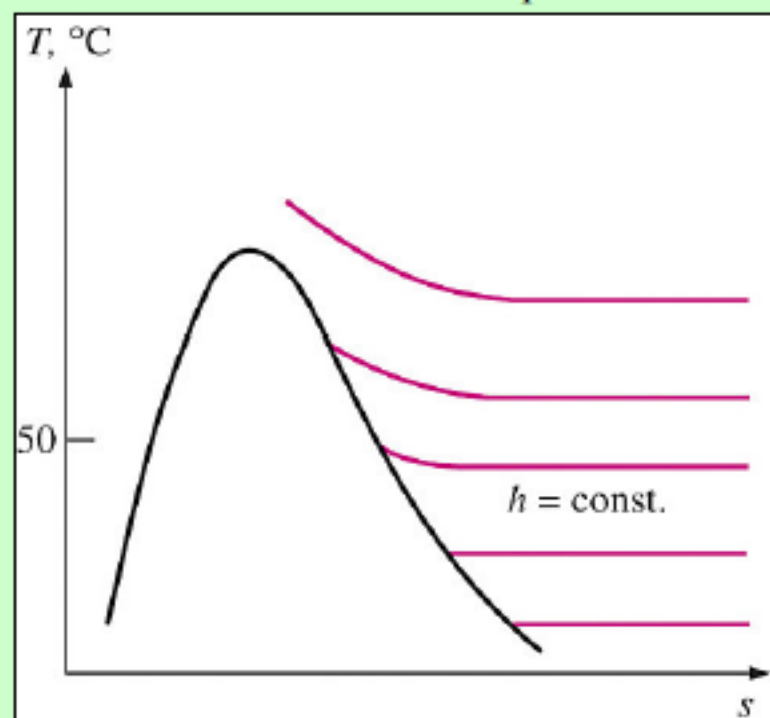
It certainly would be **very convenient** to also treat the water vapor in the air as an ideal gas and you would probably be willing to sacrifice some accuracy for such convenience.

At **50°C**, the **saturation pressure** of water is **12.3 kPa**.

At pressures below this value, water vapor **can be treated as an ideal gas** with negligible error (under 0.2 percent), even when it is a saturated vapor.

Since water vapor is an ideal gas, the enthalpy of water vapor is a **function of temperature only**, that is, $h = h(T)$.

This can also be observed from the T - s diagram of water given in Fig. A-9 where the **constant enthalpy lines** coincide with constant-temperature lines at temperatures **below 50°C**.



DRY AND ATMOSPHERIC AIR

Therefore, *the enthalpy of water vapor in air can be taken to be equal to the enthalpy of saturated vapor at the same temperature.*

WATER VAPOR			
T, °C	h_g , kJ/kg		Difference, kJ/kg
	Table A-4	Eq. 14-4	
-10	2482.1	2482.7	-0.6
0	2500.9	2500.9	0.0
10	2519.2	2519.1	0.1
20	2537.4	2537.3	0.1
30	2555.6	2555.5	0.1
40	2573.5	2573.7	-0.2
50	2591.3	2591.9	-0.6

That is,

$$h_v(T, \text{low } P) \cong h_g(T)$$

The enthalpy of water vapor at 0°C is 2501.3 kJ/kg. The average C_p value of water vapor in the temperature range -10 to 50°C can be taken to be **1.82 kJ/kg · °C**. Then the enthalpy of water vapor can be determined approximately from:

$$h_v = h_g(T) \cong 2501.3 + 1.82T \left(\frac{\text{kJ}}{\text{kg}_v} \right) \quad T \text{ in } ^\circ\text{C}$$

NOTICE:

T in °C

DRY AND ATMOSPHERIC AIR

Since water vapor **can be treated** as an ideal gas, therefore, water vapor in air **behaves as if it existed alone** and obeys the ideal-gas relation $Pv = RT$.

Then the atmospheric air **can be treated as an ideal-gas mixture** whose pressure is the sum of the partial pressure of dry air* P_a and that of water vapor P_v :

*Throughout this chapter, the subscript a denotes **dry air** and the subscript v denotes **water vapor**.

$$P = P_a + P_v$$

The partial pressure of water vapor P_v is usually referred to as the **vapor pressure**.

Dalton's law

It is the pressure water vapor would exert **if it existed alone** at the temperature and volume of atmospheric air.

dry air + water vapor = atmospheric air

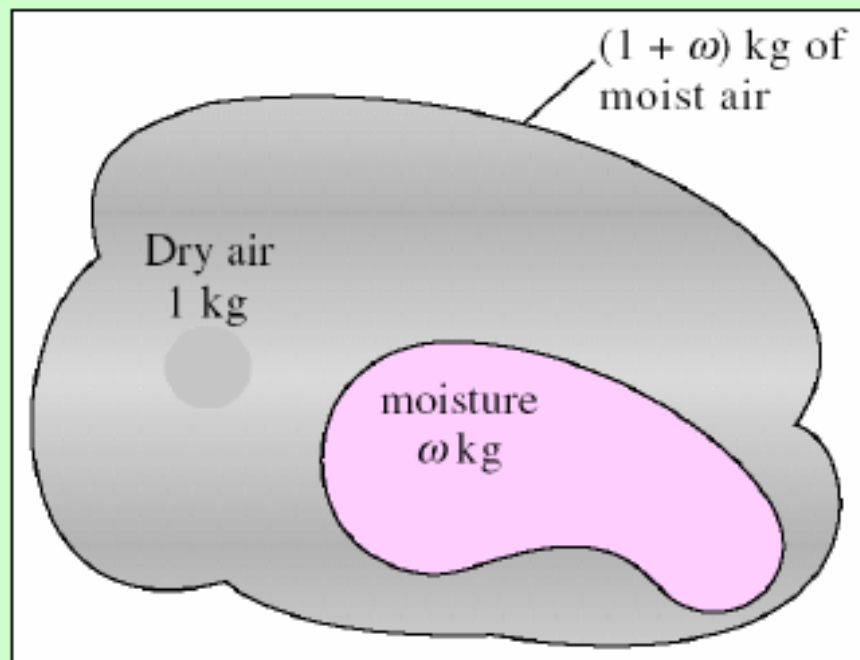
Gas A V, T P_A	+	Gas B V, T P_B	$\equiv$	Gas mixture A + B V, T $P_A + P_B$
------------------------------	---	------------------------------	----------	--

SPECIFIC AND RELATIVE HUMIDITY OF AIR

The amount of water vapor in the air can be specified in various ways.

Probably **the most logical** way is to specify directly the mass of water vapor present in a unit mass of dry air.

This is called **absolute** or **specific humidity** (also called *humidity ratio*) and is denoted by ω :



$$\omega = \frac{\text{Mass of water vapor in air}}{\text{Mass of dry air}} = \frac{m_v}{m_a}$$

The specific humidity can also be expressed as:

$$\omega = \frac{m_v}{m_a} = \frac{P_v V / (R_v T)}{P_a V / (R_a T)} = \frac{P_v / R_v}{P_a / R_a} = 0.622 \frac{P_v}{P_a}$$

or

$$\omega = \frac{0.622 P_v}{P - P_v}$$

where P is the total pressure.

SPECIFIC AND RELATIVE HUMIDITY OF AIR

Consider 1 kg of dry air.

By definition, dry air **contains no** water vapor, and thus its specific humidity is **zero**.

Now let us **add some water vapor** to this dry air.

The specific humidity will increase.

As more vapor or moisture is added, the specific humidity will keep increasing until the air **can hold no more moisture**.

At this point, the air is said to be saturated with moisture, and it is called **saturated air**.

Any moisture introduced into saturated air **will condense**.

SPECIFIC AND RELATIVE HUMIDITY OF AIR

The amount of water vapor **in saturated air** at a specified temperature and pressure can be determined from ω **by replacing** P_v by P_g , the saturation pressure of water at that temperature.

