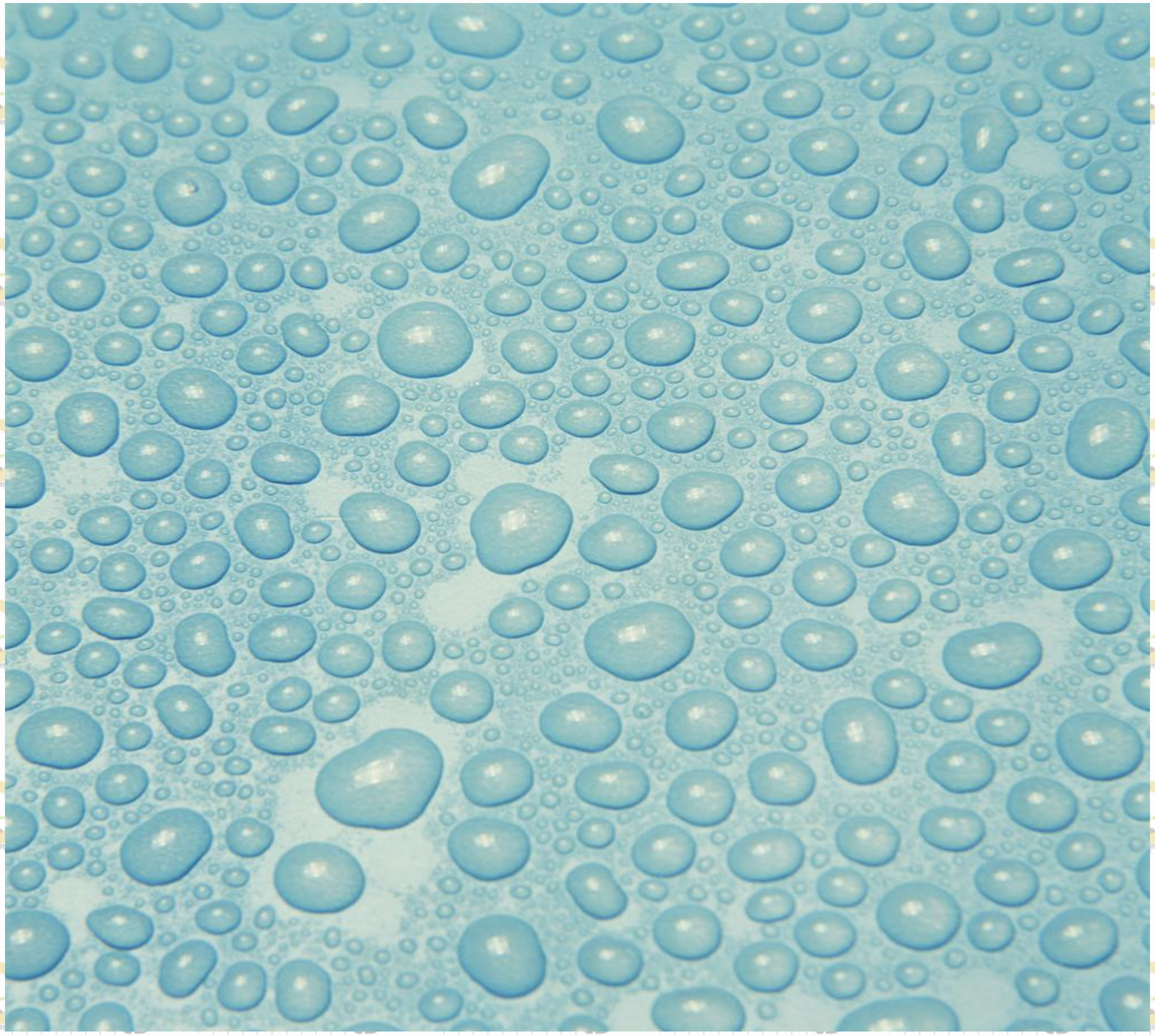
THERMAL PHYSICS

p5

HYGROMETRY

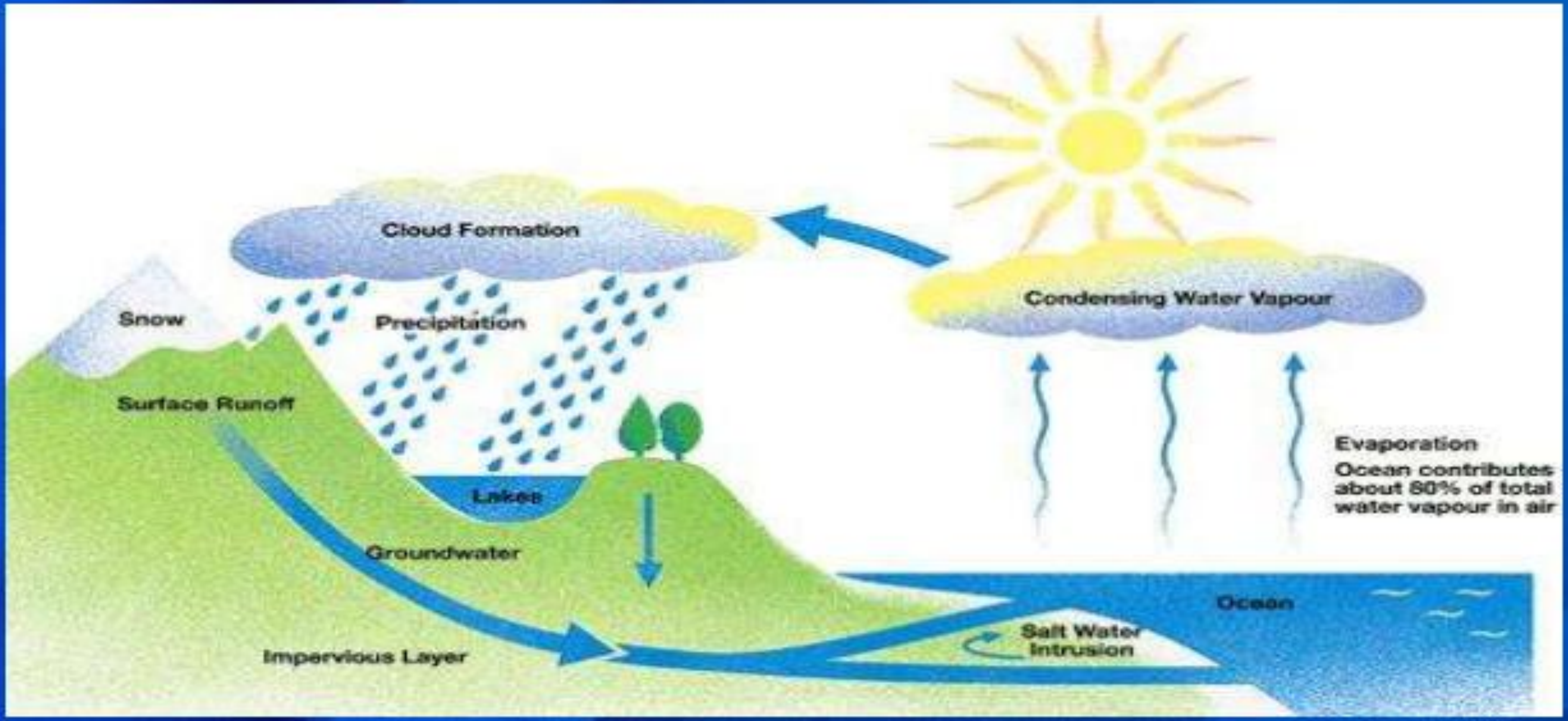
Humidity



Water in the Air

Humidity- is the state of the atmosphere in relation to the amount of water vapor it contains.

The amount of humidity found in air varies because of a number of factors. Two important factors are evaporation & condensation.



At the water, atmosphere interface over our planet's oceans, large amounts of liquid water are evaporated into atmospheric water vapor. This process is mainly caused by absorption of solar radiation and the subsequent generation of heat at the ocean's surface. In our atmosphere, water vapor is converted back into liquid form when air masses lose heat energy and cool. This process is responsible for the development of most clouds and also produces the rain that falls to the Earth's surface.

