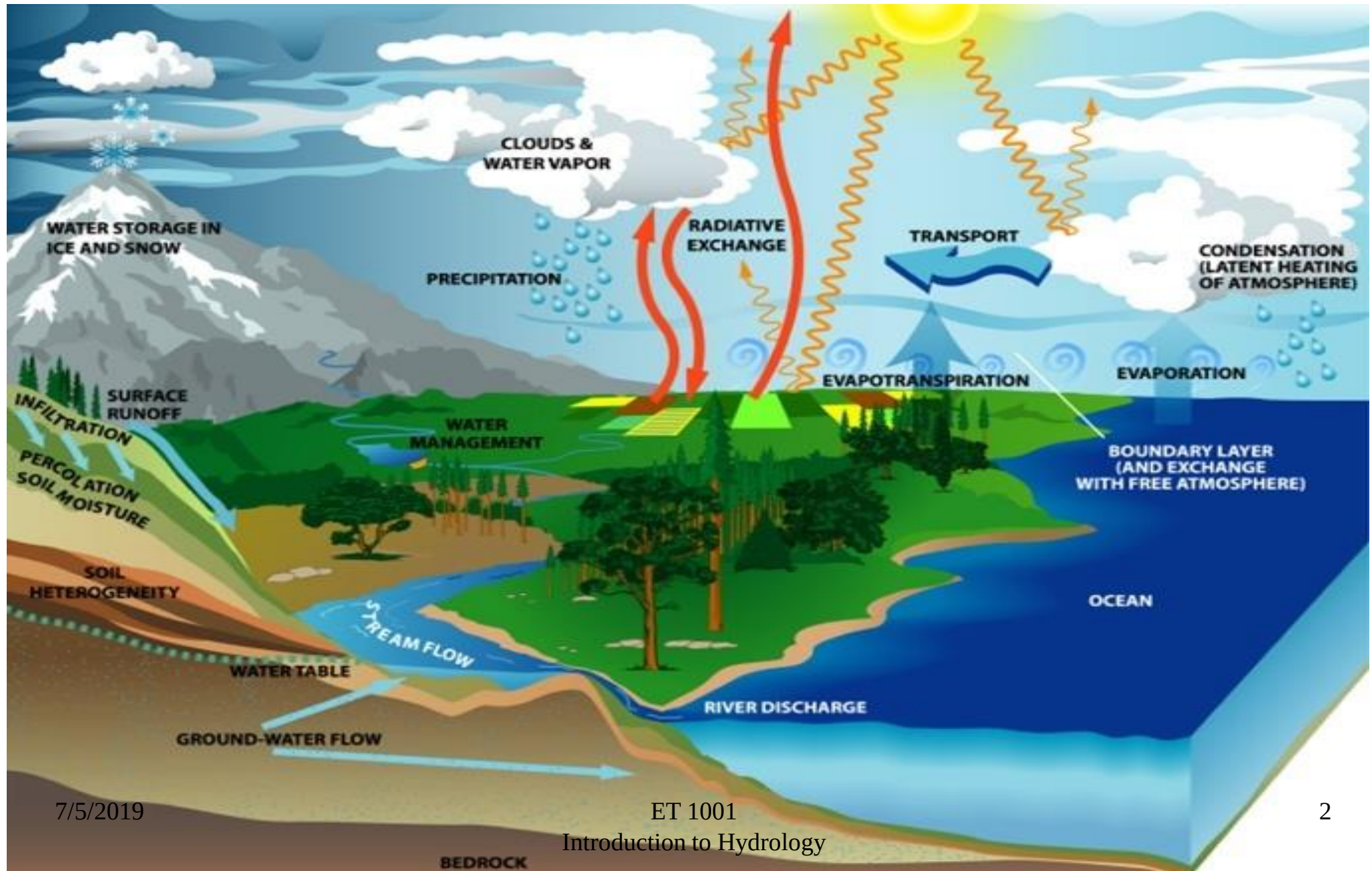


Water in the Atmosphere

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B.sc (Hons) ARMT (UOR)

