Lecture Number	3	
Lecture Title	HUMIDITY	
Lecture Items		
Item Number	**Item Subject**	**Page Number**

Lecture 3 –HUMIDITY

3.1 CIRCULATION OF WATER IN THE ATMOSPHERE

- Within the atmosphere, there is an unending circulation of water
- Since the oceans occupy over **70** percent of the earth's surface, we can think of this circulation as beginning over the ocean
- Here, the sun's energy transforms enormous quantities of liquid water into water vapor in a process called **evaporation**
- Winds then transport the moist air to other regions, where the water vapor changes back into liquid, forming clouds, in a process called **condensation**
- Under certain conditions, the liquid (or solid) cloud particles may grow in size and fall to the surface as precipitation—rain, snow, or hail
- This cycle of moving and transforming water molecules from liquid to vapor and back to liquid again is called the **hydrologic** (water) **cycle**
- In the most simplistic form of this cycle, water molecules travel from ocean to atmosphere to land and then back to the ocean as shown in figure (**3.1**)

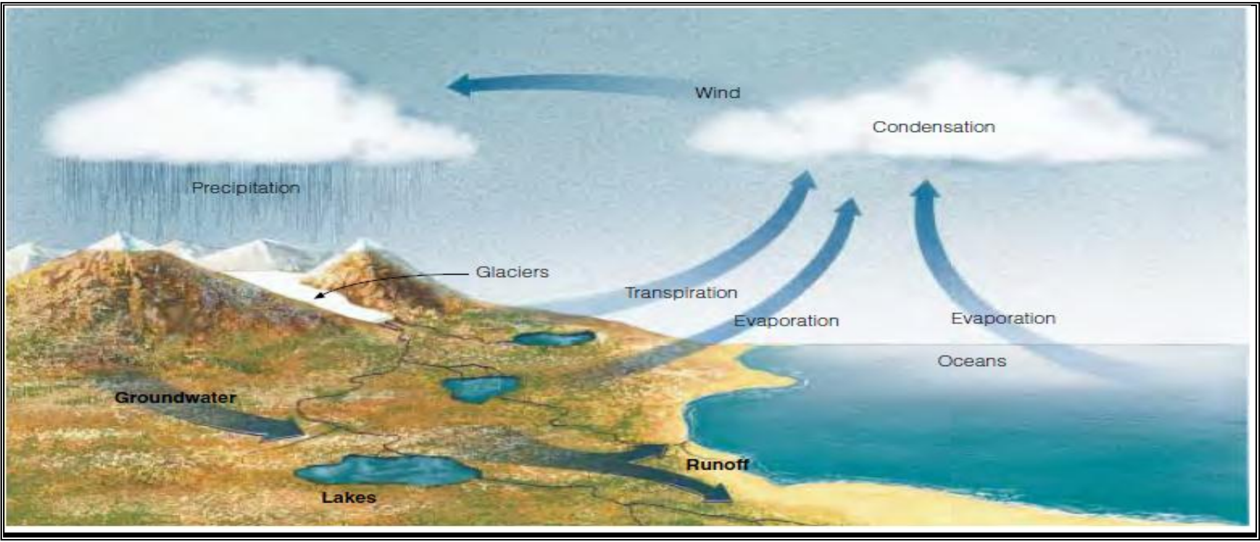

Fig.(3.1) : The hydrological cycle

3.2 PARTIAL PRESSURE

- In a mixture of gases, each gas species contributes to the total pressure
  - The pressure exerted by a single gas species is known as the ***partial pressure*** for that species
  - For a mixture of ideal gases, the partial pressure of any species can be found from the ideal gas law applied to that species only
  - For example, in air the partial pressures of $\mathbf{O_2}$, $\mathbf{N_2}$, and **Ar** would be

$$p_{O_2}V = n_{O_2}RT \qquad p_{O_2} = \rho_{O_2}R'_{O_2}T$$

$$p_{N_2}V = n_{N_2}RT \qquad p_{N_2} = \rho_{N_2}R'_{N_2}T$$

$$p_{Ar}V = n_{Ar}RT \qquad p_{Ar} = \rho_{Ar}R'_{Ar}T$$

  - The densities used in the above equations are *partial densities*
- The total pressure is equal to the sum of the partial pressures, and the total density is equal to the sum of the partial densities
- The partial pressure of a species is proportional to the number of moles of the species