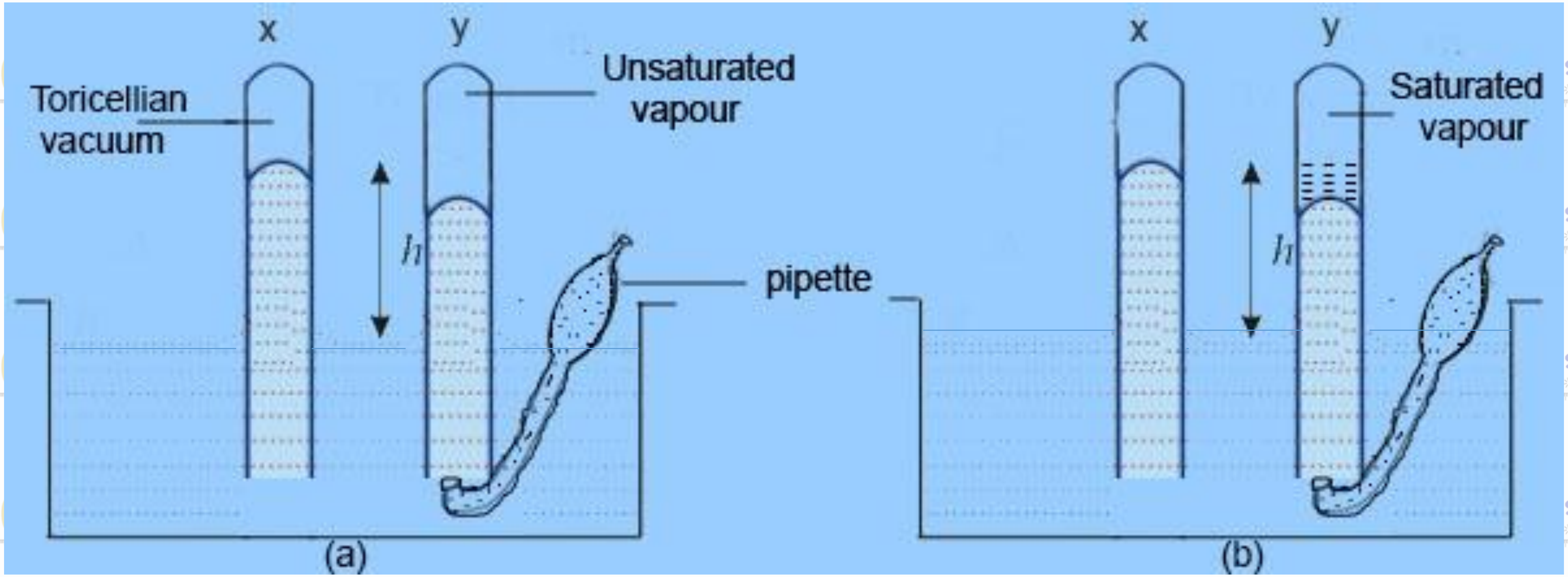
OBJECTIVES

- Explain and compare evaporation and vaporization (boiling).
- Explain the state of dynamic equilibrium between liquid and vapour.
- Describe the behavior of unsaturated vapour and saturated vapour.
- Describe using graphs, how unsaturated vapour pressure and saturated vapour pressure varies with volume, and with temperature.
- Describe the relationship between boiling point and saturated vapour pressure and explain how pressure affects the boiling point.
- Explain humidity as the measure of moisture content of the atmosphere and define absolute humidity and relative humidity.
- Explain dew point.
- Give expression for relative humidity using partial pressure and saturated pressure of vapour.
- Give expression for relative humidity using saturated vapour pressure at the temperature concerned and at the dew point.

Evaporation and Boiling

Evaporation	Boiling
Evaporation is the process of converting liquid into vapours.	Boiling is the process of converting liquid into vapours at the boiling point.
As a result of increasing the temperature of liquid the molecules start moving faster and gain enough energy to break the intermolecular bonding and escape from the surface.	As a result of increasing the temperature of liquid the molecules start moving faster and gain enough energy to break the intermolecular bonding and escape from the liquid.
It happens at any temperature.	It happens only at the boiling point of the liquid.
It happens at the liquid surface only.	It happens anywhere within the liquid.
Average E_k decreases and therefore the temperature of liquid decreases	Average E_k stays the same and therefore the temperature of liquid does not increase
Bubbles not formed	Bubbles formed
The opposite of evaporation is condensation by cooling	The opposite of boiling is condensation by cooling

Saturated and Unsaturated Vapour



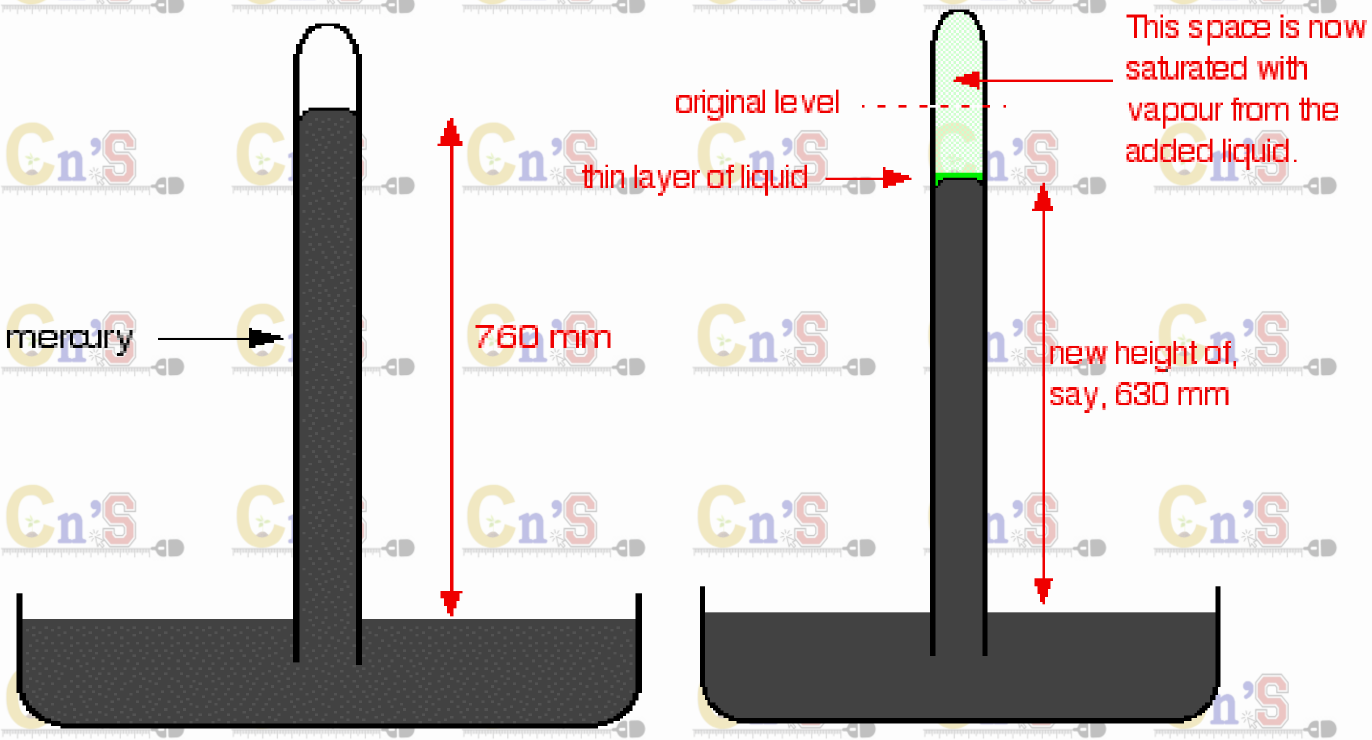
- Let us consider two barometer tubes X and Y each of length about 1 m filled with mercury, when the tubes are inverted into the trough containing mercury, the mercury level in the tube falls down so that a vacuum is created there. The vacuum is called toricellian vacuum. The height of mercury in the tube from mercury level in the trough measures the atmospheric pressure.* *

- Let us introduce few drops of water in water in Y by means of a pipette, water rises in it as water is lighter than mercury and vaporises there. So, mercury level falls in tube Y. Here difference in the mercury levels of Y and X measures vapours pressure. Vapour so produced in tube Y is called unsaturated vapour and pressure given by it is called unsaturated vapour pressure.

- If more water drops are introduced in B, the mercury level will fall more which shows that vapour increases with increase in water vapour. Now water drops do not evaporate and mercury level remains steady. As no more evaporation takes place and vapours are in contact with its liquid, the vapour is called saturated vapour pressure. This is measured by the difference of mercury levels in tube X and Y in fig.b

If you have a mercury barometer tube in a trough of mercury, at 1 atmosphere pressure the column will be 760 mm tall. 1 atmosphere is sometimes quoted as 760 mmHg ("millimetres of mercury").

If you squirt a few drops of liquid into the tube, it will rise to form a thin layer floating on top of the mercury. Some of the liquid will evaporate and you will get the equilibrium we've just been talking about - provided there is still some liquid on top of the mercury. It is only an equilibrium if both liquid and vapour are present.



The saturated vapour pressure of the liquid will force the mercury level down a bit. You can measure the drop - and this gives a value for the saturated vapour pressure of the liquid at this temperature. In this case, the mercury has been forced down by a distance of 760 - 630 mm. The saturated vapour pressure of this liquid at the temperature of the experiment is 130 mmHg.

The variation of saturated vapour pressure with temperature

The effect of temperature on the equilibrium between liquid and vapour

- It can be explained in two ways.
- A) If you increase the temperature, you are increasing the average energy of the particles present. That means that more of them are likely to have enough energy to escape from the surface of the liquid. That will tend to increase the saturated vapour pressure.

B) When the space above the liquid is saturated with vapour particles, you have this equilibrium occurring on the surface of the liquid:

$$\text{liquid} \rightleftharpoons \text{vapour} \qquad \Delta H \text{ is +ve}$$