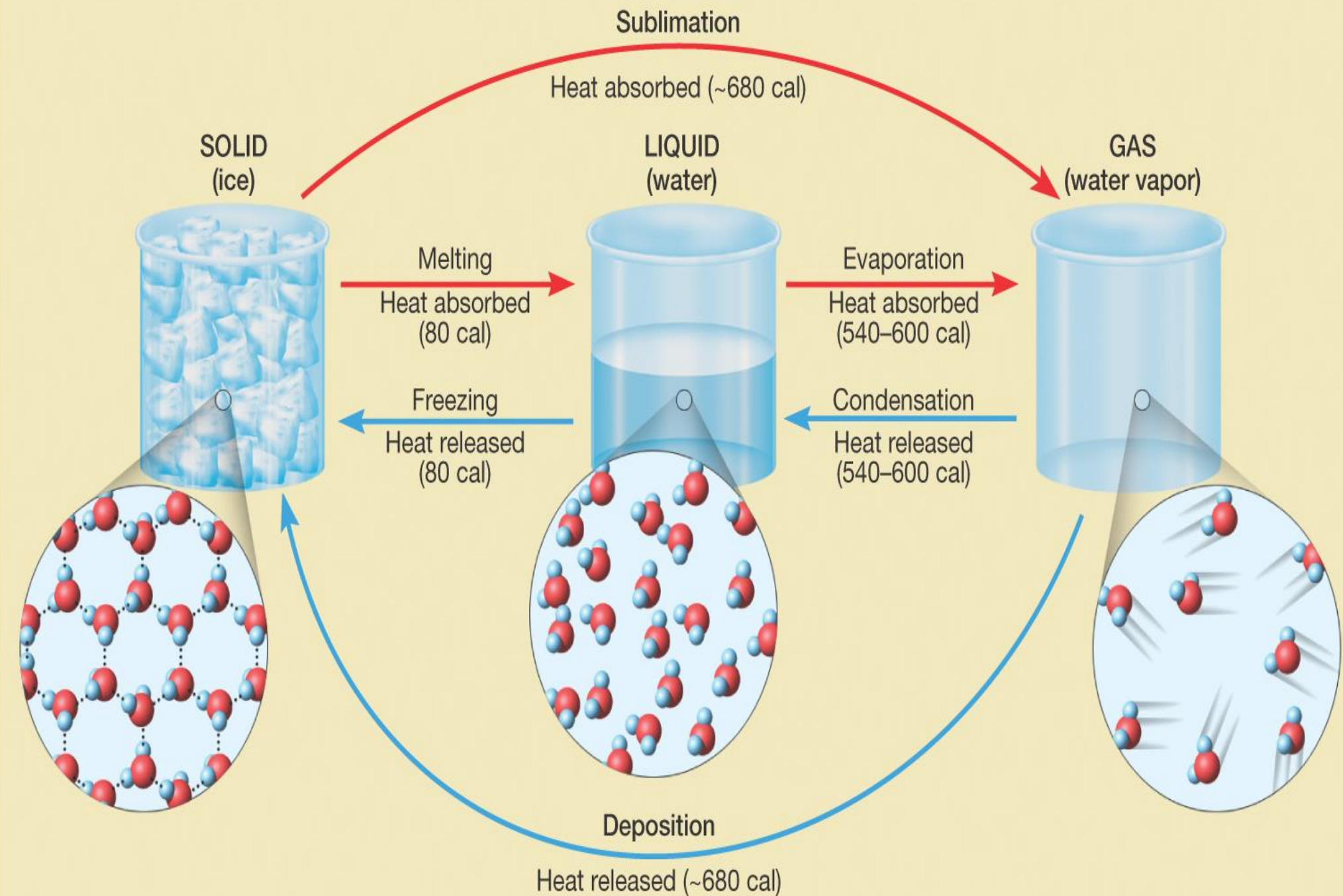
ET 1001
Introduction to Hydrology

Water Is Important!!!



Properties of Water

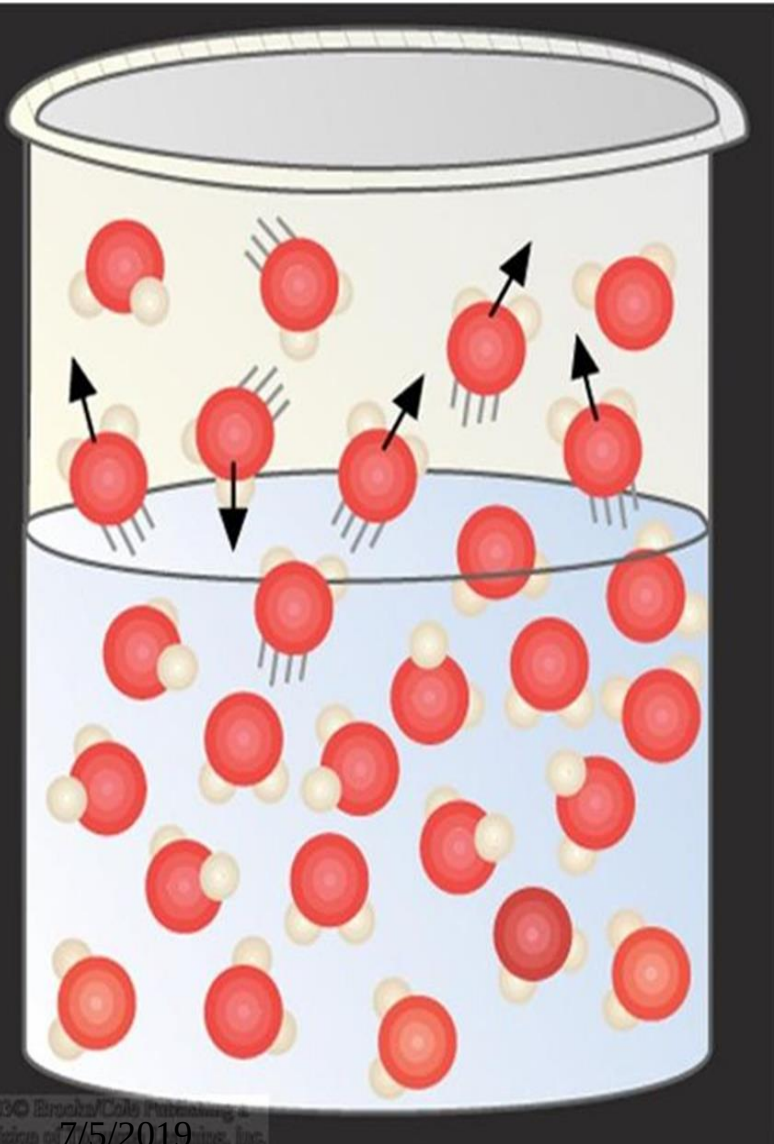
- Heat Capacity
 - Highest of all common solids and liquids
- Compressibility
 - Virtually incompressible as a liquid
- Density
 - Liquid water has maximum density at $+4^{\circ}\text{C}$
 - Solid phase has lower density since it must form crystal structure
 - What would happen if ice was more dense than water???