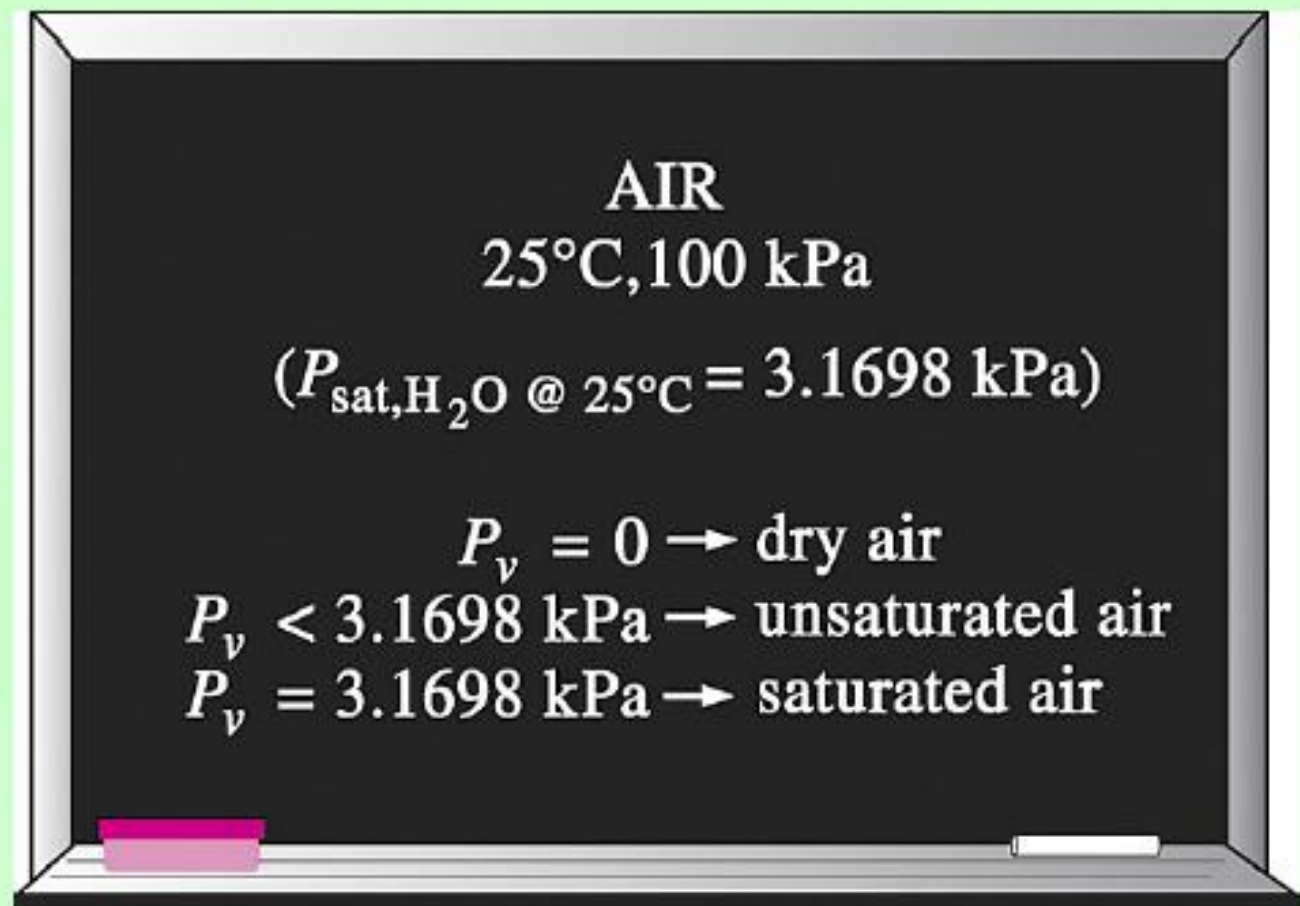
$$\omega = \frac{0.622 P_v}{P - P_v}$$

Becomes

$$\omega = \frac{0.622 P_g}{P - P_g}$$

Where

$$P_g = P_{sat @ T}$$

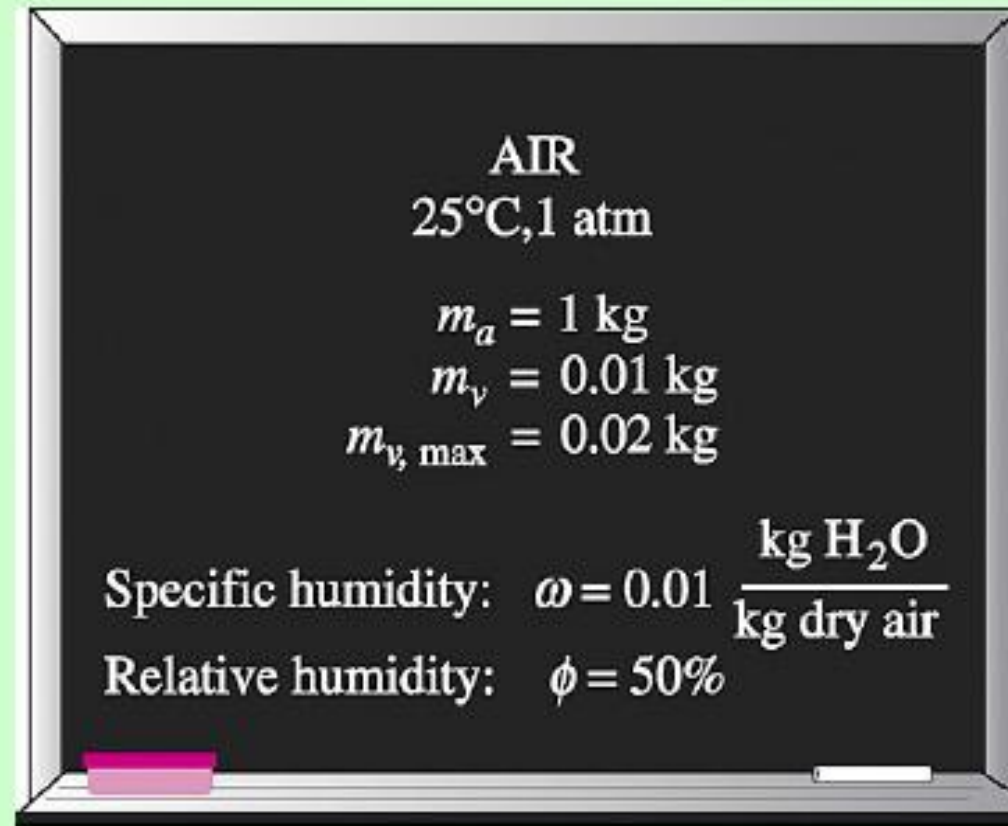


SPECIFIC AND RELATIVE HUMIDITY OF AIR

The amount of moisture in the air has a definite effect on how comfortable we feel in an environment.

However, the comfort level depends more on the amount of moisture the air holds (m_v) relative to the maximum amount of moisture the air can hold at the same temperature (m_g).

The ratio of these two quantities is called the relative humidity ϕ



AIR
25°C, 1 atm

$m_a = 1 \text{ kg}$
 $m_v = 0.01 \text{ kg}$
 $m_{v, \max} = 0.02 \text{ kg}$

Specific humidity: $\omega = 0.01 \frac{\text{kg H}_2\text{O}}{\text{kg dry air}}$
Relative humidity: $\phi = 50\%$

$$\phi = \frac{\text{Mass of vapor in air}}{\text{Mass of saturated air}} = \frac{m_v}{m_g}$$

$$\phi = \frac{m_v}{m_g} = \frac{P_v V / (R_v T)}{P_g V / (R_v T)} = \frac{P_v}{P_g}$$

SPECIFIC AND RELATIVE HUMIDITY OF AIR

Combining ω and ϕ , we can also express the relative humidity as:

$$\omega = \frac{0.622 P_v}{P - P_v}$$

$$\phi = \frac{P_v}{P_g}$$

$$\omega = \frac{0.622 \phi P_g}{P - \phi P_g} \quad \text{and} \quad \phi = \frac{\omega P}{(0.622 + \omega) P_g}$$

The relative humidity ranges from 0 for dry air to 1 for saturated air.

Note that the amount of moisture that air can hold depends on its temperature.

Therefore, the relative humidity of air ϕ changes with temperature even when its specific humidity remains constant.

SPECIFIC AND RELATIVE HUMIDITY OF AIR

Atmospheric air is a mixture of dry air and water vapor, and thus the **enthalpy of air is expressed** in terms of the enthalpies of the dry air and the water vapor.

The **total enthalpy** (an extensive property) of atmospheric air is the sum of the enthalpies of dry air and the water vapor:

$$H = H_a + H_v = m_a h_a + m_v h_v$$

In most practical applications, **the amount of dry air** (m_a) in the air–water–vapor mixture **remains constant**, but the amount of water vapor changes.

Therefore, the enthalpy of atmospheric air **is expressed *per unit mass of dry air*** instead of per unit mass of the air–water vapor mixture.