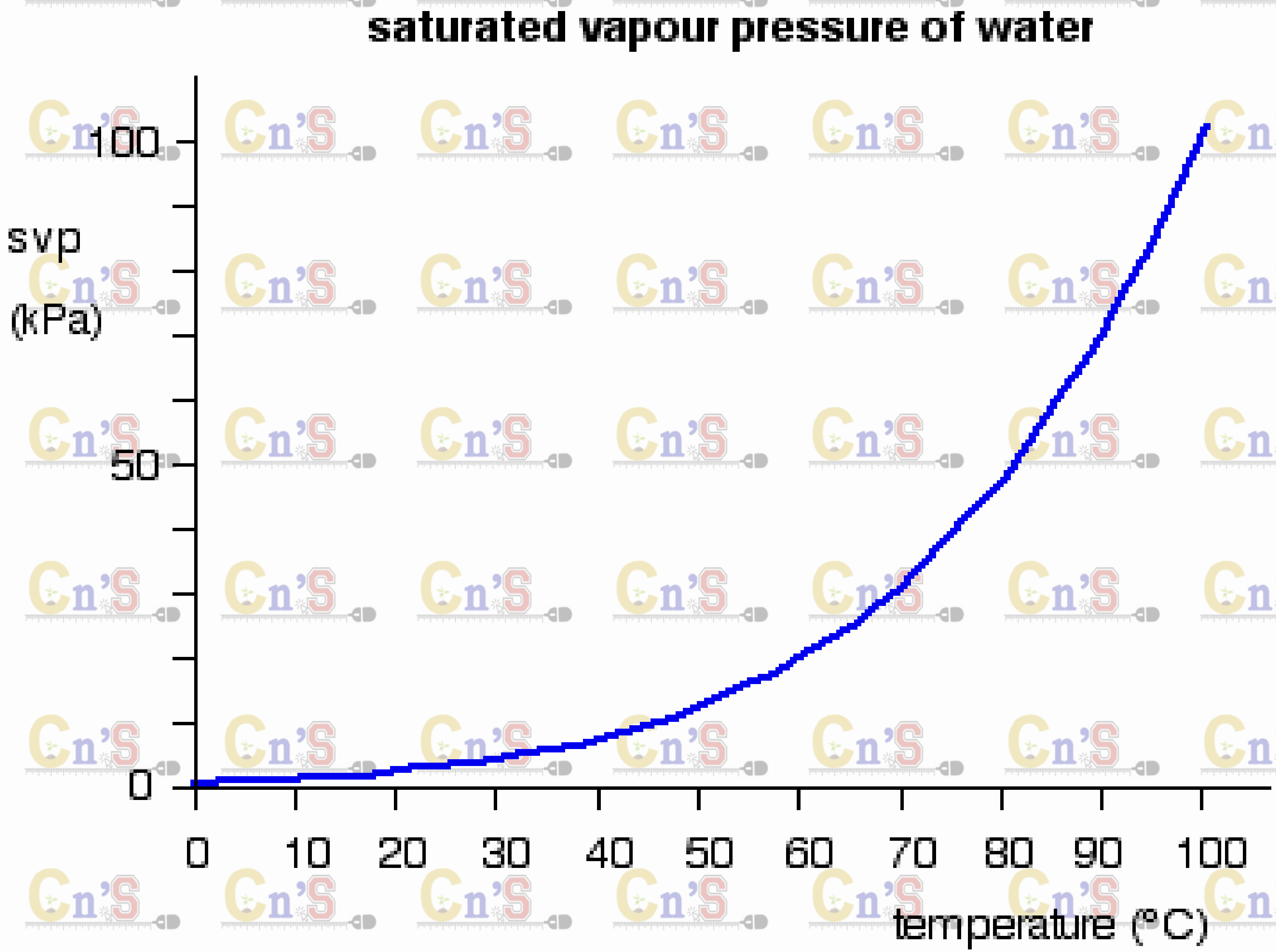
- The forward change (liquid to vapour) is endothermic. It needs heat to convert the liquid into the vapour.
- According to Le Chatelier, increasing the temperature of a system in a dynamic equilibrium favours the endothermic change. That means that increasing the temperature increases the amount of vapour present, and so increases the saturated vapour pressure.

The effect of temperature on the saturated vapour pressure of water

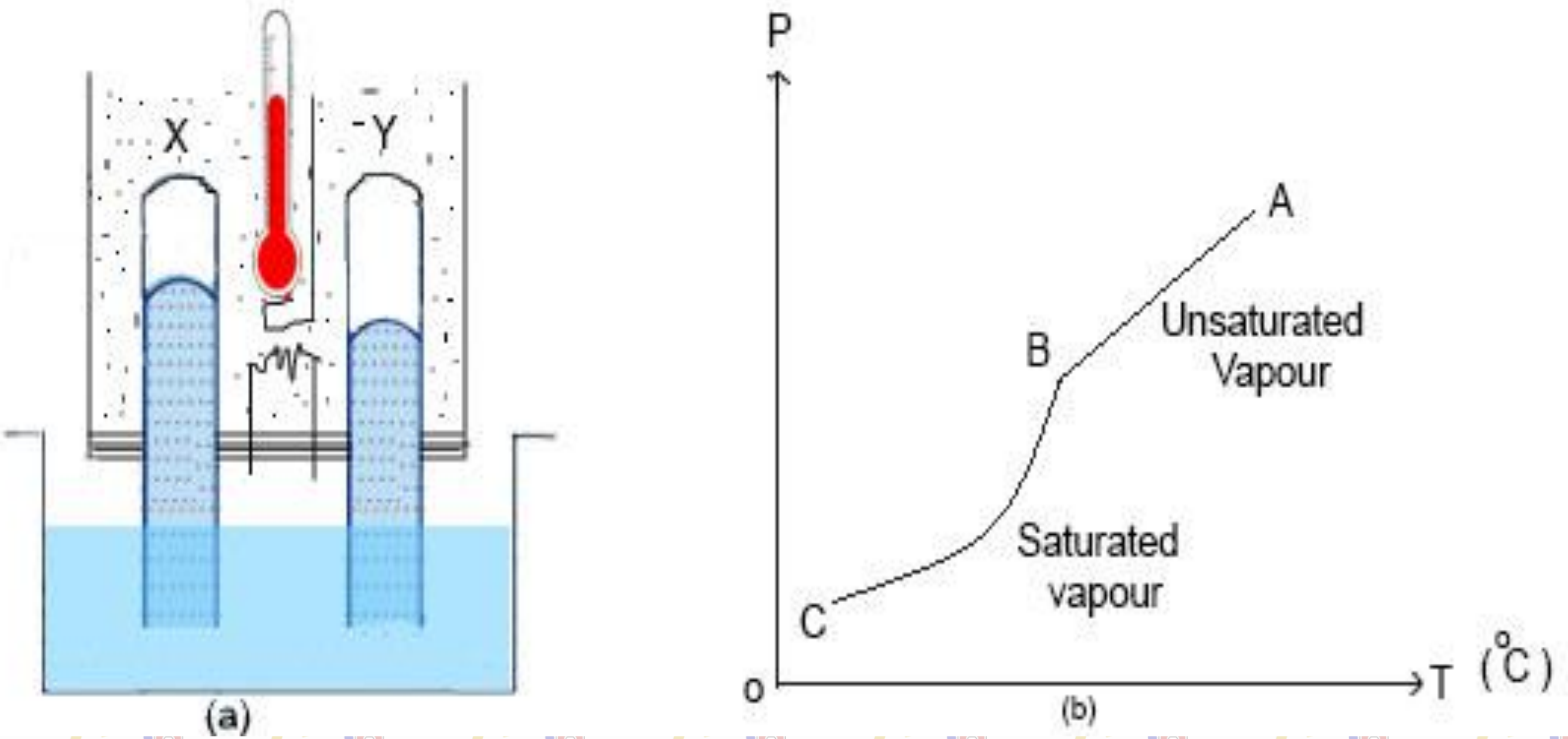
The graph shows how the saturated vapour pressure (svp) of water varies from 0°C to 100 °C.

The pressure is measured in kilopascals (kPa).

1 atmosphere pressure is 101.325 kPa.