— Releases latent heat to the environment
7/5/2019
— Absorbs latent heat from environment

Water vapor saturation

- Water molecules **move** between the liquid and gas phases.
- When the rate of water molecules entering the liquid equals the rate leaving the liquid, we have **equilibrium**.



The air is said to be **saturated** with water vapor at this point.

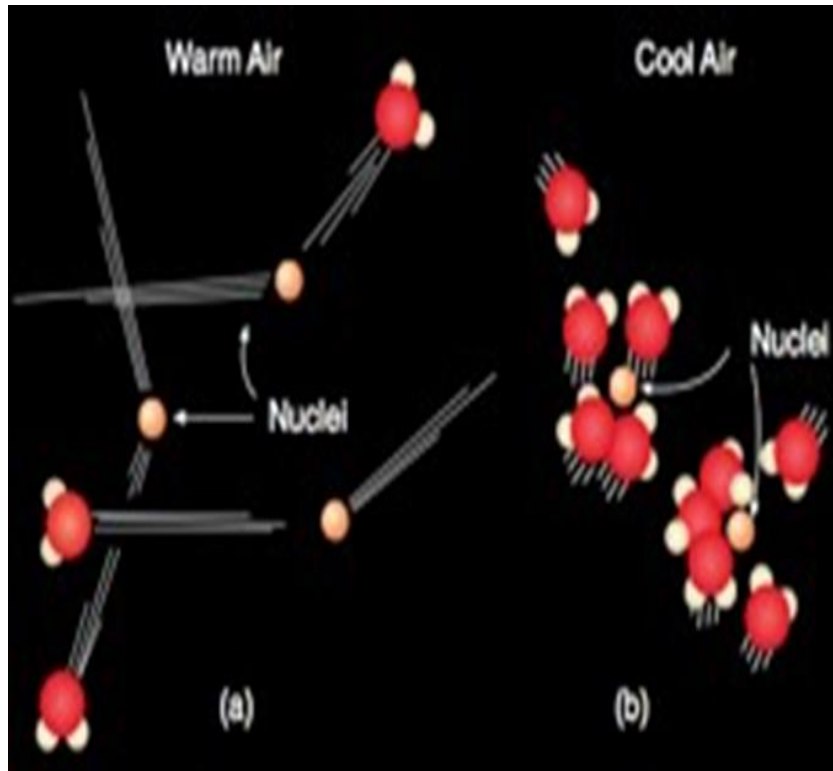
Equilibrium does not mean no exchange occurs.

Condensation

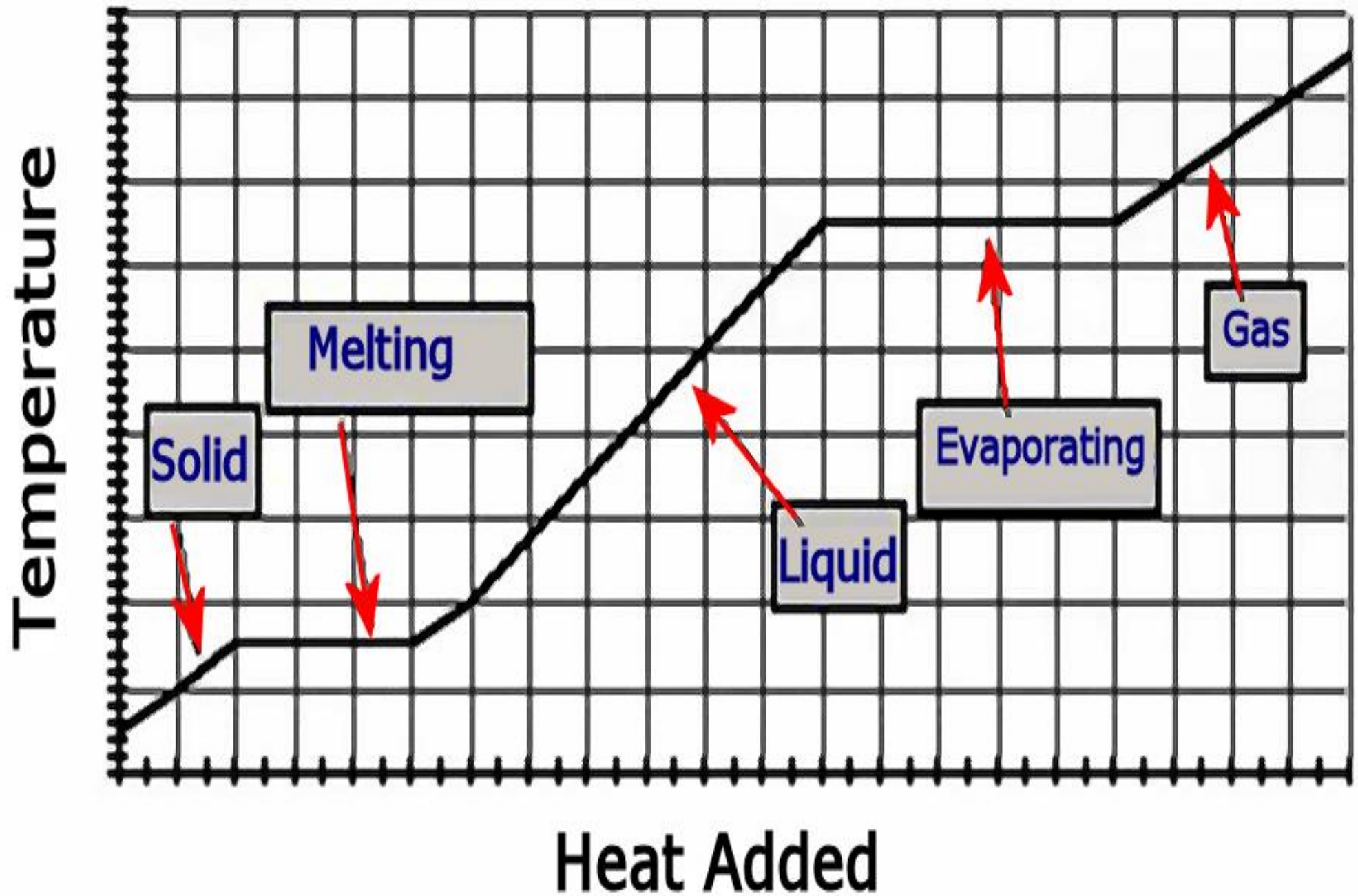
The process by which water vapor changes to a cloud droplet.