Dividing by m_a gives:

$$h = \frac{H}{m_a} = h_a + \frac{m_v}{m_a} h_v = h_a + \omega h_v$$

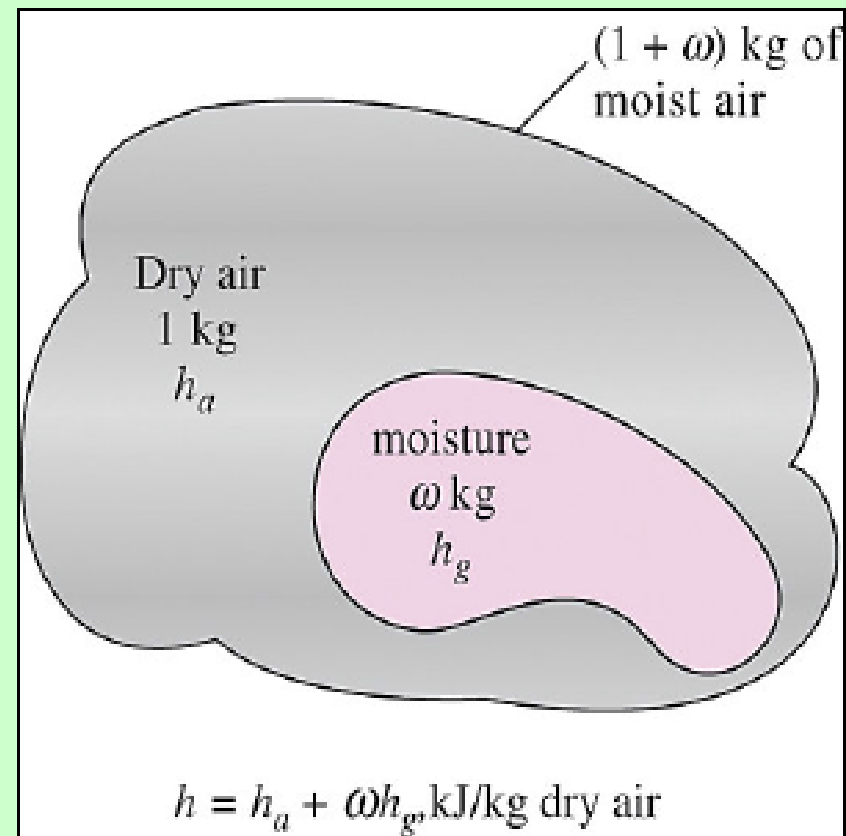
SPECIFIC AND RELATIVE HUMIDITY OF AIR

$$h = \frac{H}{m_a} = h_a + \frac{m_v}{m_a} h_v = h_a + \omega h_v$$

since $h_v = h_g$ (see this Figure).

$$h = h_a + \omega h_g$$

Also note that the **ordinary temperature** of atmospheric air is frequently referred to as the **dry-bulb temperature** to differentiate it from other forms of temperatures that shall be discussed.



The Amount of Water Vapor in Room Air

A 5-m X 5-m X 3-m room shown contains air at 25°C and 100 kPa at a relative humidity of 75 percent. Determine:

- (a) the partial pressure of dry air,
- (b) the specific humidity,
- (c) the enthalpy per unit mass of the dry air, and
- (d) the masses of the dry air and water vapor in the room.

$$P_a = P - P_v$$

$$P_v = \phi P_g = \phi P_{\text{sat}} @ 25^\circ\text{C}$$

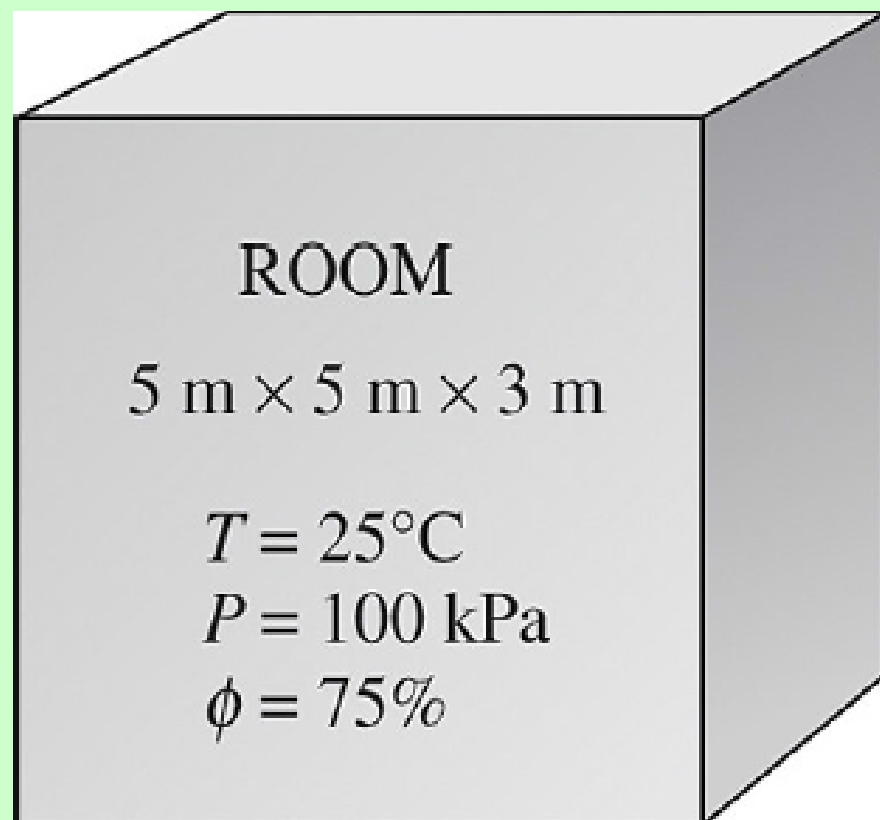
$$\omega = \frac{0.622 P_v}{P - P_v}$$

$$h = h_a + \omega h_v \cong c_p T + \omega h_g$$

$$V_a = V_v = V_{\text{room}}$$

$$m_a = \frac{P_a V_a}{R_a T}$$

$$m_v = \frac{P_v V_v}{R_v T}$$



DEW-POINT TEMPERATURE

The **dew-point temperature** T_{dp} is defined as *the temperature at which condensation begins when the air is cooled at constant pressure*.

In other words, T_{dp} is the **saturation temperature** of water corresponding to the vapor pressure:

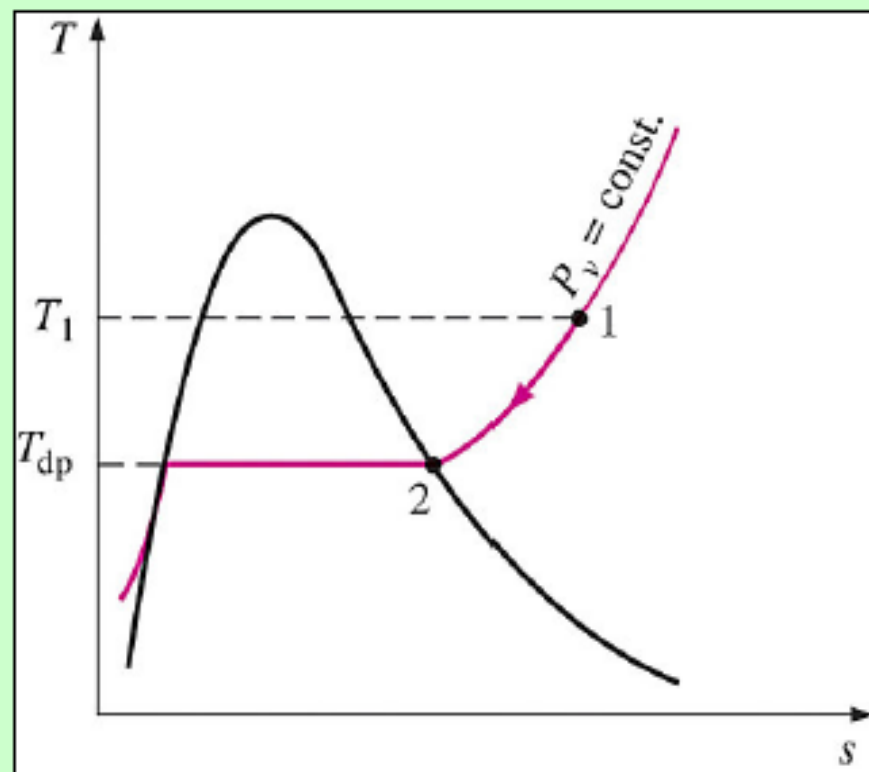
$$T_{dp} = T_{sat} @ P_v$$

If the temperature drops any further from (2), some vapor condenses out.

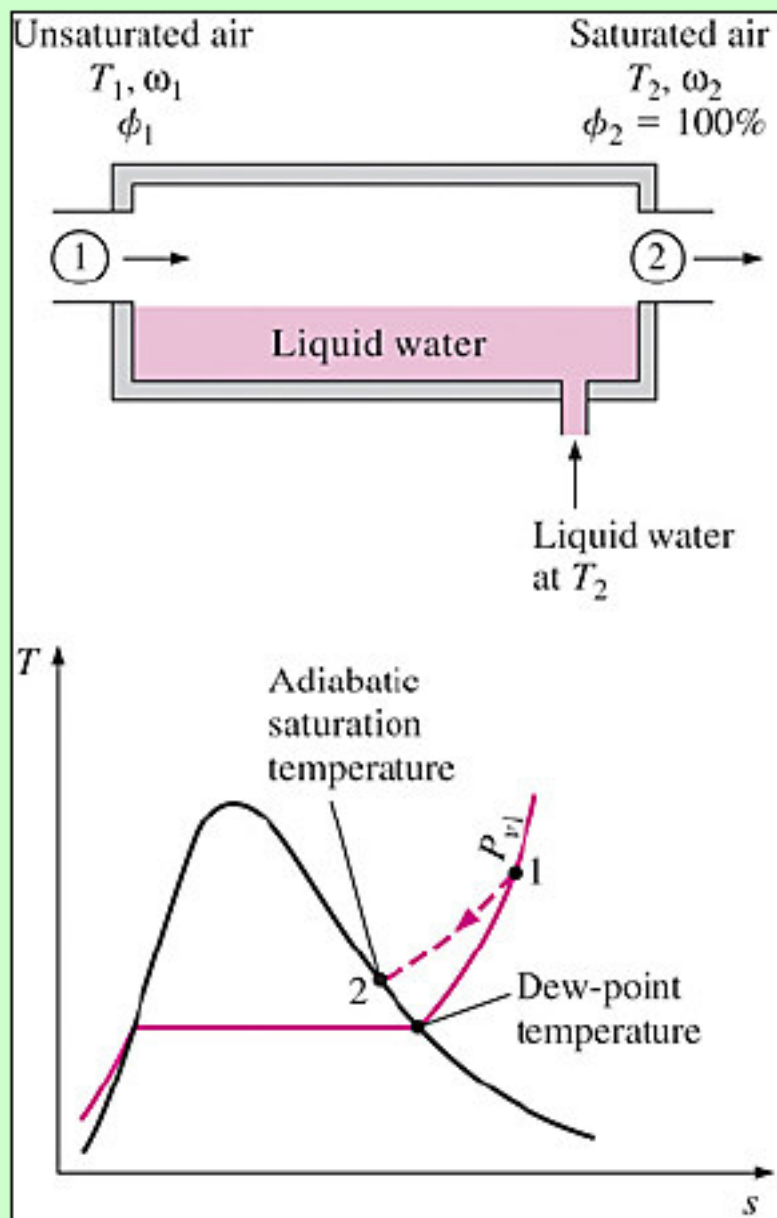
As a result, the amount of **vapor in the air decreases**, which results in a **decrease in P_v** .