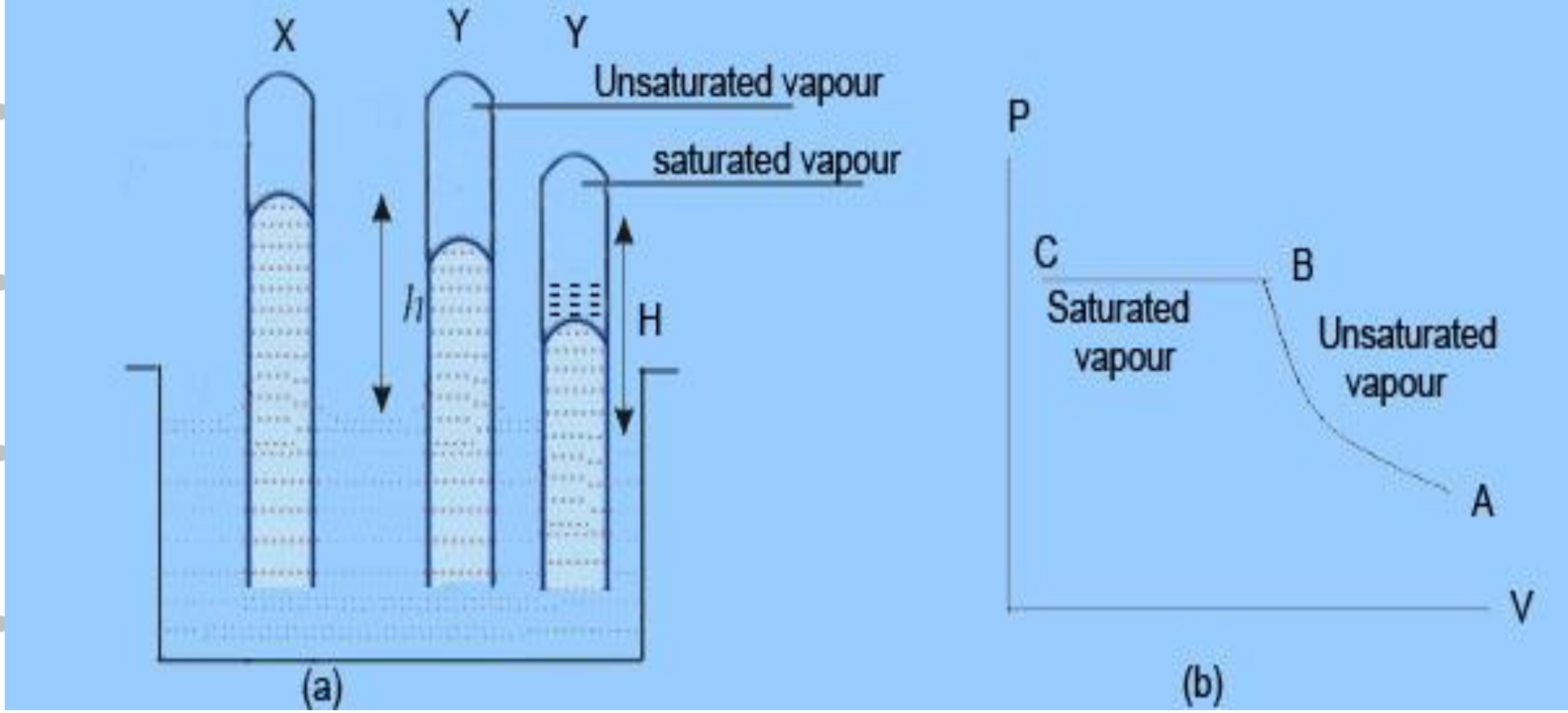


Variation with Vapour Pressure with Temperature

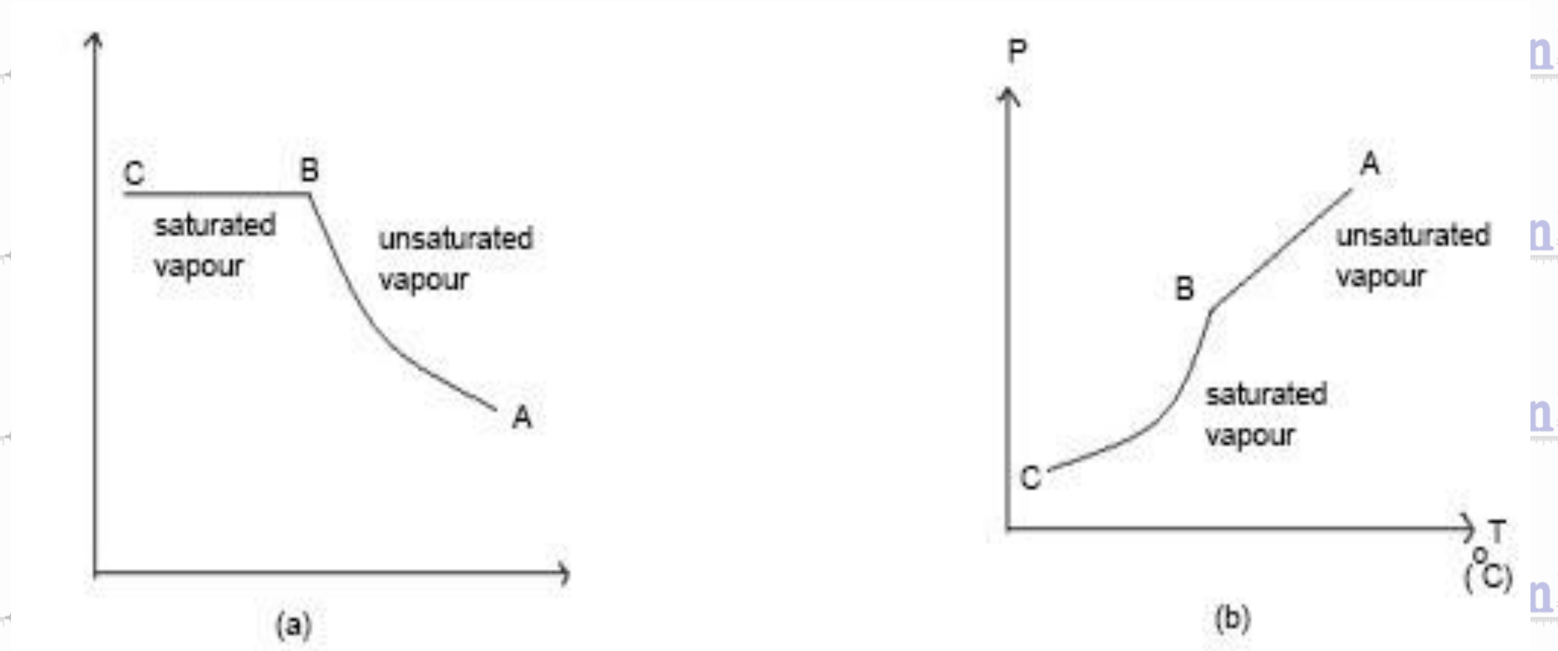


- Let us take two barometer tube X and Y, filled with mercury inverted in a trough. Here X has toricellian vacuum and Y has unsaturated vapour. Both tubes are enclosed by wider gas tube containing water which can be heated with a heating coil and temperature can be noted with thermometer.
- Water is heated to about 80 ^{o}C. The vapour in Y at higher temperature becomes unsaturated and vapour pressure increases. When temperature decreases vapour pressure also decreases in Y.

Variation of Vapour Pressure with Volume



- Let us take a barometer trough X and Y, filled with mercury inverted in a trough. Here X has Torricelli an vacuum and Y has unsaturated water vapour. When volume of unsaturated vapour is decreased by lowering the tube Y in the mercury, the pressure increases with the decrease in the volume and reaches to point B from A. The difference in the levels of mercury in the tube X and Y shows unsaturated vapour pressure. On further decreasing of the volume, a point B is reached at which the vapour is saturated and exerts maximum pressure. There is no change in pressure on further decreasing of volume and a vapour condenses into water.



- In figure a) curve AB shows that pressure increases with decrease in volume. From A to B graph follows Boyle's law. At point B, the vapour is unsaturated and exerts maximum pressure. Beyond B with decrease in volume, pressure remains constant. From B to C graph represents the change from the saturated vapour to the liquid state.

- In figure b) curve CB shows that pressure increases with increase in temperature. From C to B vapour is saturated. Beyond B with increase in Temperature the vapour becomes unsaturated and pressure increase with increase in temperature. In BA, the pressure of unsaturated vapour is directly proportional to its absolute temperature.

Behavior of saturated vapour pressure

1. The saturated vapour pressure depends on the nature of the substance.
2. The saturated vapour pressure of a liquid depends on its temperature. The saturated vapour pressure increases with increase in temperature and decreases with decrease in temperature.
3. The saturated vapour pressure is always greater than unsaturated vapour pressure.
4. It does not depend on the volume occupied by the vapours.
5. It is independent of the pressure of vapours of other liquid present. The vapours should not have any chemical reaction.
6. The total pressure exerted by the vapours of all substances is equal to the sum of the pressure exerted by the vapour of the individual substance i.e. $P = P_1 + P_2 + P_3$ …..
7. The saturated vapour does not obey the gas laws whereas unsaturated vapour obeys the gas laws.

Effect of Pressure on Boiling Point

- The boiling point of a liquid increases with increase in pressure and vice-versa. So, water boils at higher temperature at sea level and lower temperature at high altitudes. The atmospheric pressure decreases with increase in height from earth's surface.
- Actually, the boiling point of a liquid depends on the external pressure over its surface. Liquid boils at a temperature when its saturated vapour pressure is equal to the external pressure.

- When that happens, it enables bubbles of vapour to form throughout the liquid.
- If the external pressure is higher than the saturated vapour pressure, these bubbles are prevented from forming, and you just get evaporation at the surface of the liquid.
- If the liquid is in an open container and exposed to normal atmospheric pressure, the liquid boils when its saturated vapour pressure becomes equal to 1 atmosphere (or 101325 Pa or 101.325 kPa or 760 mmHg). This happens with water when the temperature reaches 100°C.
- But at different pressures, water will boil at different temperatures. For example, at the top of Mount Everest the pressure is so low that water will boil at about 70°C.

Humidity

Water vapour present in the air is known as Humidity

Absolute Humidity

- The **actual** amount of the water vapour present in the atmosphere is known as the **absolute humidity.**
- It is the **weight** of water vapour per unit volume of air and is expressed in terms of grams per cubic metre.
- The absolute humidity **differs** from place to place on the surface of the earth.
- The ability of the air to hold water vapour depends entirely on its temperature **(Warm air can hold more moisture than cold air)**.

Relative Humidity

- **RELATIVE HUMIDITY** is <u>**the amount of water in the air**</u> **compared to** <u>**the amount of water the air could possibly hold.**</u>

- The **percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature** is known as the relative humidity.

- ***R H =***

<u>[Actual amount of water vapor in air (absolute humidity) X 100</u>

Humidity at saturation point (the maximum water vapor air can hold at a given T)

Examples:

- **if the air is holding half the water it could hold**, it's Relative Humidity is **50%.**
- If the air is holding **ALL the water it can hold** it is **saturated** and the relative humidity is 100%
- If the air is holding no water, relative humidity is 0%
- If it holding a quarter of the water it could hold, 25%

- Water is added to the air by the process of **EVAPORATION.**
- The **relative humidity** determines the **amount and rate of evaporation** and hence it is an **important climatic factor.**
- **Relative humidity is greater over the oceans and least over the continents**