Water vapor molecules may 'stick' to condensation nuclei and grow (billions) to eventually form cloud droplet.

Examples : Dust / Salt / Smoke.

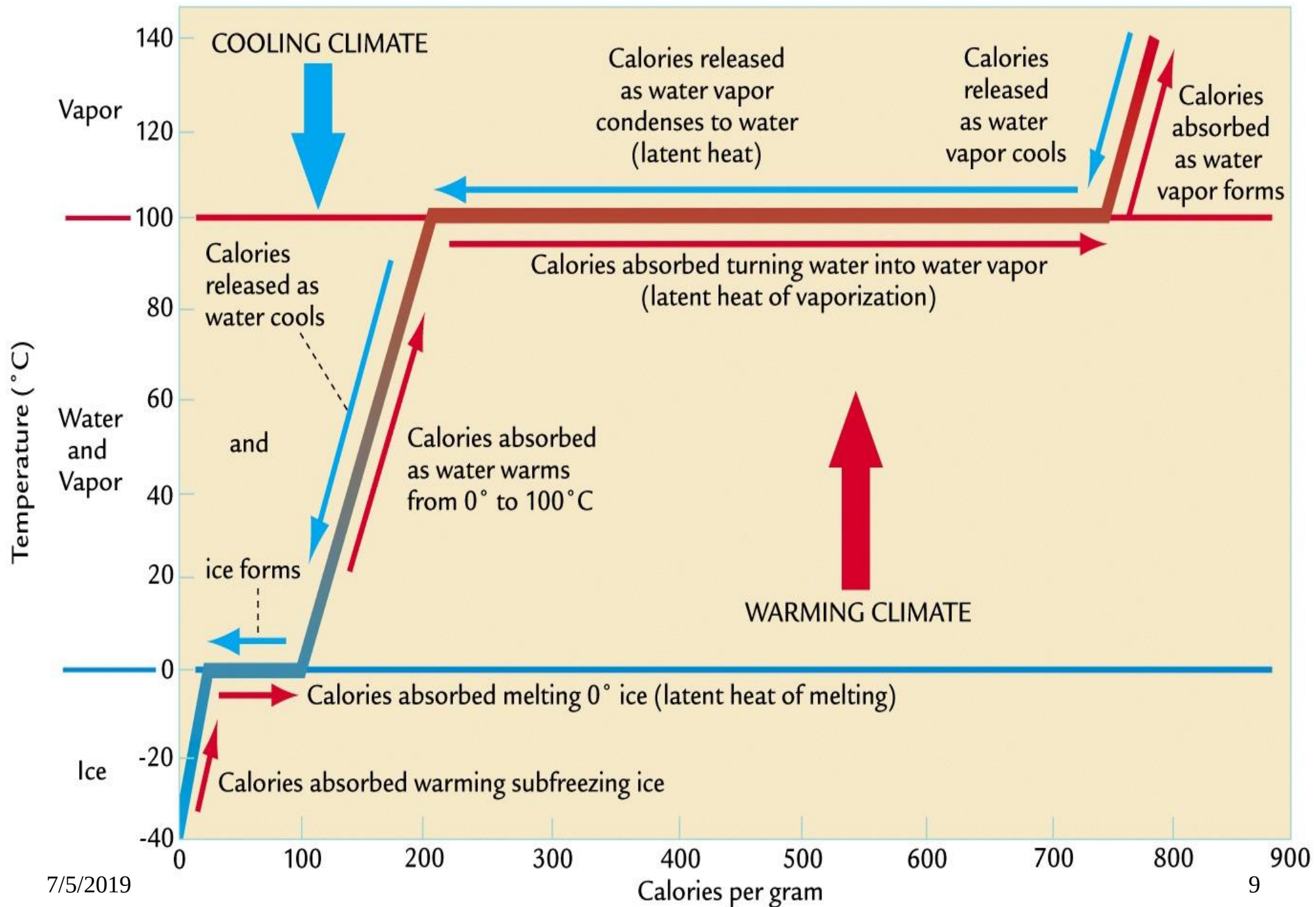


Condensation occurs primarily as temperature cools - colder the molecules more likely they are to 'stick' to other molecules