3.3 VAPOR PRESSURE AND ABSOLUTE HUMIDITY

- If you have a substance in liquid form, some of the molecules will escape into the vapor phase
- The partial pressure due to these vapor molecules is known as the *vapor pressure*
- Since the vapor pressure due to water molecules is proportional to the number of water vapor molecules in the atmosphere, vapor pressure is one measure of humidity
- We usually denote vapor pressure as ***e***
- ***Absolute humidity****:* is defined as the mass of water vapor per unit volume

$$AH(\rho_V) = \frac{mass\ of\ water\ vapor}{volume\ of\ air}$$

- It is represent the density of the water vapor, ρ_v
- Vapor pressure is related to absolute humidity via the ideal gas law,

$$e = \rho_v . R_v . T$$

where R_v is the specific gas constant for water vapor (462 $J.kg^{-1}.K^{-1}$)

3.4 SATURATION VAPOR PRESSURE

- The vapor molecules are colliding with each other
- Some may stick together briefly to form tiny water droplets
- If enough vapor molecules are present, there may be enough collisions to form a stable population of liquid water droplets
- This is called *saturation*, and the vapor pressure at this point is called the *saturation vapor pressure* (e_s)
- The saturation vapor pressure is a function of temperature as shown in figure (**3.2**)
- It is given by the Clausius-Clapeyron equation

$$e_s = e_o . \exp\left[\frac{L}{R_v} . \left(\frac{1}{T_o} - \frac{1}{T}\right) \right]$$

Where:

e_0 : is the vapor pressure at some known temperature T_0

L : is the latent heat of vaporization

We typically use T_0 **= 273.15K**, e_0 **= 611 Pa**, and L **=** $\mathbf{2.5 \times 10^6}$ **J.kg**$^{-1}$