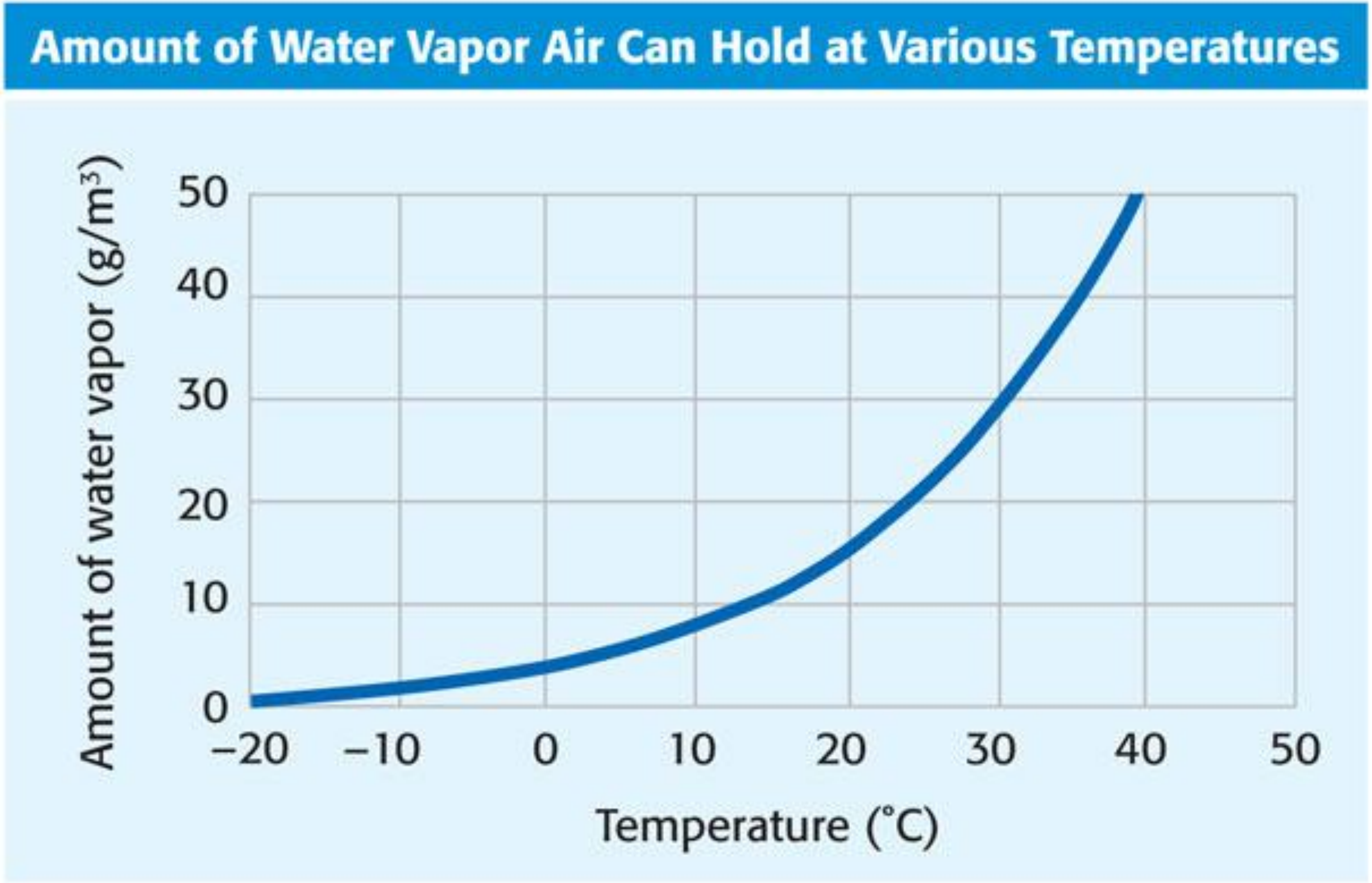
Factors that Affect Relative Humidity

Amount of water: If you **increase the amount of water in the air** If moisture is added by evaporation, the relative humidity will increase and vice versa.

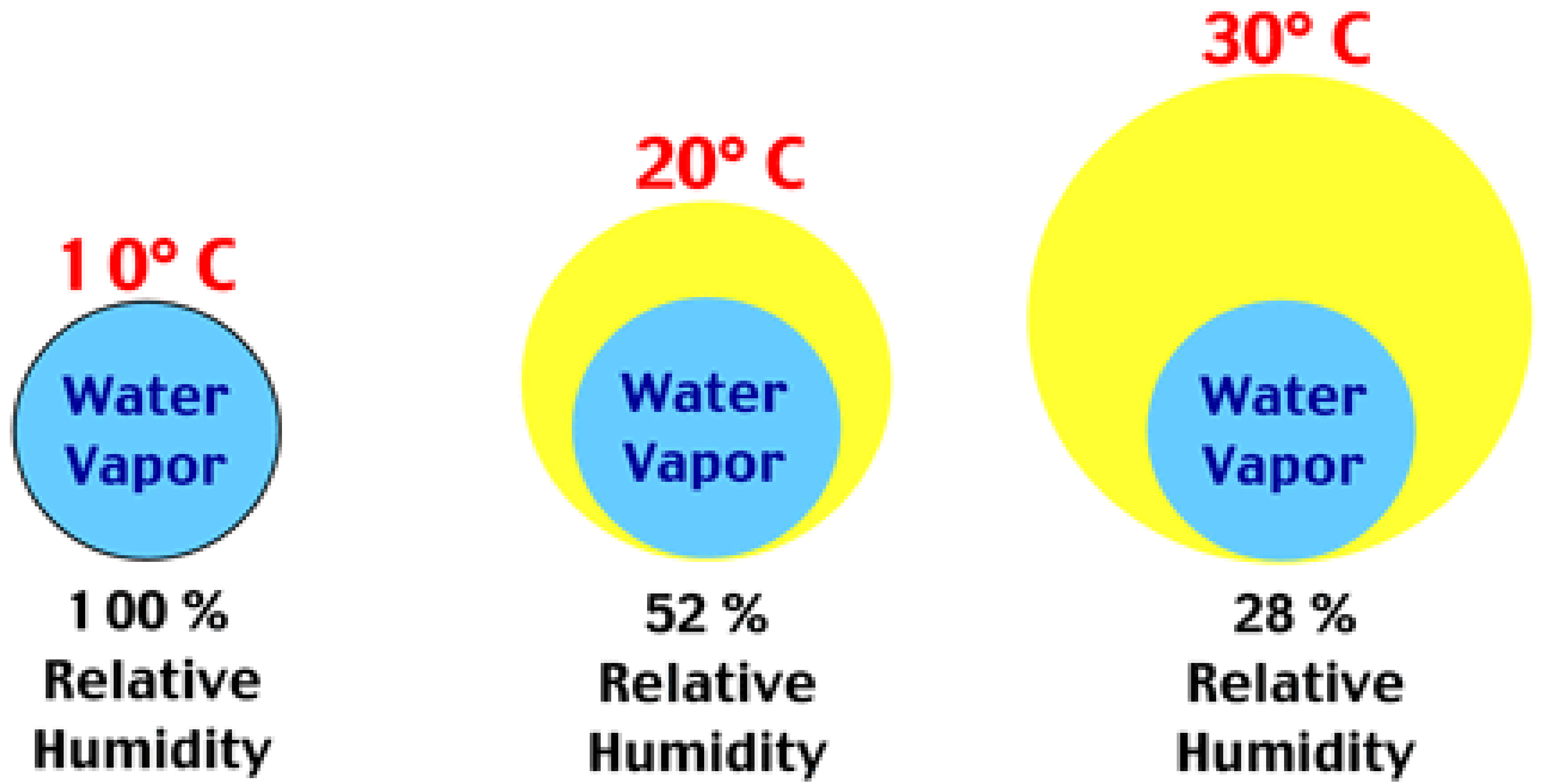
Temperature: With the change of air temperature, the capacity to retain moisture increases or decreases and the relative humidity is also affected. Since warm air can hold more water than cold air, **if you lower the temperature** the Relative Humidity will **go up**, even if you don't add more water.

i.e. *a decrease in temperature (hence, decrease in moisture-holding capacity/decrease in saturation point) will cause an increase in relative humidity and vice versa.*

What temperature can hold more water vapor?



Water capacity of air at different temperatures



- Consider 1 m^3 of air at a temperature ‘T’.
- Let us assume that saturation occurs when 0.5 kg of water vapor is present in 1 m^3 of air.
- That is, relative humidity will be 100% if 1 m^3 of air contains 0.5 kg of water vapor at temperature T (saturation temperature or saturation point).
- Assume that 1 m^3 of air at a given time consists of 0.2 kg of water vapor at a temperature ‘T’.
- Now the relative humidity = 40 % ===> 0.2 kg of water vapor per 1 m^3 of air ===> the air can still hold 0.3 kg of water vapor since saturation occurs at 0.5 kg.
- **Absolute Humidity = 0.2 kg/ m^3 and**
- **Relative Humidity = 40 %**

- Now to make the air saturated (100 % relative humidity),
- we can add that additional 0.3 kg of water vapor by evaporation. **OR**
- we can decrease the temperature.
- If we decrease the temperature, the saturation point will come down.
- Let us assume that the temperature of 1 m^3 of air is decreased by 2 °C. The water holding capacity will fall due to decrease in temperature. Let us assume that the water holding capacity decreases by 0.1 kg per m^3 of air per 1 °C fall in temperature.
- So, for 2 °C fall in temperature, the fall in water holding capacity is 0.2 kg/m^3 of air (0.1 kg/m^3 x 2).

- Hence the new saturation point occurs at 0.3 kg/m^3 of air [0.5 kg/m^3 – 0.2 kg/m^3].
- That is, the 'new saturation point' (relative humidity = 100%)" occurs when the water vapor content is 0.3 kg per 1 m^3 of air.
- So now we can saturate 1 m^3 of air by adding just 0.1 kg instead of 0.3 kg as in the earlier case.
- [because, initially, we assumed that 1 m^3 of air at a given time consists of 0.2 kg of water vapor at a temperature 'T'.]

- If the air is **SATURATED**, **it is holding ALL of the water that it can hold.**

- Condensation will occur when the air is **SATURATED**, or has a relative humidity of **100%.** The air can't hold any more water vapor, so the water condensed out of the air. This commonly happens when ***moist air is cooled***, or ***comes in contact with a cool surface.***
  - **WARM** air **expands** and can hold more water vapor than **COLD** air, so it takes more water to saturate warm air.

Saturation

Condensation

Dew Point

- **DEW POINT** is **the temperature at which condensation will occur**.

- The temperature at which saturation occurs in a given sample of air.

- Dew point occurs when Relative Humidity = 100%
- *Remember, cooling the air makes it unable to hold as much water vapor, so water will condense out at a certain temperature.*

The ice makes the air near the glass cooler and it reaches its’ **dew point**, cool air can’t hold as much moisture and **condensation** occurs

- Relative humidity

$$= \frac{\text{Mass of water vapour in a certain volume } (m)}{\text{Mass needed to saturate the same volume at the same temperat. } (M)} \times 100\%$$

- Relative humidity

$$= \frac{\text{Partial water vapour pressure}}{\text{Saturated water vapour pressure at room temperature}} \times 100\%$$

- Relative humidity

$$= \frac{\text{Water vapour pressure at dew point}}{\text{Saturated water vapour pressure at room temperature}} \times 100\%$$

Measuring Humidity

- Relative Humidity is measured using a **PSYCHROMETER**.
  - A **psychrometer** is made of **two thermometers**. One is covered with a wet cloth. When air moves over the wet cloth, **evaporation** occurs and lowers the temperature on that thermometer. If you compare the temperature on the two thermometers you can get the relative humidity.