Latent heat

- Latent heat is **the heat released or absorbed by a body or a thermodynamic system during a process that occurs without a change in temperature.**
- A typical example is a change of state of matter, meaning a phase transition such as the melting of ice or the boiling of water.
- Latent heat: Temperature remains fairly constant when phase is changing



- Typical heat capacity of air:
 - 0.24 calorie raises 1 gram (0.8 liter) air 1°C
- Typical heat capacity of liquid water:
 - 1 calorie raises 1 gram (0.001 liter) water 1°C
- Latent heat:
 - 80 calories to melt 1 gram ice
 - 540 to 600 calories to evaporate 1 gram liquid water

Evaporation & condensation carry hundreds of times more heat than changing temperature at constant humidity

Measuring water vapor

- A measure of the water vapor content of the air is called humidity.
- Humidity is exposed as;
 - Vapor pressure (e)
 - Absolute humidity
 - Specific humidity
 - Humidity mixing ratio / Mixing ratio (W)
 - Relative humidity (RH)
 - Dew point (T_d)
 - Wet bulb temperature (T_w)

Properties of Gas Mixtures

The total pressure in a gas mixture = Sum of all the individual pressures of its gas components.

The atmospheric pressure, usually around 1000 hPa, is the total of the partial gas pressure of nitrogen (~775 hPa), oxygen (~205 hPa), water vapor (~10 hPa), argon (~10 hPa) carbon dioxide (~0.4 hPa) and a number of other gases with lower partial pressures.

Partial pressure of X: The proportion by volume of the various gases

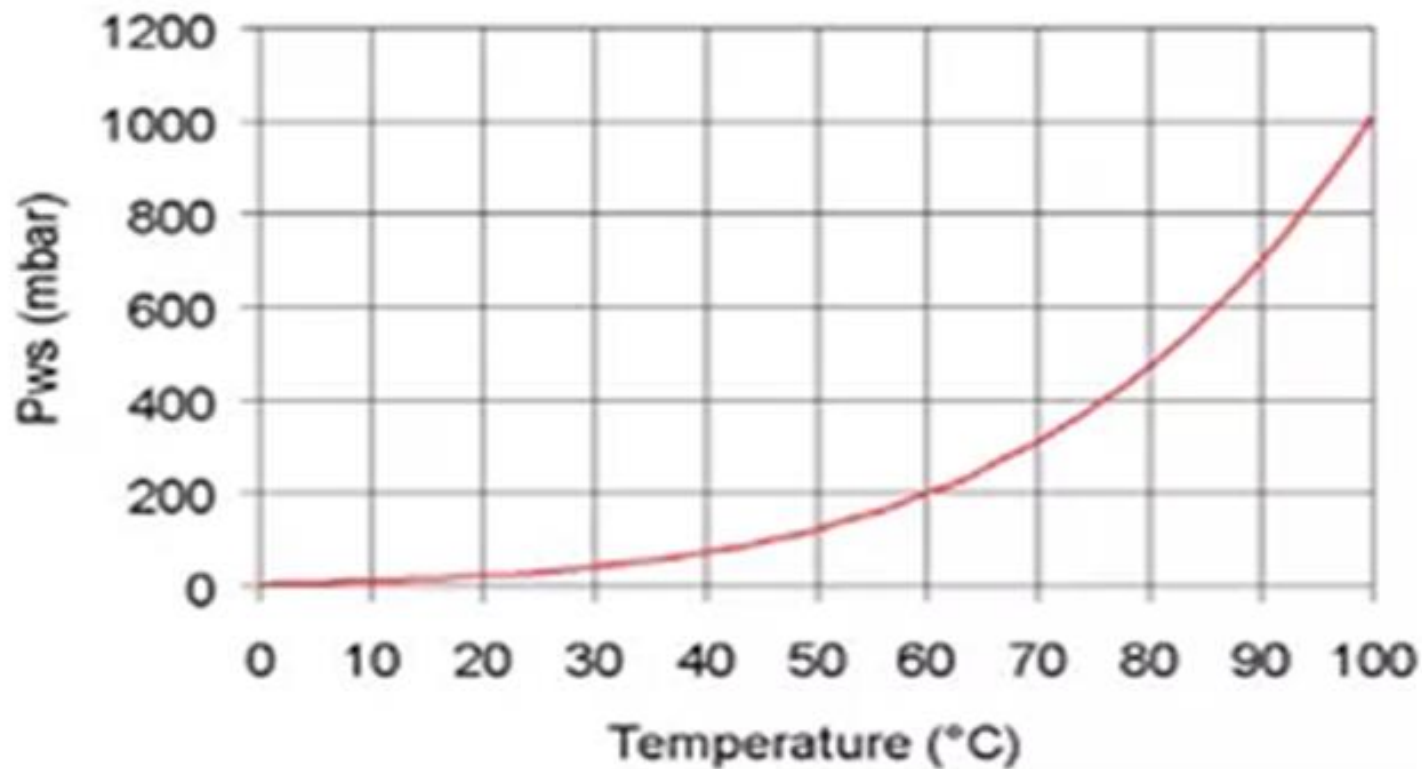
Air at sea level: 1013 millibar total pressure