- The saturation vapor pressure rapidly increases as temperature increases

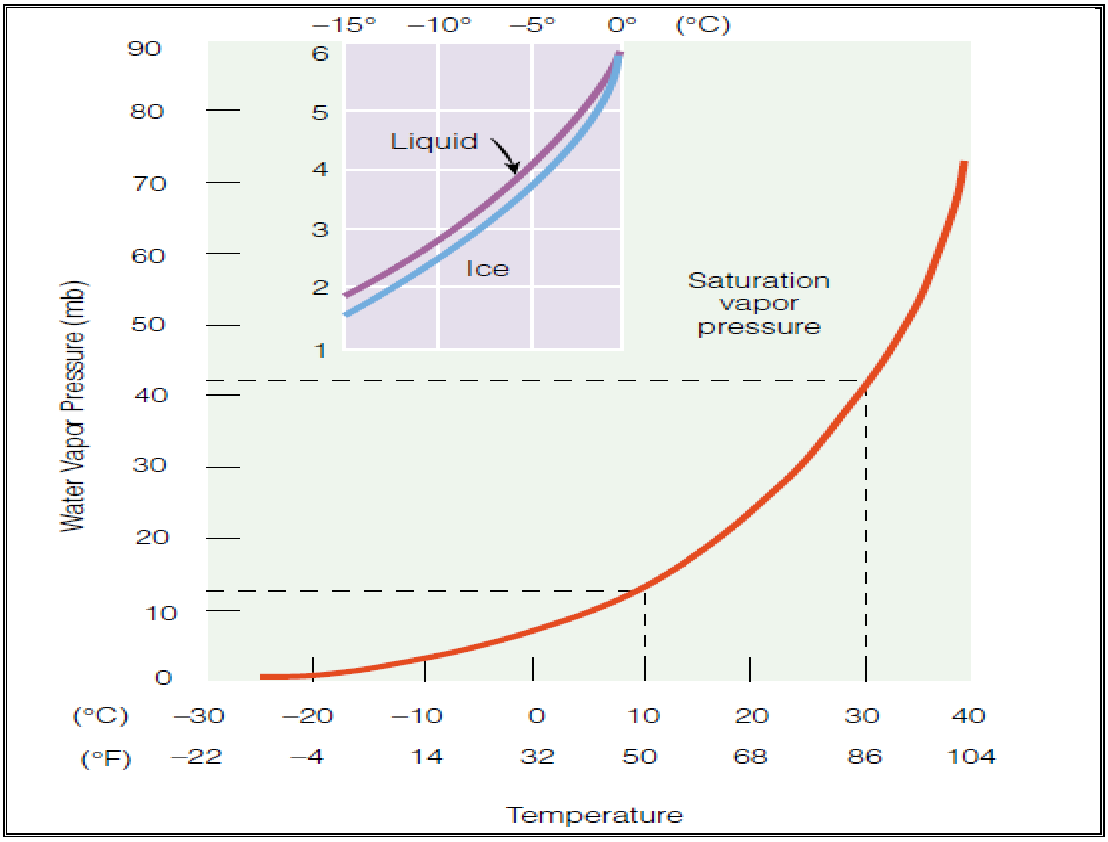

Fig.(3.2) : The relationship between saturation water vapor pressure and temperature

- From the figure (**3.2**) above we notice :
- Saturation vapor pressure increases with increasing temperature
- At a temperature of **10°C**, the saturation vapor pressure is about **12 mb**, whereas at **30°C** it is about **42 mb**
- The insert illustrates that the saturation vapor pressure over water is greater than the saturation vapor pressure over ice

3.5 MIXING RATIO AND SPECIFIC HUMIDITY

- Vapor pressure and absolute humidity are expressions for humidity
- We define some other measures of humidity
- ***Mixing ratio***: The ratio of the mass of water vapor in to the mass of dry air
- This would be dimensionless (if expressed as kg/kg, or g/g)

$$MR = \frac{mass\ of\ \ water\ \ vapor}{mass\ of\ \ dry\ air}$$

- We usually denote mixing ratio as ***r***
- Mixing ratio can be related to vapor pressure via

$$r = \frac{\rho_v}{\rho_d} = \frac{\dfrac{e}{R_v.T}}{\dfrac{p_d}{R_d.T}} = \frac{R_d}{R_v}.\frac{e}{p_d} = \varepsilon\frac{e}{p-e}$$

where $\boldsymbol{\varepsilon = R_d/R_v}$

- ***Specific humidity:*** The ratio of the mass of water vapor in a given parcel to the total mass of air in the parcel

$$SH = \frac{mass\ of\ water\ vapor}{total\ mass\ of\ air}$$

- We usually denote specific humidity as ***q***
- Specific humidity is very close to mixing ratio, as shown

$$q = \frac{\rho_v}{\rho} = \frac{\rho_v}{\rho_d + \rho_v} = \frac{\frac{\rho_v}{\rho_d}}{1 + \frac{\rho_v}{\rho_d}} = \frac{r}{1+r} \approx r$$

since $r << 1$ (expressed as g/g or kg/kg)

3.6 DEW POINT TEMPERATURE

- The temperature at which the air must be cooled *at constant pressure* in order to reach saturation is called the *dew point*, or ***dew point temperature***
- The dew point temperature can be found from the Clausius-Clapeyron equation by using the vapor pressure instead of the saturation vapor pressure, and solving for ***T***
- This gives

$$T_{dew} = \left[\frac{1}{T_o} - \frac{R_v}{L} \ln\left(\frac{e}{e_o}\right) \right]^{-1}$$

- There is only one way to change mixing ratio, specific humidity, or dew point , represented by : Add or subtract water vapor