Determining Relative Humidity

Find the relative humidity by locating the column head that is equal to the difference between the wet-bulb and dry-bulb readings. Then, locate the row head that equals the temperature reading on the dry-bulb thermometer. The value that lies where the column and row intersect equals the relative humidity. You can see a psychrometer below.

Relative Humidity (%)

Dry-bulb reading (°C)	Difference between wet-bulb reading and dry-bulb reading (°C)							
	1	2	3	4	5	6	7	8
0	81	64	46	29	13			
2	84	68	52	37	22	7		
4	85	71	57	43	29	16		
6	86	73	60	48	35	24	11	
8	87	75	63	51	40	29	19	8
10	88	77	66	55	44	34	24	15
12	89	78	68	58	48	39	29	21
14	90	79	70	60	51	42	34	26
16	90	81	71	63	54	46	38	30
18	91	82	73	65	57	49	41	34
20	91	83	74	66	59	51	44	37

Determining Relative Humidity

Ex. 1

Dry Bulb = 14 degrees C

Wet Bulb = 10 degrees C

Difference is 14-10 = 4

1st – look at dry bulb reading (14)

2nd – find difference (4)

3rd – RH is where they meet = 60%

Relative Humidity (%)

Dry-bulb reading (°C)	Difference between wet-bulb reading and dry-bulb reading (°C)							
	1	2	3	4	5	6	7	8
0	81	64	46	29	13			
2	84	68	52	37	22	7		
4	85	71	57	43	29	16		
6	86	73	60	48	35	24	11	
8	87	75	63	51	40	29	19	8
10	88	77	66	55	44	34	24	15
12	89	78	68	58	48	39	29	21
14	90	79	70	60	51	42	34	26
16	90	81	71	63	54	46	38	30
18	91	82	73	65	57	49	41	34
20	91	83	74	66	59	51	44	37

Determining Relative Humidity

Dry Bulb= 4 degrees

Wet Bulb= 3 degrees

Difference is
4-3 = 1

RH =85 %

Relative Humidity (%)								
Dry-bulb reading (°C)	Difference between wet-bulb reading and dry-bulb reading (°C)							
	1	2	3	4	5	6	7	8
0	81	64	46	29	13			
2	84	68	52	37	22	7		
4	85	71	57	43	29	16		
6	86	73	60	48	35	24	11	
8	87	75	63	51	40	29	19	8
10	88	77	66	55	44	34	24	15
12	89	78	68	58	48	39	29	21
14	90	79	70	60	51	42	34	26
16	90	81	71	63	54	46	38	30
18	91	82	73	65	57	49	41	34
20	91	83	74	66	59	51	44	37

Determining Relative Humidity

Ex. 3

Dry Bulb = 6 degrees C

Wet Bulb = 6 degrees C

Difference is 6-6 = 0

RH = 100%

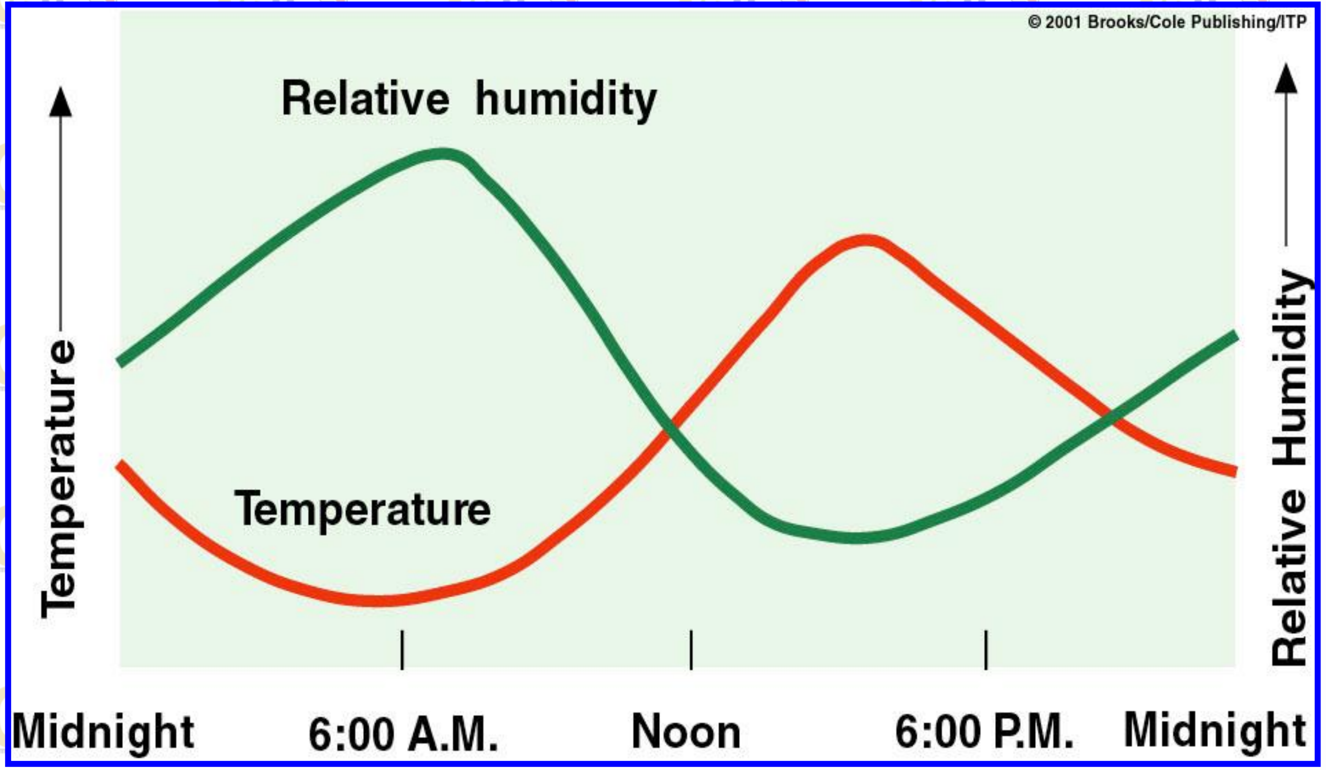
Relative Humidity (%)

Dry-bulb reading (°C)	Difference between wet-bulb reading and dry-bulb reading (°C)							
	1	2	3	4	5	6	7	8
0	81	64	46	29	13			
2	84	68	52	37	22	7		
4	85	71	57	43	29	16		
6	86	73	60	48	35	24	11	
8	87	75	63	51	40	29	19	8
10	88	77	66	55	44	34	24	15
12	89	78	68	58	48	39	29	21
14	90	79	70	60	51	42	34	26
16	90	81	71	63	54	46	38	30
18	91	82	73	65	57	49	41	34
20	91	83	74	66	59	51	44	37

Relative Humidity and Temperature

- RH is usually maximum in the morning (low T) and minimum during the afternoon (high T).
- Watering the plants is more effective when RH is high: less evaporation from the ground (morning, evening hours).
- The air's total vapor content is ~ constant during the day

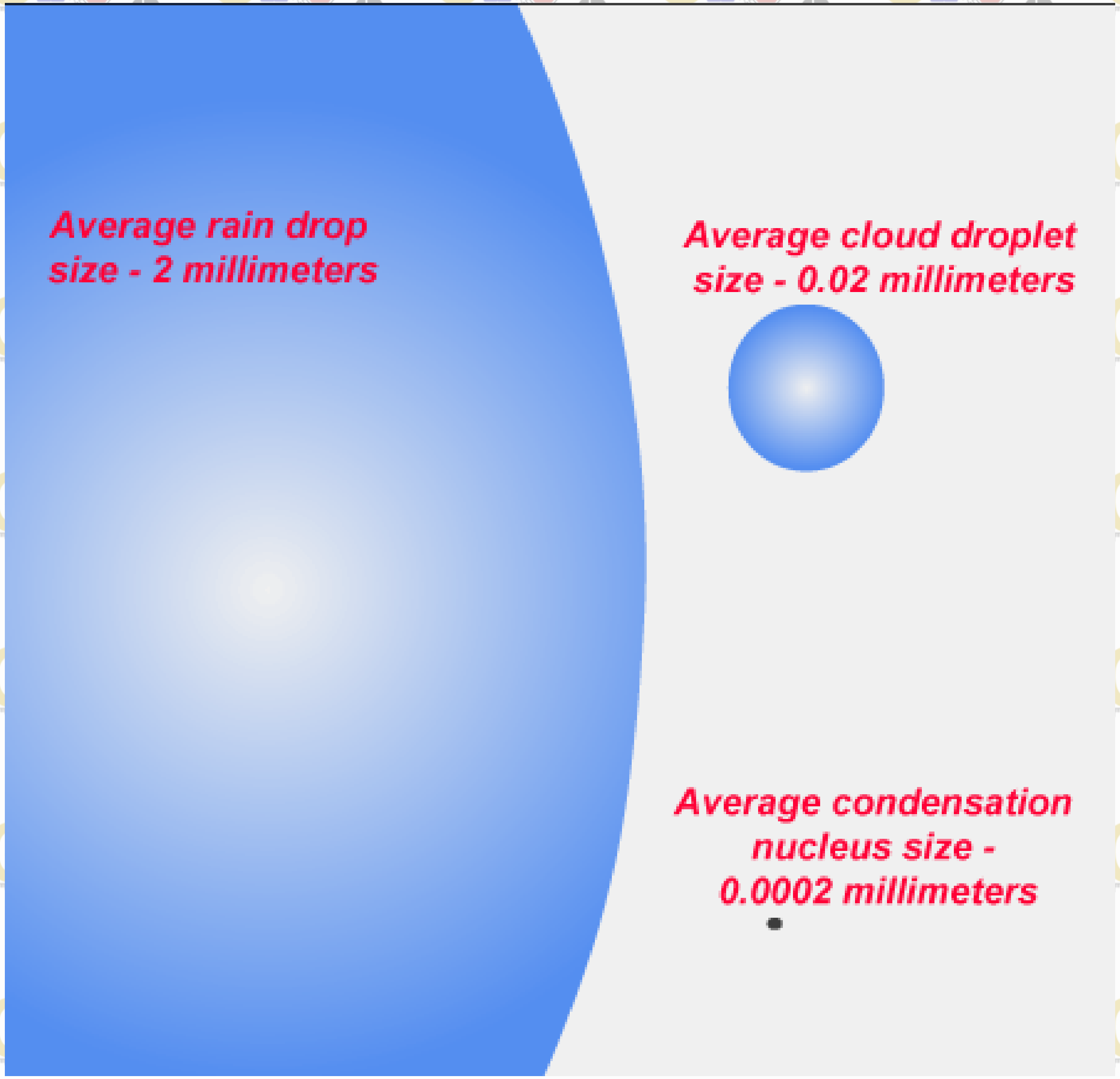
$$RH = \frac{P(H_2O)}{P_s(H_2O)} \times 100\%$$