Water Vapor Pressure - p_w

[hPa, PSI, Pa, mbar, mmHg, inHg, mmH₂O or inH₂O]

- The air temperature dictates the maximum partial water vapor pressure in air, in other words, the **water vapor saturation pressure**. The ability of water to be in gaseous form is strongly dependent on its temperature.
- The partial water vapor pressure in the immediate presence of liquid water equals the saturation pressure at that specific temperature.

Water vapor saturation pressure curve



Absolute Humidity & Specific Humidity

Absolute humidity refers to the weight of water in a certain volume of gas.



g m^{-3}



g/Kg

Mixing Ratio (r)

Mixing ratio defines the weight of water in the volume occupied by one kilogram of dry gas.

The density of air varies with pressure, so the mixing ratio is also dependent on the pressure of the gas.

$$r = \frac{m_{\text{water}}}{m_{\text{dry air}}}$$

Very similar to specific humidity

- Uses only dry air, where specific humidity uses the dry air PLUS the water vapor itself

Humidity mixing ratio

$$= \frac{mv}{md}$$

mv- mass of water vapor

md- mass of dry air

Humidity mixing ratio (*w*)

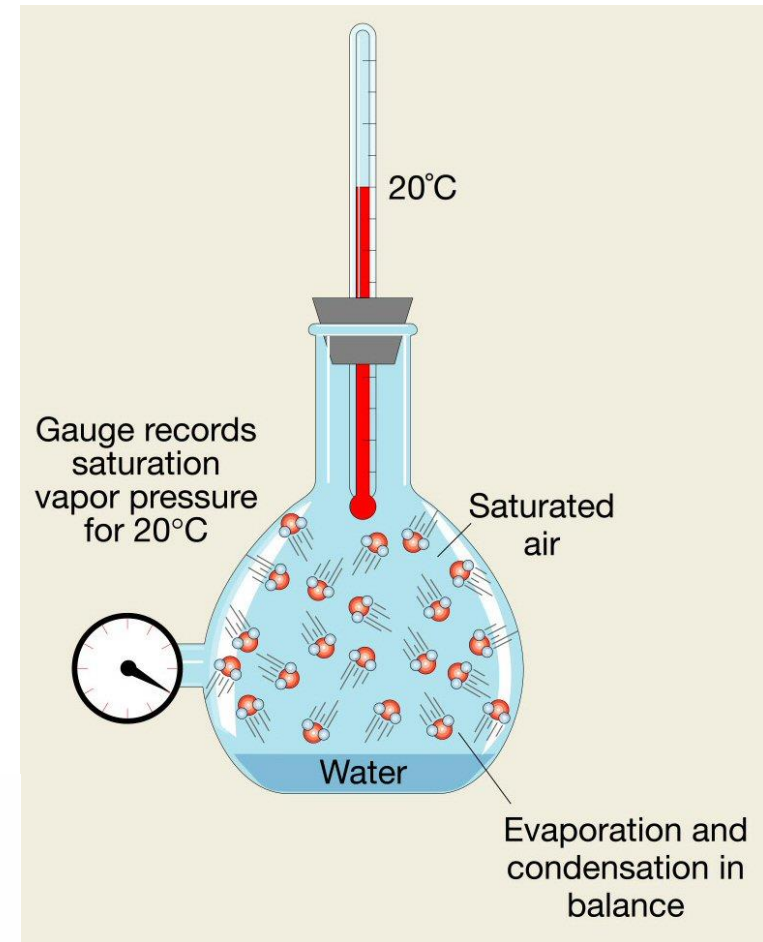
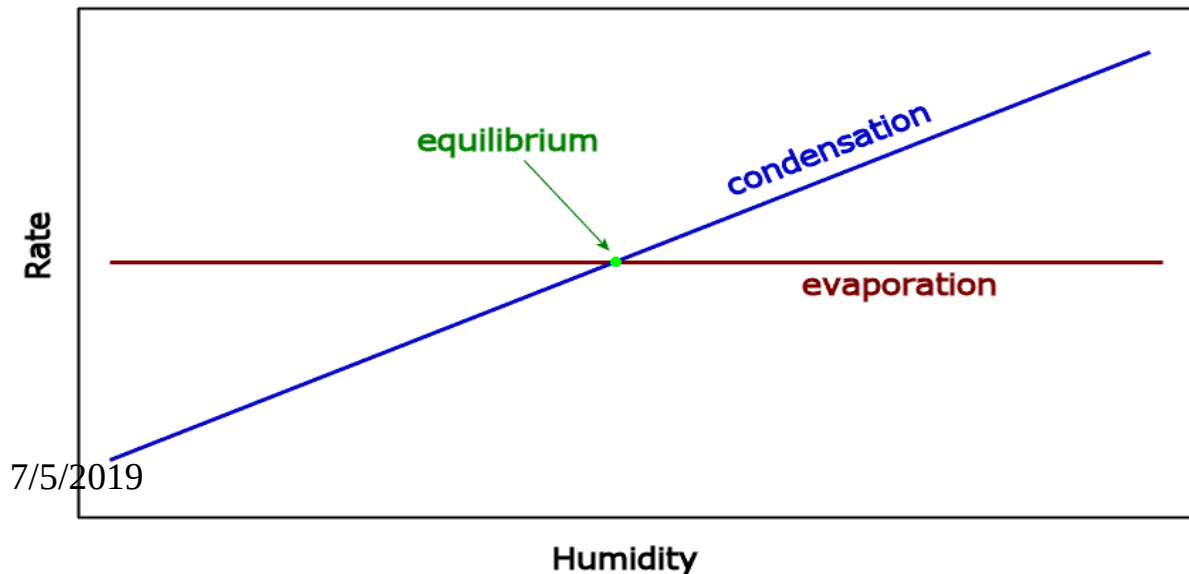
$$= \frac{\rho_v}{\rho_d}$$