3.7 RELATIVE HUMIDITY

- Relative Humidity is the most commonly used way of describing atmospheric moisture
- It is defined as the ratio of the vapor pressure to the saturation vapor pressure,

$$R.H = \frac{e}{e_s}.100\%$$

- Relative humidity is given as a percent
- An increase in air temperature lowers the relative humidity, **while** a decrease in air temperature raises the relative humidity as shown in figure (**3.3**)

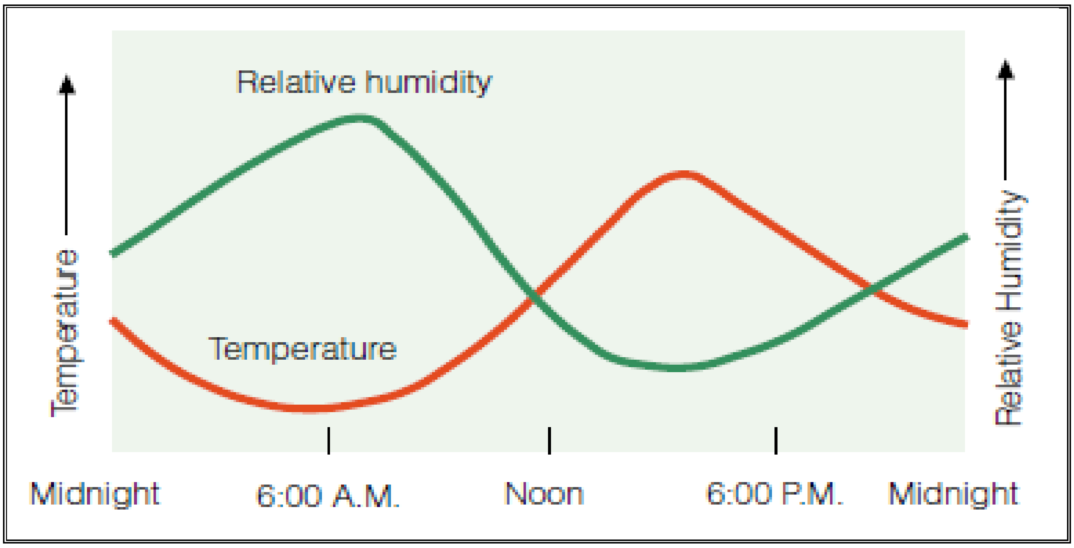

Fig.(3.3) : The daily changes of relative humidity

- From the figure (**3.3**) above we notice :
- When the air is cool (morning), the relative humidity is high
- When the air is warm (afternoon), the relative humidity is low
- These conditions exist in clear weather when the air is calm or of constant wind speed

- There are **two** ways to change the relative humidity, or absolute humidity of an air parcel:
  - Add or subtract water vapor
  - Change the temperature
- A change in the air's water vapor content can change the air's actual vapor pressure
- If the air temperature remains constant, an increase in the air's water vapor content increases the air's actual vapor pressure and raises the relative humidity
- The relative humidity increases as the actual vapor pressure approaches the saturation vapor pressure and the air approaches saturation
- Conversely, if the air temperature remains constant, a decrease in the air's water vapor content decreases the air's actual vapor pressure and lowers the relative humidity
- In summary, ***as water vapor is added to the air (with no change in air temperature), the relative humidity increases, and, as water vapor is removed from the air, the relative humidity lowers***

- A change in the air temperature can bring about a change in the relative humidity
- This phenomenon happens because a change in air temperature alters the air's saturation vapor pressure
- If the air temperature increases, the saturation vapor pressure also increases, which raises the air's water vapor capacity
- If there is no change in the air's actual water vapor content, the relative humidity lowers
- If, on the other hand, the air temperature decreases, so does the air's saturation vapor pressure
- As the saturation vapor pressure approaches the actual vapor pressure, the relative humidity increases as the air approaches saturation
- In summary, ***with no change in water vapor content, an increase in air temperature lowers the relative humidity, while a decrease in air temperature raises the relative humidity***