RH=100% :the air is saturated. (clouds, fog, rain)

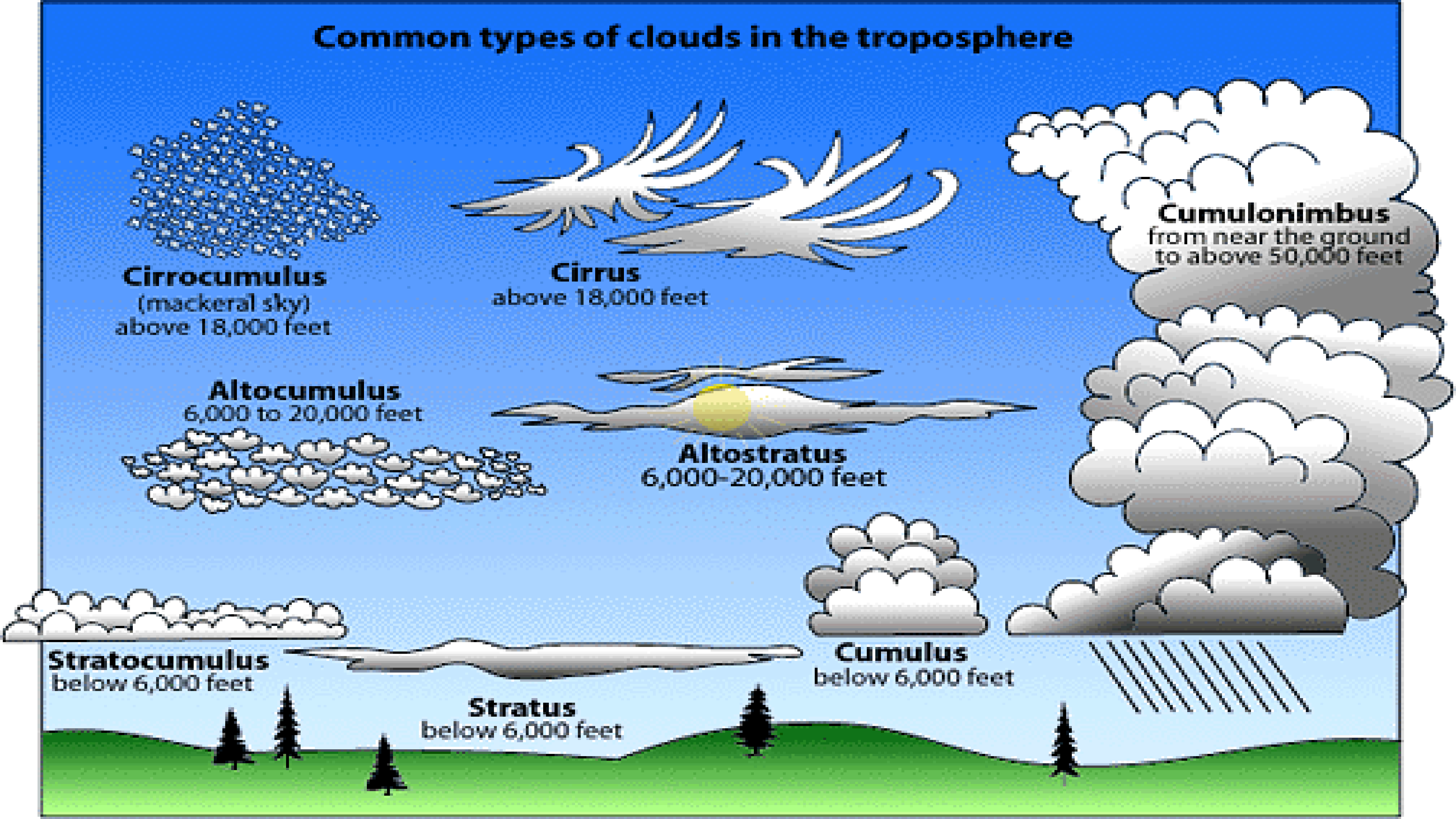
Cloud Formation

Clouds form when water vapor condenses on **CONDENSATION NUCLEI**.



CONDENSATION NUCLEI- solid particles in the air that water can condense on.

Examples: Smoke particles, ash, dust, pollen, pollutants


Common types of clouds in the troposphere
Cirrocumulus
(mackeral sky)
above 18,000 feet
Cirrus
above 18,000 feet
Cumulonimbus
from near the ground
to above 50,000 feet
Altocumulus
6,000 to 20,000 feet
Altostratus
6,000-20,000 feet
Stratocumulus
below 6,000 feet
Stratus
below 6,000 feet
Cumulus
below 6,000 feet

Cirrus

- Indicate fair weather or approaching storms

- High altitude, made of ice crystals
- Look like feathers

Cumulus Clouds

- Indicate fair weather or approaching storms
- Form at all altitudes
- To "heap upon" like piles of cotton balls.