The air remains saturated during the condensation process and thus follows a path of **100 percent relative humidity** (the saturated vapor line).

The ordinary temperature and the dew-point temperature of saturated air are **identical**.



ADIABATIC SATURATION AND WET-BULB TEMPERATURES



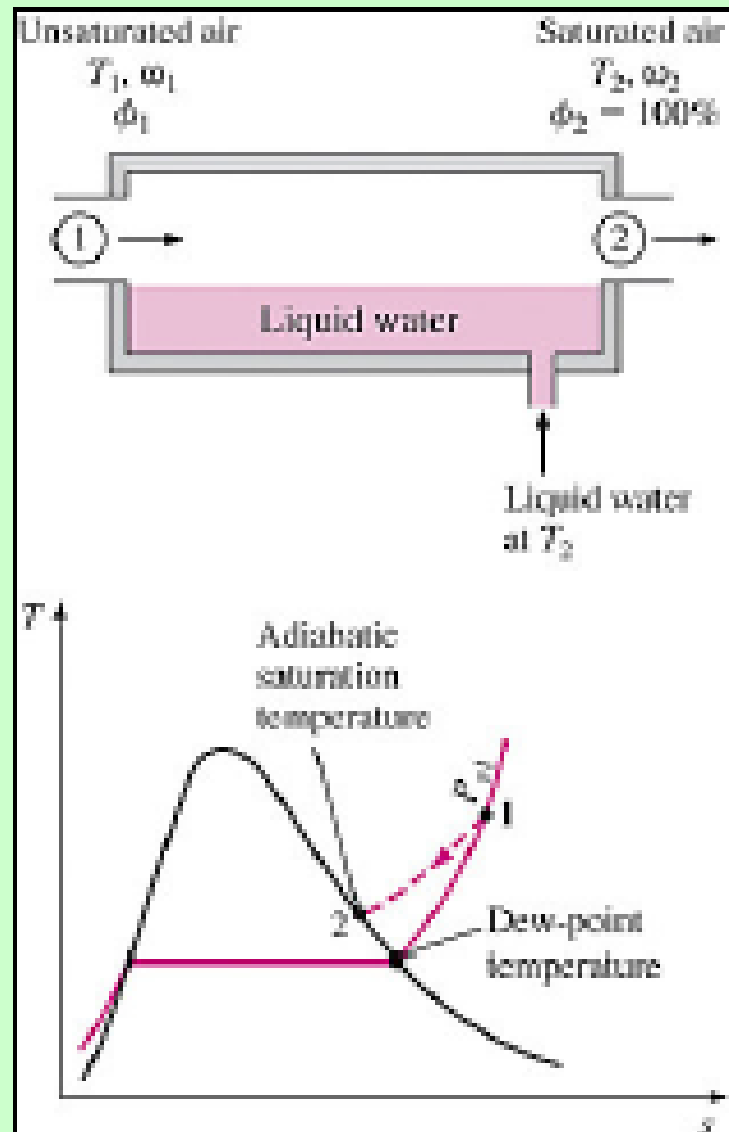
Relative humidity and specific humidity are frequently used in engineering and atmospheric sciences, and it is desirable to relate them to **easily measurable quantities** such as temperature and pressure.

One way of determining the relative humidity is **to determine the dew-point** temperature of air.

This approach is **simple**, but **not** quite practical.

Another way of determining the absolute or relative humidity is related to an **adiabatic saturation process**, shown schematically and on a $T-s$ diagram.

ADIABATIC SATURATION AND WET-BULB TEMPERATURES



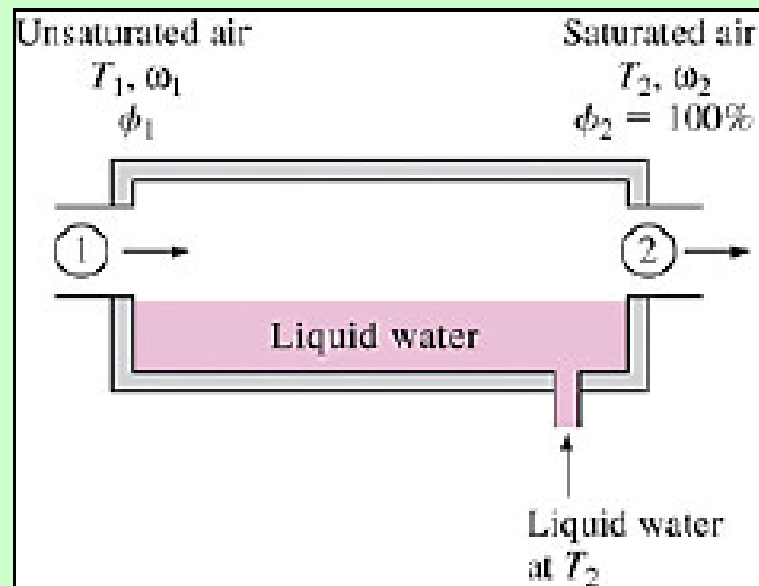
The system consists of a **long insulated channel** that contains a pool of water.

A steady stream of unsaturated air that has a specific humidity of ω_1 (**unknown**) and a temperature of T_1 is passed through this channel.

As the air flows over the water, some water evaporates and mixes with the airstream. The **moisture content of air increases** during this process, and its temperature decreases.

If the channel is long enough, the airstream exits as saturated air ($\phi = 100$ percent) at temperature T_2 , which is called the **adiabatic saturation temperature**.

ADIABATIC SATURATION AND WET-BULB TEMPERATURES



Mass balance:

$$\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$$

OR

$$\dot{m}_{w_1} + \dot{m}_f = \dot{m}_{w_2}$$

$$\dot{m}_a \omega_1 + \dot{m}_f = \dot{m}_a \omega_2$$

Thus,

$$\dot{m}_f = \dot{m}_a (\omega_2 - \omega_1)$$

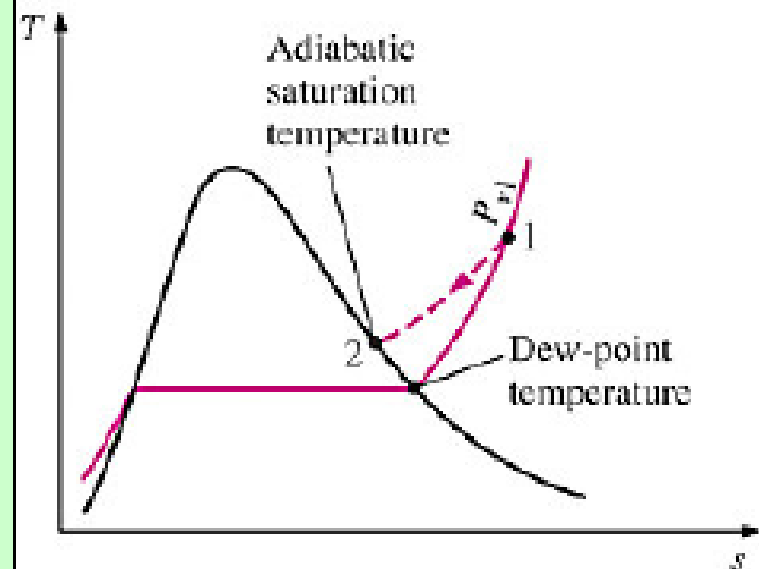
Energy balance:

$$\dot{E}_{in} = \dot{E}_{out}$$

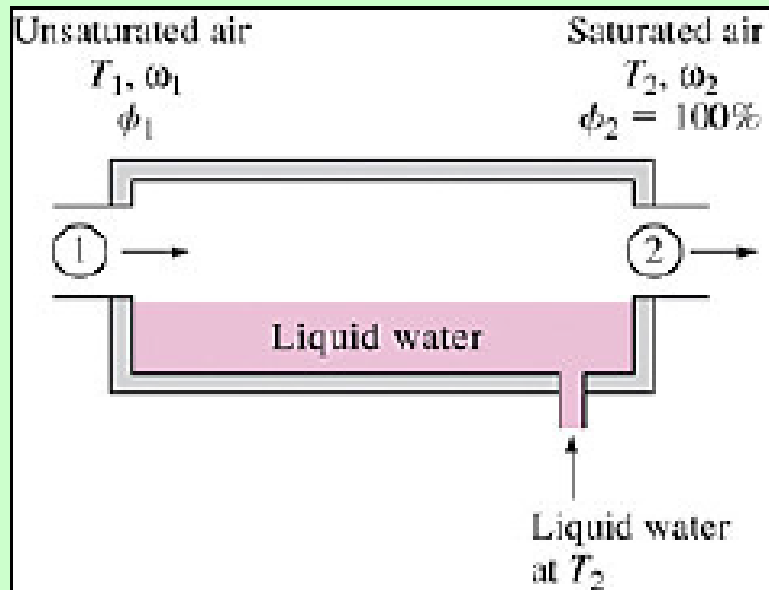
$$\dot{m}_a h_1 + \dot{m}_f h_{f_2} = \dot{m}_a h_2$$

$$\dot{m}_a h_1 + \dot{m}_a (\omega_2 - \omega_1) h_{f_2} = \dot{m}_a h_2$$

$$(c_p T_1 + \omega_1 h_{g_1}) + (\omega_2 - \omega_1) h_{f_2} = (c_p T_2 + \omega_2 h_{g_2})$$



ADIABATIC SATURATION AND WET-BULB TEMPERATURES



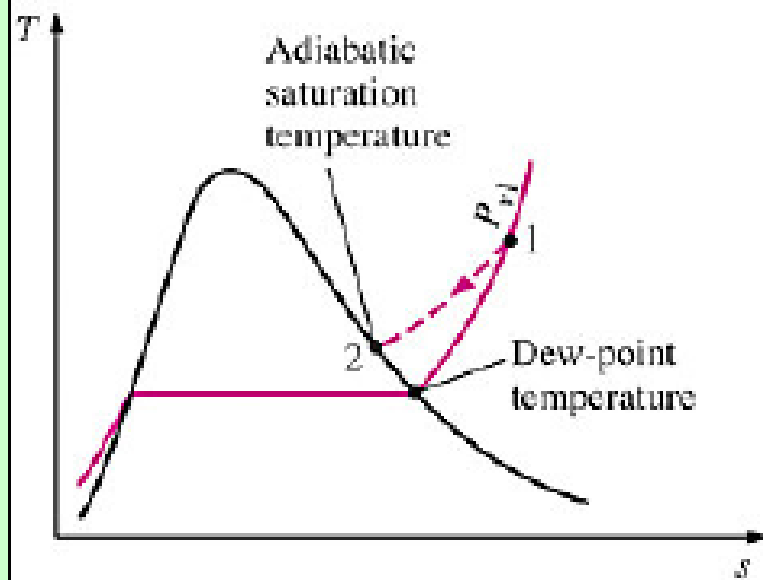
Applying the conservation of mass and conservation of energy principal for this adiabatic saturator reduces to the following:

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

where

$$\omega_2 = \frac{0.622 P_{g2}}{P_2 - P_{g2}}$$

since $\phi_2 = 100\%$



Thus we conclude that the specific humidity (and relative humidity) of air can be determined by measuring the pressure and temperature of air at the inlet and the exit of an adiabatic saturator.

ADIABATIC SATURATION AND WET-BULB TEMPERATURES

The adiabatic saturation process requires a long channel or a spray mechanism to achieve saturation conditions at the exit.

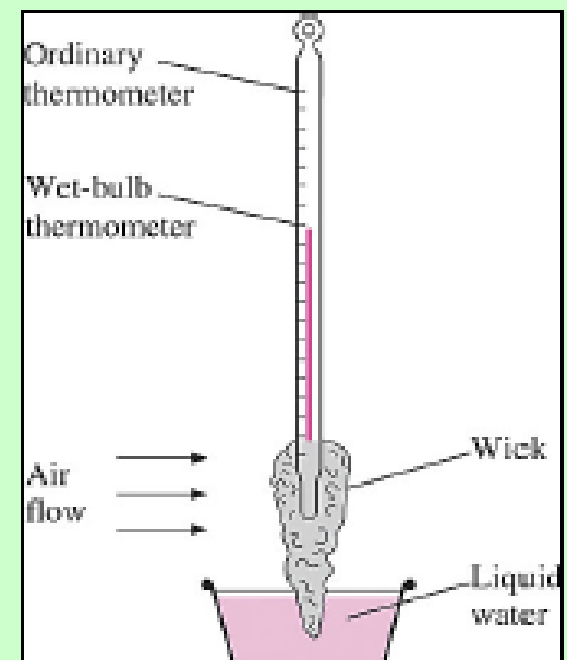
A more practical approach is to use a thermometer whose bulb is covered with a cotton wick saturated with water and to blow air over the wick, as shown.

The temperature measured in this manner is called the **wet-bulb temperature** T_{wb} , and it is commonly used in air-conditioning applications.

The basic principle involved is similar to that in adiabatic saturation process.

Therefore, the wet-bulb temperature T_{wb} can be used in place of T_2 to determine the specific humidity of air.

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$



ADIABATIC SATURATION PROCESS

Relative humidity and specific humidity are frequently used in engineering and atmospheric sciences, and it is desirable to relate them to easily measurable quantities such as temperature and pressure.

- ✓ One way of determining the relative humidity is to determine the dew-point temperature of air, as discussed in the last section. Knowing the dew-point temperature, we can determine the vapor pressure P_v and thus the relative humidity. This approach is simple, but not quite practical.

Another way of determining the absolute or relative humidity is related to an adiabatic saturation process, shown schematically in Fig. below.

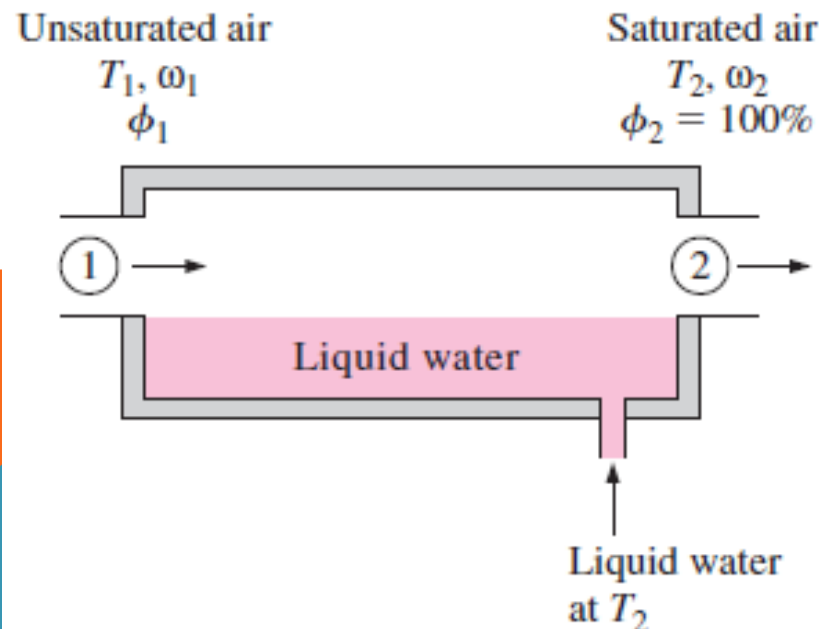


Figure: The adiabatic saturation process.

CONT...

- The system consists of a **long insulated channel** that contains a pool of water. A steady stream of **unsaturated air** that has a specific humidity of ω_1 (unknown) and a temperature of T_1 is passed through this channel. As the air flows over the water, some water evaporates and mixes with the airstream. The moisture content of air increases during this process, and its temperature decreases, since part of the latent heat of vaporization of the water that evaporates comes from the air. If the channel is long enough, the airstream exits as saturated air ($\phi = 100$ percent) at temperature T_2 , which is called the **adiabatic saturation temperature**.
- If makeup water is supplied to the channel at the rate of evaporation at temperature T_2 , the adiabatic saturation process described above can be analyzed as a steady-flow process. The process involves **no heat or work interactions**, and neglecting the **kinetic and potential energy changes**, the conservation of mass and conservation of energy relations for this two inlet, one-exit steady-flow system reduces to the following:

Mass balance:

$$\dot{m}_{a_1} = \dot{m}_{a_2} = \dot{m}_a$$

(The mass flow rate of dry air remains constant)

$$\dot{m}_{w_1} + \dot{m}_f = \dot{m}_{w_2}$$

.....***

(The mass flow rate of vapor in the air increases by an amount equal to the rate of evaporation $\dot{m}_f$)

Where, $\dot{m}_{w_1}$ is mass flow rate of water(vapor) at point 1, and $\dot{m}_{w_2}$ is mass flow rate of water(vapor) at point 2

CONT...

or $\dot{m}_a \omega_1 + \dot{m}_f = \dot{m}_a \omega_2$

Since, we know that

at point 1, $\omega_1 = \frac{m_{v1}}{m_{a1}} = \frac{m_{w1}}{m_{a1}},$

From this we obtain $m_{w1} = \omega_1 m_{a1},$

Similarly at point 2, $m_{w2} = \omega_2 m_{a2},$

However, since the mass of dry air remains constant, i. e.

$$m_{a1} = m_{a2} = m_a$$

Thus $m_{w1} = \omega_1 m_a$ and $m_{w2} = \omega_2 m_a$

Thus dividing both side by time we get

$$\dot{m}_{w1} = \omega_1 \dot{m}_{a1} = \omega_1 \dot{m}_a, \text{ and}$$

$$\dot{m}_{w2} = \omega_2 \dot{m}_{a2} = \omega_2 \dot{m}_a$$

Substituting this in to equation***

We get

$$\dot{m}_a \omega_1 + \dot{m}_f = \dot{m}_a \omega_2$$

CONT...