ρ_v = Density of water vapor (Pa)

ρ_d = Density dry air (Pa)

Saturation mixing ratio

- Evaporation & Condensation
 - Rate of **evaporation** depends on **temperature**
 - Rate of **condensation** depends on **concentration** (abs. humidity)
 - For a given temp., there is some absolute humidity at which **evaporation = condensation**
 - Equilibrium, Saturation



Relative Humidity

- Humidity is most often expressed as a ratio of the amount of water vapor present in a given volume of air compared to the total amount of water vapor which that same unit of air could actually hold.
- This ratio we call relative humidity and it is always expressed as a percentage.
- When the relative humidity reaches 100%, the air has become saturated and water vapor will begin to condense into liquid water or ice crystals

Relative Humidity

$$RH = \frac{e}{e_s}$$

$$RH = \frac{p}{p_s}$$

$$RH = \frac{p}{p_s}$$

Relative Humidity

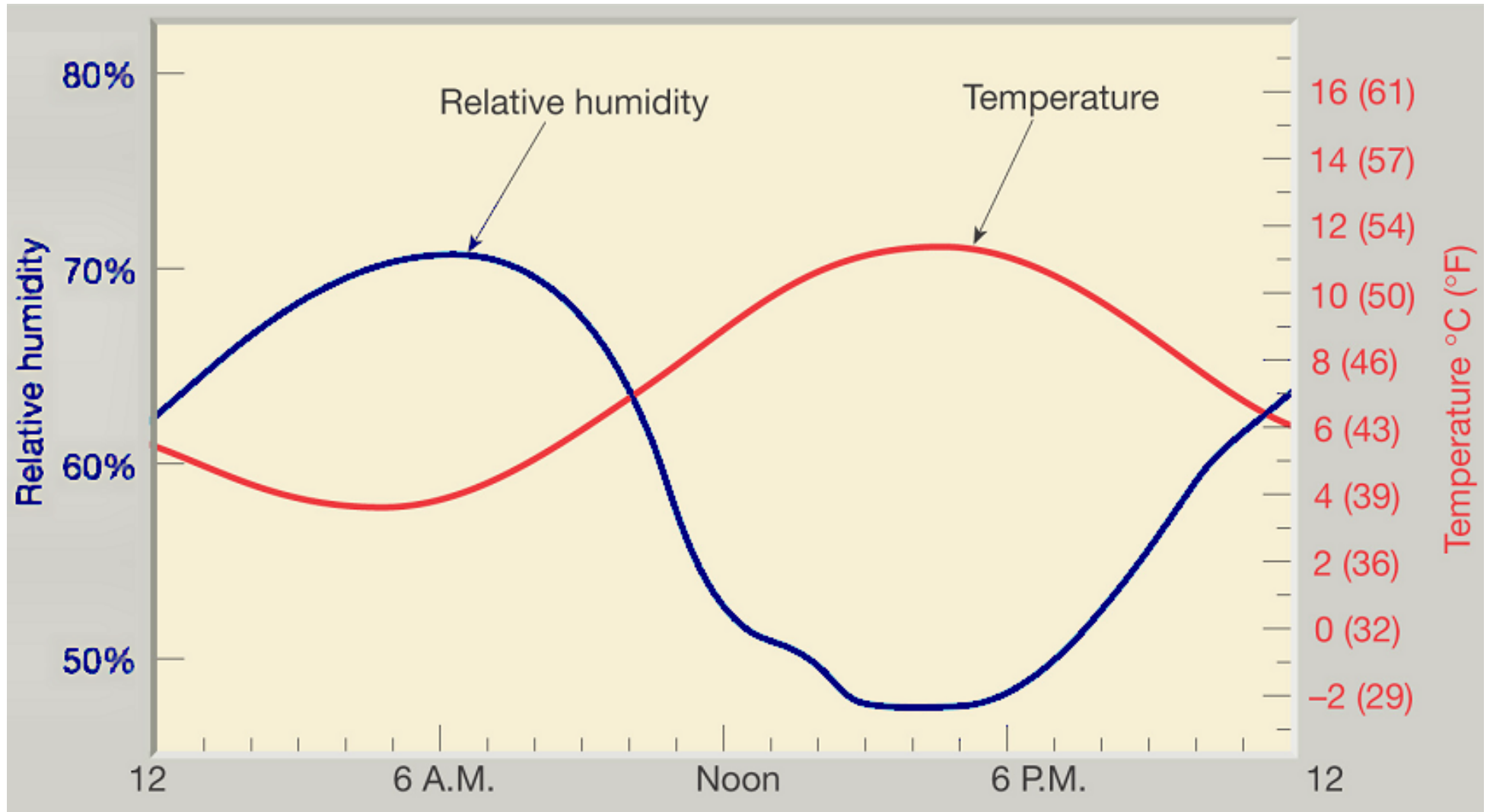
(3 equivalent definitions)