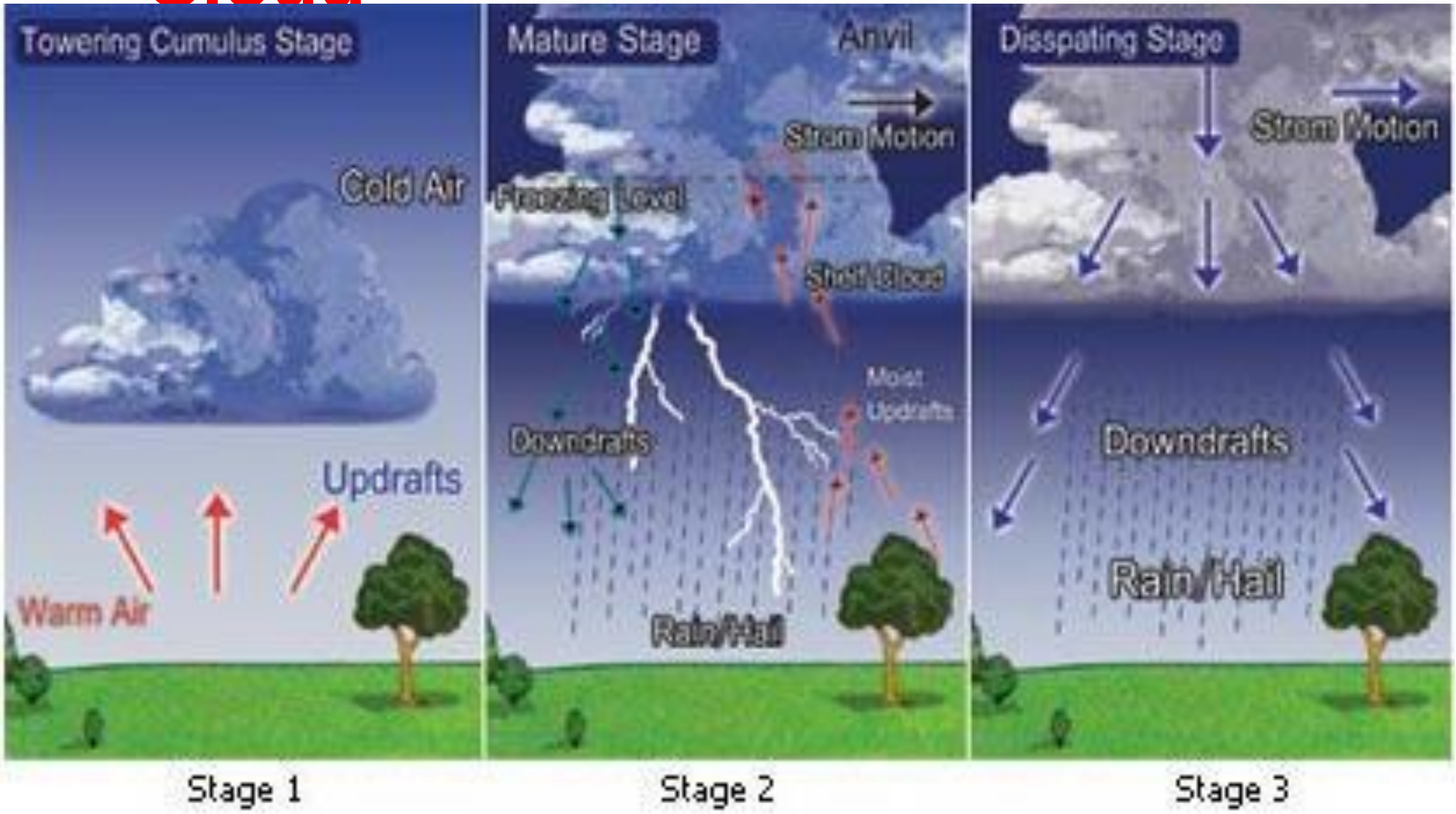
Stratus Clouds

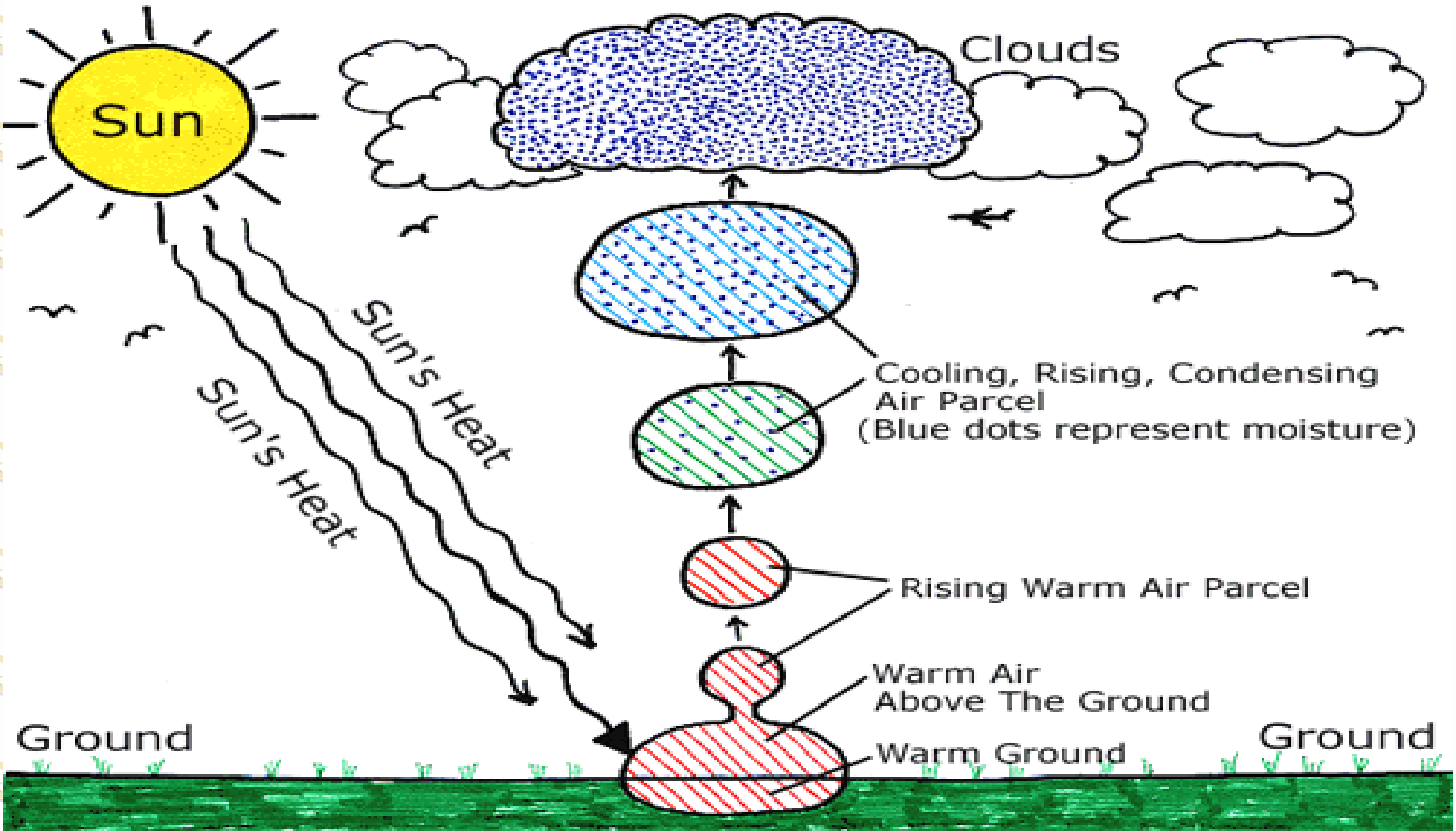
- **Indicates fair weather or rain and snow**
- **Low altitude clouds**
- **Fog is a stratus cloud**
- **Strata= "to layer"**

Cumulonimbus Clouds

- Indicate Storms
- NIMBUS means “rain”
- Usually dark

Stages of a Cumulonimbus Cloud




Sun
Clouds
Sun's Heat
Sun's Heat
Cooling, Rising, Condensing
Air Parcel
(Blue dots represent moisture)
Rising Warm Air Parcel
Warm Air
Above The Ground
Ground
Warm Ground
Ground

Fundamental Behavior of Water

Water changes:

- length of organic materials
- conductivity and weight of hygroscopic material and chemical absorbents
- impedance of almost any material
- color of chemicals
- refractive index of air and liquids
- velocity of sound in air
- electromagnetic radiation in solids
- thermal conductivity of gases, liquids, and solids

Water absorbs:

- infrared radiation
- ultraviolet radiation & microwave radiation

Extreme danger | Danger | Extreme caution | Caution

Apparent temperature

is how hot the heat-humidity combination makes it feel.

RELATIVE HUMIDITY (PERCENT)

AIR TEMPERATURE (DEGREES FAHRENHEIT)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
140	125																				
135	120	128																			
130	117	122	131																		
125	111	116	123	131	141																
120	107	111	116	123	130	139	148														
115	103	107	111	115	120	127	135	143	151												
110	99	102	105	108	112	117	123	130	137	143	150										
105	95	97	100	102	105	109	113	118	123	129	135	142	149								
100	91	93	95	97	99	101	104	107	110	115	120	126	132	138	144						
95	87	88	90	91	93	94	96	98	101	104	107	110	114	119	124	130	136				
90	83	84	85	86	87	88	90	91	93	95	96	98	100	102	106	109	113	117	122		
85	78	79	80	81	82	83	84	85	86	87	88	89	90	91	93	95	97	99	102	105	108
80	73	74	75	76	77	77	78	79	79	80	81	81	82	83	85	86	86	87	88	89	91
75	69	69	70	71	72	72	73	73	74	74	75	75	76	76	77	77	78	78	79	79	80
70	64	64	65	65	66	66	67	67	68	68	69	69	70	70	70	71	71	71	71	71	72

The weight of humid air

- Mean molecular mass of dry air:

gas	m	%	mass of the gas mixture
N_2	28	78%	28x78/100+32x21/100=28.6
O_2	32	21%	

- Mean molecular mass of wet air.

gas	m	%	mass of the gas mixture
Dry air	28.6	90%	28.6x90/100+18x10/100=27.5
H_2O	18	10%	

- Moist air is lighter and less dense than dry air at the same temperature.

- Moist air rises more readily. Evaporation enhances convection in the atmosphere.

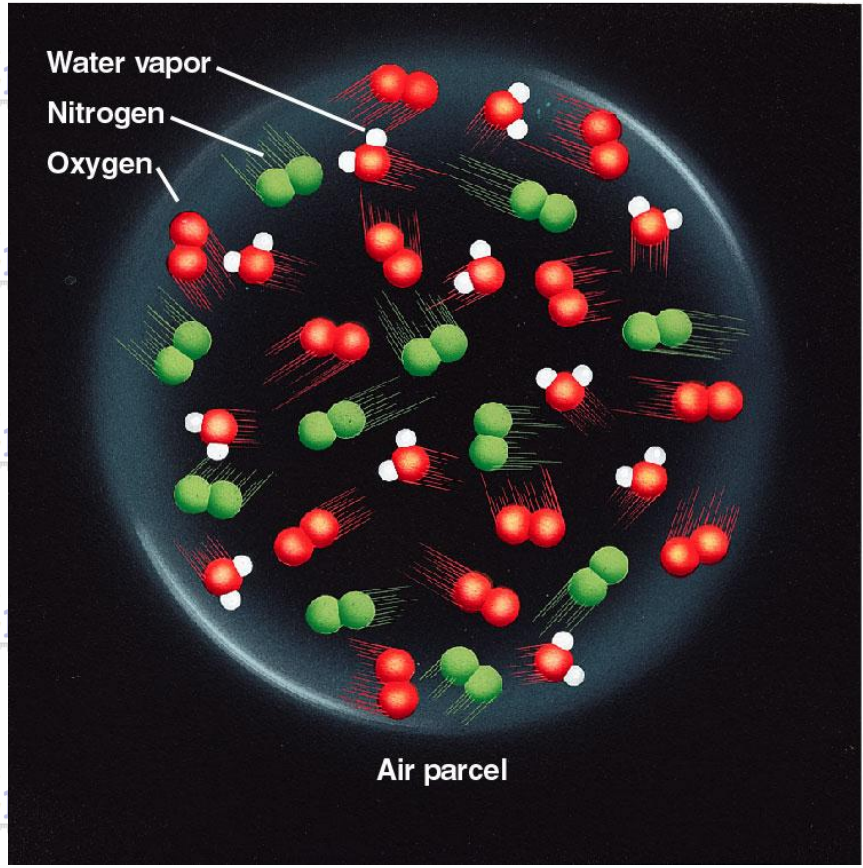
Vapor pressure

- Partial pressure: the pressure of each gaseous component in a mixture of gases.

- Dalton's law of partial pressure: the total pressure of a mixture of gases is the sum of the partial pressures of each gas component.

$$\boxed{P = P_1 + P_2 + P_3 + \ldots}$$

$$\boxed{P = P(N_2) + P(O_2) + P(Ar) + \ldots + P(H_2O) + \ldots}$$



- Vapor pressure: the partial pressure of H_2O vapor.
  - What is the H_2O vapor pressure if 1% of the air is H_2O and the total air pressure is 1bar?

- The pressure of a gas is proportional to the number of molecules and to the temperature of the gas.

$$\boxed{P \propto nT}$$