Thus, $\dot{m}_f = \dot{m}_a(\omega_2 - \omega_1)$

Energy balance: $\dot{E}_{\text{in}} = \dot{E}_{\text{out}}$ (since $\dot{Q} = 0$ and $\dot{W} = 0$)

$$\dot{m}_a h_1 + \dot{m}_f h_{f_2} = \dot{m}_a h_2$$

$$\dot{m}_a h_1 + \dot{m}_a(\omega_2 - \omega_1)h_{f_2} = \dot{m}_a h_2$$

Dividing by $\dot{m}_a$ gives $h_1 + (\omega_2 - \omega_1)h_{f_2} = h_2$

Since, $h = h_a + \omega h_g$ (kJ/kg dry air)

$$h_1 = C_p T_1 + \omega_1 h_{v1} \text{ and } h_2 = C_p T_2 + \omega_2 h_{v2}$$

and we know that $h_{v1} = h_{g1}$ and $h_{v2} = h_{g2}$ up on substitution we get

$$(c_p T_1 + \omega_1 h_{g1}) + (\omega_2 - \omega_1)h_{f_2} = (c_p T_2 + \omega_2 h_{g2})$$

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f_2}} \dots\dots\dots (a)$$

CONT...

Recalling that

$$\omega = \frac{0.622\phi P_g}{P - \phi P_g}$$

Thus, at state 2 or exit, since $\phi_2 = 100\%$ ω_2 would be

$$\omega_2 = \frac{0.622P_{g2}}{P_2 - P_{g2}} \dots\dots\dots (b)$$

Thus we conclude that the **specific humidity** (and **relative humidity**) of air can be determined from Eqs. (a) and (b) above by measuring the **pressure** and **temperature** of air at the inlet and the exit of an adiabatic saturator.

- If the air entering the channel is already **saturated**, then the adiabatic saturation temperature T_2 will be identical to the inlet temperature T_1 , in which case Eq. (a) yields $\omega_1 = \omega_2$. In general, the adiabatic saturation temperature is between the **inlet** and dew-point temperatures.

Dry and wet-bulb temperature

- The adiabatic saturation process discussed above provides a means of determining the absolute or relative humidity of air, but **it requires a long channel or a spray** mechanism to achieve saturation conditions at the exit. A more practical approach is to use a thermometer whose bulb is covered with a cotton wick saturated with water and to blow air over the wick, as shown in Fig. below. The temperature measured in this manner is called the **wet-bulb temperature T_{wb}** , and it is commonly used in air-conditioning applications.
- The dry bulb thermometer is used simply to measure the temperature of the air
- The wet bulb temperature is lower than the dry bulb temperature
- Advances in electronics made it possible to measure humidity directly in a fast and reliable way. It appears that sling psychrometers and wet-wicked thermometers are about to become things of the past. Today, hand-held electronic humidity measurement devices based on the **capacitance change in a thin polymer film** as it absorbs water vapor are capable of sensing and digitally displaying the relative humidity within 1 percent accuracy in a matter of seconds. In general, the adiabatic saturation temperature and the wet-bulb temperature are not the same. However, for air–water vapor mixtures at atmospheric pressure, the wet-bulb temperature happens to be approximately equal to the adiabatic saturation temperature. Therefore, the wet-bulb temperature T_{wb} can be used in Eq. (a) above in place of T_2 to determine the specific humidity of air.

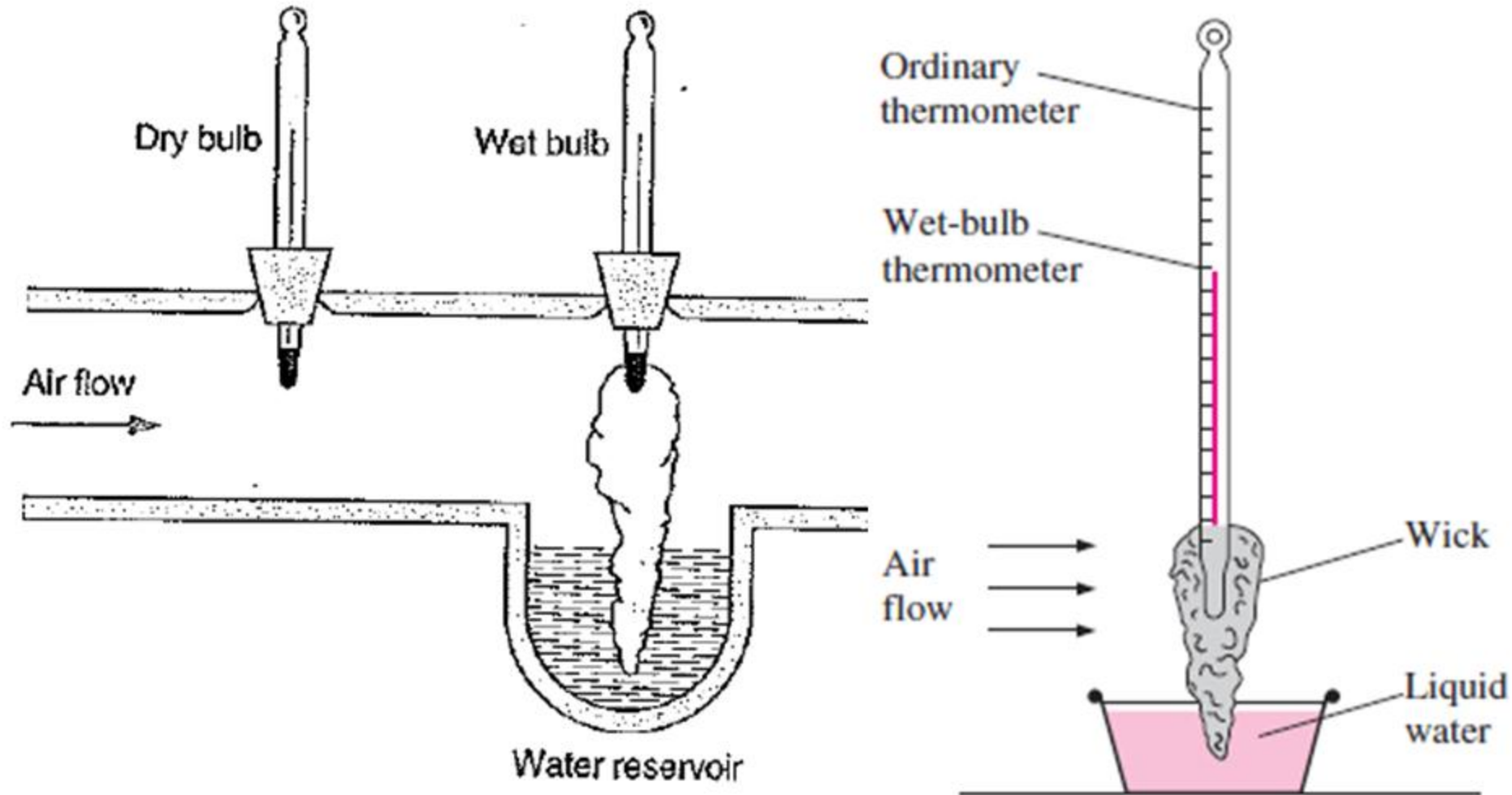


FIGURE: A simple arrangement to measure the wet-and dry-bulb temperature.

EXAMPLE

The dry- and the wet-bulb temperatures of atmospheric air at 1 atm (101.325 kPa) pressure are measured with a sling psychrometer and determined to be 25 and 15 degree centigrade , respectively. Determine (a) *the specific humidity*, (b) *the relative humidity*,

and (c) *the enthalpy of the air*.

- **Solution Dry- and wet-bulb temperatures are given.**
The specific humidity, relative humidity, and enthalpy are to be determined.

Properties *The saturation pressure of water is 1.7057 kPa at 15 degree centigrade and 3.1698 kPa at 25 degree centigrade (Table A-4).* The constant-pressure specific heat of air at room temperature is c_p 1.005 kJ/kg .K (Table A-2a)

$$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

where T_2 is the wet-bulb temperature and ω_2 is

$$\begin{aligned}\omega_2 &= \frac{0.622 P_{g2}}{P_2 - P_{g2}} = \frac{(0.622)(1.7057 \text{ kPa})}{(101.325 - 1.7057) \text{ kPa}} \\ &= 0.01065 \text{ kg H}_2\text{O/kg dry air}\end{aligned}$$

Thus,

$$\begin{aligned}\omega_1 &= \frac{(1.005 \text{ kJ/kg} \cdot ^\circ\text{C})[(15 - 25)^\circ\text{C}] + (0.01065)(2465.4 \text{ kJ/kg})}{(2546.5 - 62.982) \text{ kJ/kg}} \\ &= \mathbf{0.00653 \text{ kg H}_2\text{O/kg dry air}}\end{aligned}$$

Cont.

(b) The relative humidity ϕ_1

$$\phi_1 = \frac{\omega_1 P_2}{(0.622 + \omega_1) P_{g1}} = \frac{(0.00653)(101.325 \text{ kPa})}{(0.622 + 0.00653)(3.1698 \text{ kPa})} = \mathbf{0.332 \text{ or } 33.2\%}$$

(c) The enthalpy of air per unit mass of dry air is determined from Eq.

$$\begin{aligned} h_1 &= h_{a1} + \omega_1 h_{v1} \cong c_p T_1 + \omega_1 h_{g1} \\ &= (1.005 \text{ kJ/kg} \cdot ^\circ\text{C})(25^\circ\text{C}) + (0.00653)(2546.5 \text{ kJ/kg}) \\ &= \mathbf{41.8 \text{ kJ/kg dry air}} \end{aligned}$$

The psychrometric chart

- Properties of air-water-vapor mixtures are given in graphical form on psychrometric charts. These are available in a number of different forms, and only the main features are considered here. It should be recalled that three independent properties such as pressure, temperature and mixture composition will describe the state of this binary mixture.
- Thus, the state of the atmospheric air for example at a specified pressure is completely specified by two independent intensive properties.
- A **psychrometric chart for a pressure of 1 atm** (101.325 kPa or 14.696 psia) is given in **Fig. A–31** in SI units and in Fig. A–31E in English units.
- Psychrometric charts at other pressures (for use at considerably higher elevations than sea level) are also available.
- A simplified version of the chart is shown in fig. below

CONT...

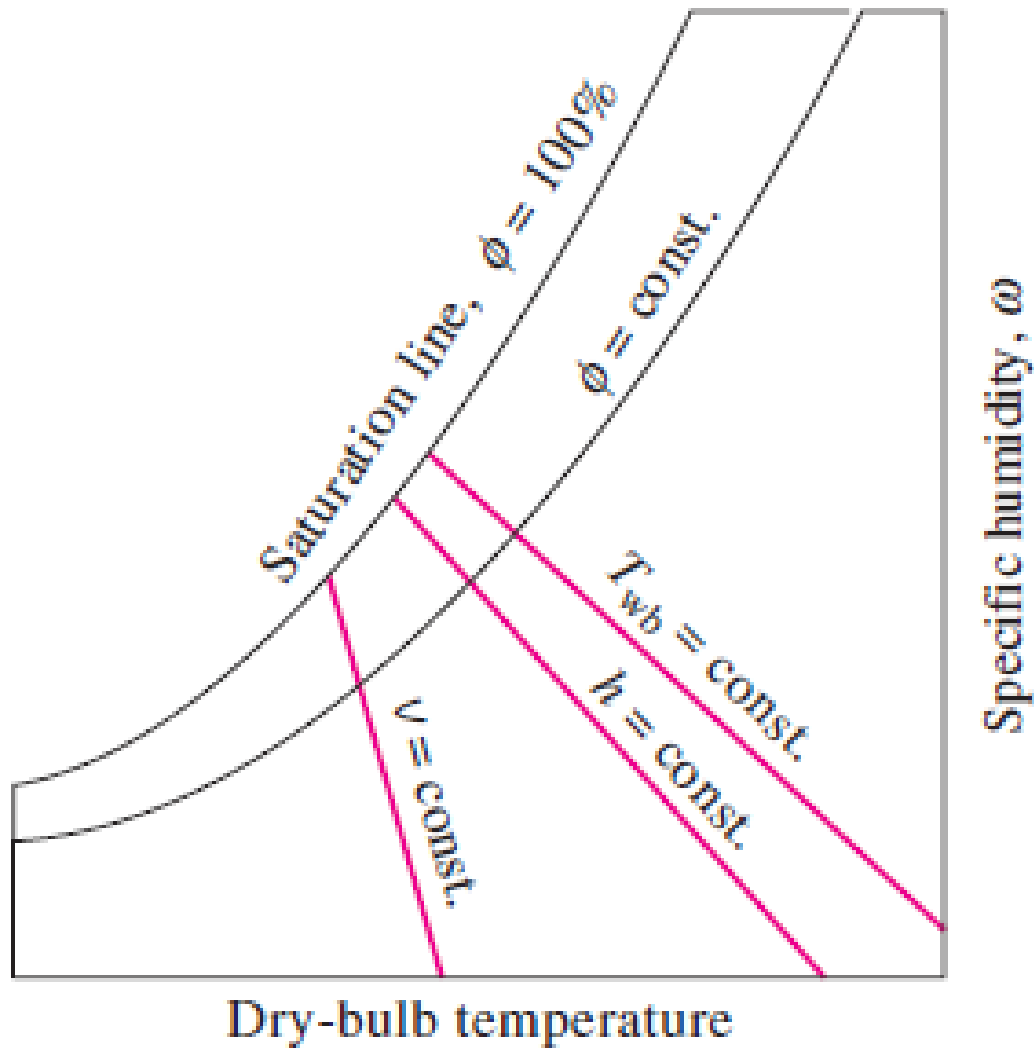


Figure : Schematic for a psychrometric chart.

CONT...

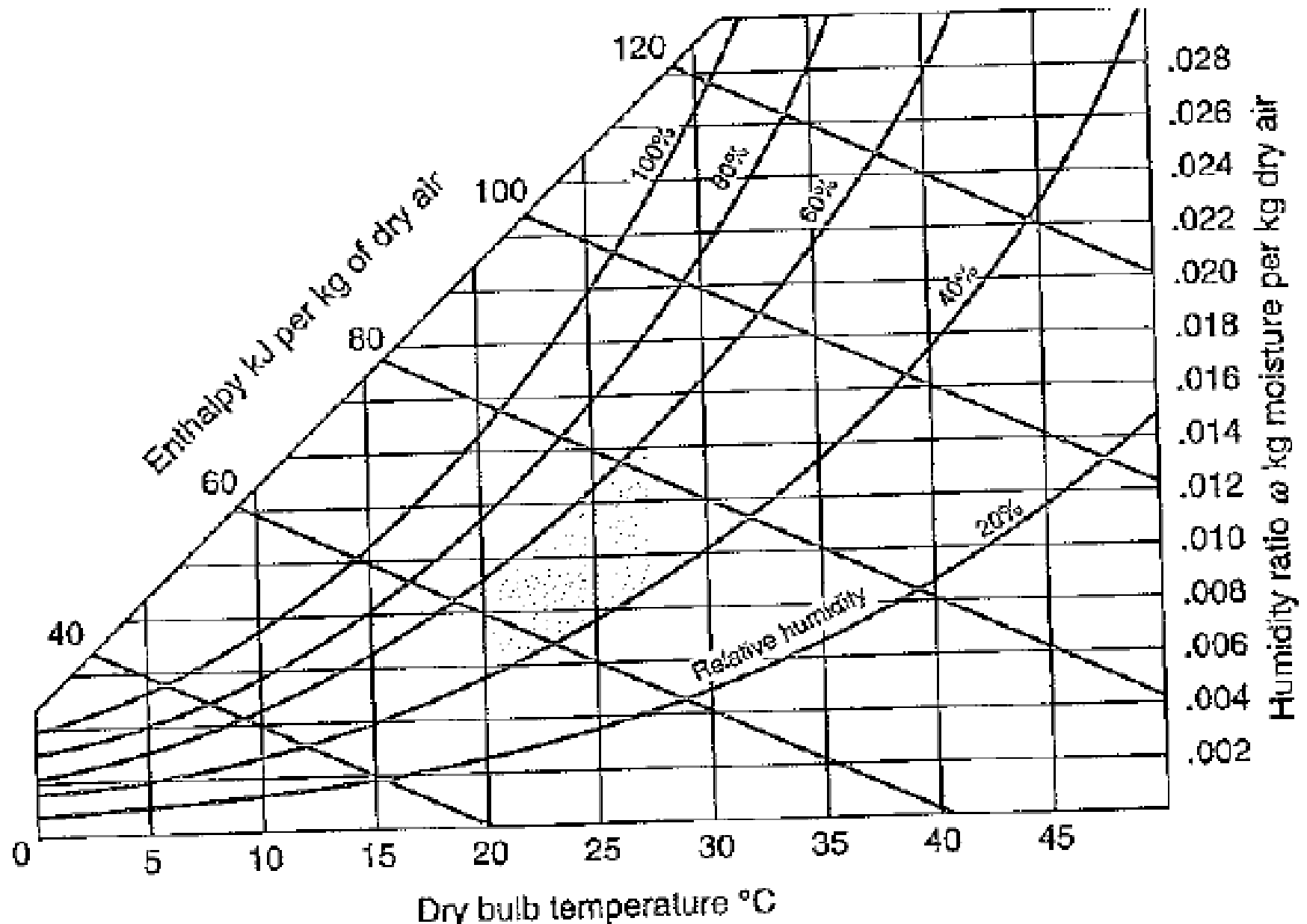


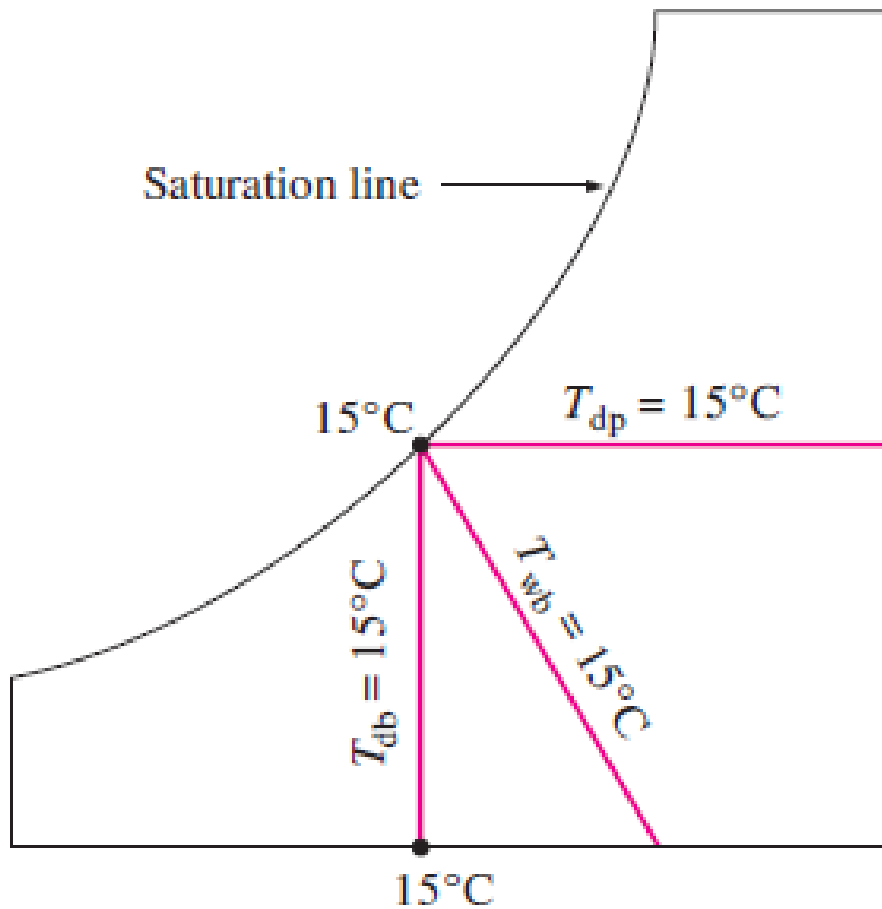
Figure : Schematic for a psychrometric chart.

CONT...

- The basic features of the psychrometric chart is a plot of humidity ratio, ω on the vertical axis (ordinate) as a function of the dry bulb temperature, T_{db} on the horizontal axis (i.e. abscissa), with relative humidity ϕ , wet bulb temperature T_{wb} , and mixture enthalpy per mass of dry air as parameters. (Some charts also show the vapor pressure on the vertical axis since at a fixed total pressure P there is a one-to-one correspondence between the specific humidity ω and the vapor pressure P_v)
- As shown in fig. above, on the left end of the chart, there is a curve (called the **saturation line**) instead of a straight line. All the saturated air states are located on this curve. Therefore, it is also the curve of **100 percent relative humidity**. Other constant relative-humidity curves have the same general shape.
- Lines of **constant wet-bulb temperature** have a downhill appearance to the **right**. Lines of constant specific volume (in m^3/kg dry air) look similar, except they are **steeper**. Lines of constant enthalpy (in kJ/kg dry air) lie very nearly parallel to the lines of constant wet-bulb temperature. Therefore, the **constant wet-bulb-temperature lines** are used as constant-enthalpy lines in some charts.

CONT...

For saturated air, the **dry-bulb**, **wet-bulb**, and **dew-point temperatures** are **identical** as shown in fig. below.



- Therefore, the dew-point temperature of atmospheric air at any point on the chart can be determined by **drawing a horizontal line** (a line of ω constant or P_v constant) from the point to the saturated curve. The temperature value at the intersection point is the **dew-point temperature, T_{dp}** .

Figure: For saturated air, the dry-bulb, wet-bulb, and dew-point temperatures are identical.

CONT...

EXAMPLE: The Use of the Psychrometric Chart to answer the following questions

- Consider a room that contains air at 1 atm, 35°C, and 40 percent relative humidity. Using the psychrometric chart, determine (a) the specific humidity, (b) the enthalpy, (c) the wet-bulb temperature, (d) the dew-point temperature, and (e) the specific volume of the air.

Solutions

Analysis: At a given total pressure, the state of atmospheric air is completely specified by **two independent properties** such as the dry-bulb temperature and the relative humidity. Other properties are determined by directly reading their values at the specified state.

CONT...

(a) The specific humidity is determined by drawing a horizontal line from the specified state to the right until it intersects with the ω axis, as shown in Fig. At the intersection point we read

$$\omega = 0.0142 \text{ kg H}_2\text{O/kg dry air}$$

(b) The enthalpy of air per unit mass of dry air is determined by drawing a **line parallel to the h constant lines** from the specific state until it intersects the enthalpy scale, giving

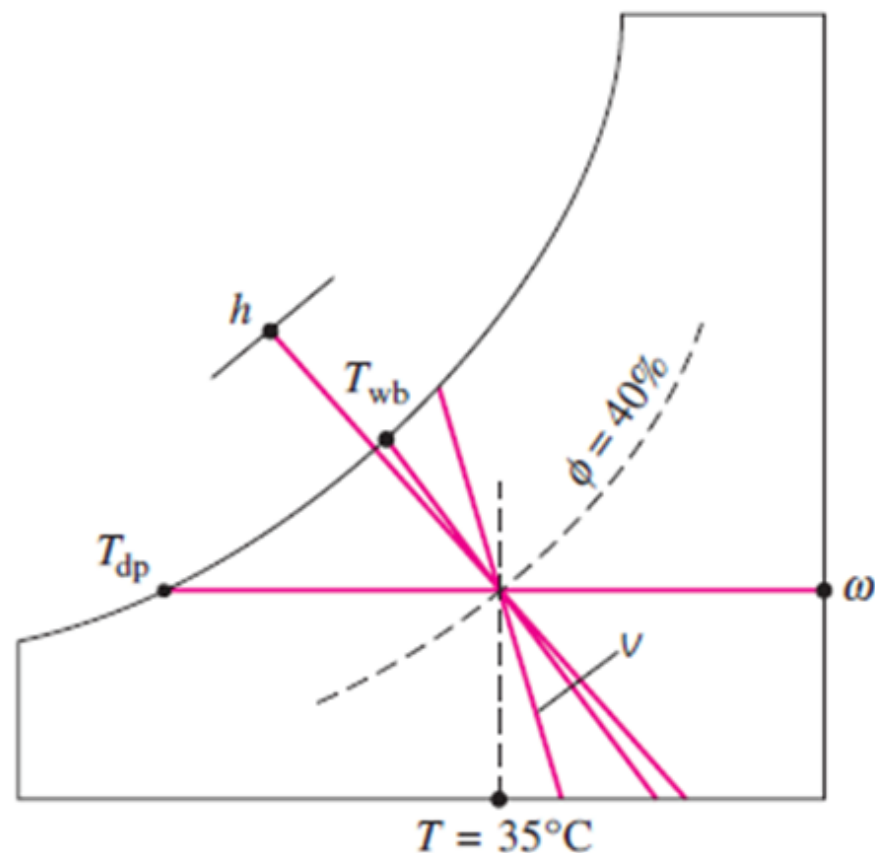
$$h = 71.5 \text{ kJ/kg dry air}$$

(c) The wet-bulb temperature is determined by drawing a **line parallel to the T_{wb} constant lines** from the specified state until it intersects the saturation line, giving

$$T_{wb} = 24^\circ\text{C}$$

(d) The dew-point temperature is determined by drawing a **horizontal line from the specified state to the left** until it intersects the saturation line, giving

$$T_{dp} = 19.4^\circ\text{C}$$



(e) The specific volume per unit mass of dry air is determined by noting the distances between the specified state and the $v = \text{constant}$ lines on both sides of the point. The specific volume is determined by visual interpolation to be $v = 0.893 \text{ m}^3/\text{kg dry air}$

CONT...

Conclusion: Values read from the psychrometric chart **inevitably** involve **reading errors**, and thus are of limited accuracy.