$$\frac{\text{Absolute humidity}}{\text{Saturation humidity}}$$

$$\frac{\text{Mixing ratio of water vapor}}{\text{Saturation mixing ratio}}$$

$$\frac{\text{Partial pressure of water vapor}}{\text{Saturation vapor pressure}}$$

Changing humidity during day



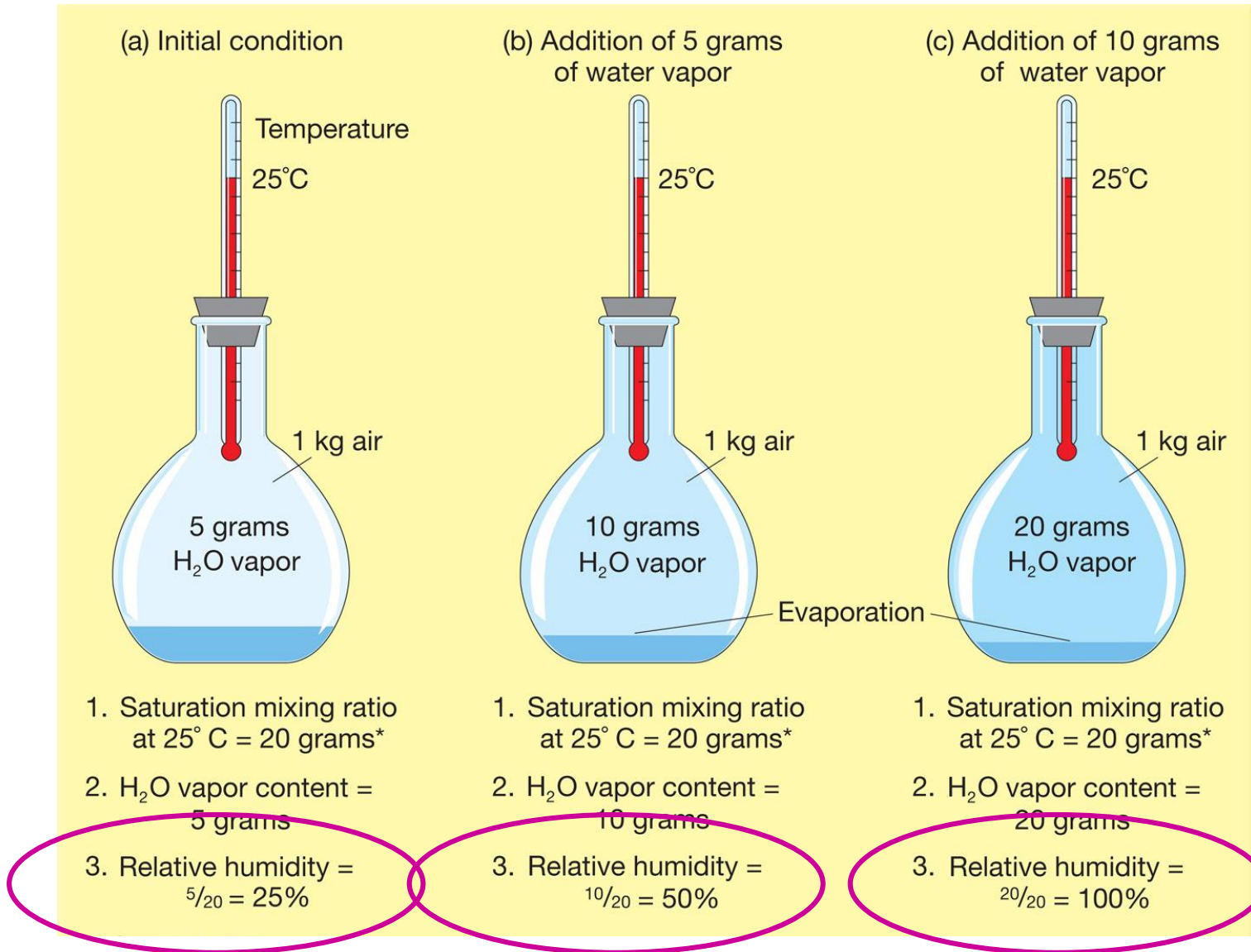
- Changing Temperature:
 - Daily (sunlight)
 - Advection (horizontal movement of air)
 - Convection (vertical movement of air)
- Changing Absolute Humidity:
 - Evaporation
 - Condensation
 - Mixing

Relative humidity

Temperature °C (°F)	Saturation Mixing Ratio g/kg
−40 (−40)	0.1
−30 (−22)	0.3
−20 (−4)	0.75
−10 (14)	2
0 (32)	3.5
5 (41)	5
10 (50)	7
15 (59)	10
20 (68)	14
25 (77)	20
30 (86)	26.5
35 (95)	35
40 (104)	47

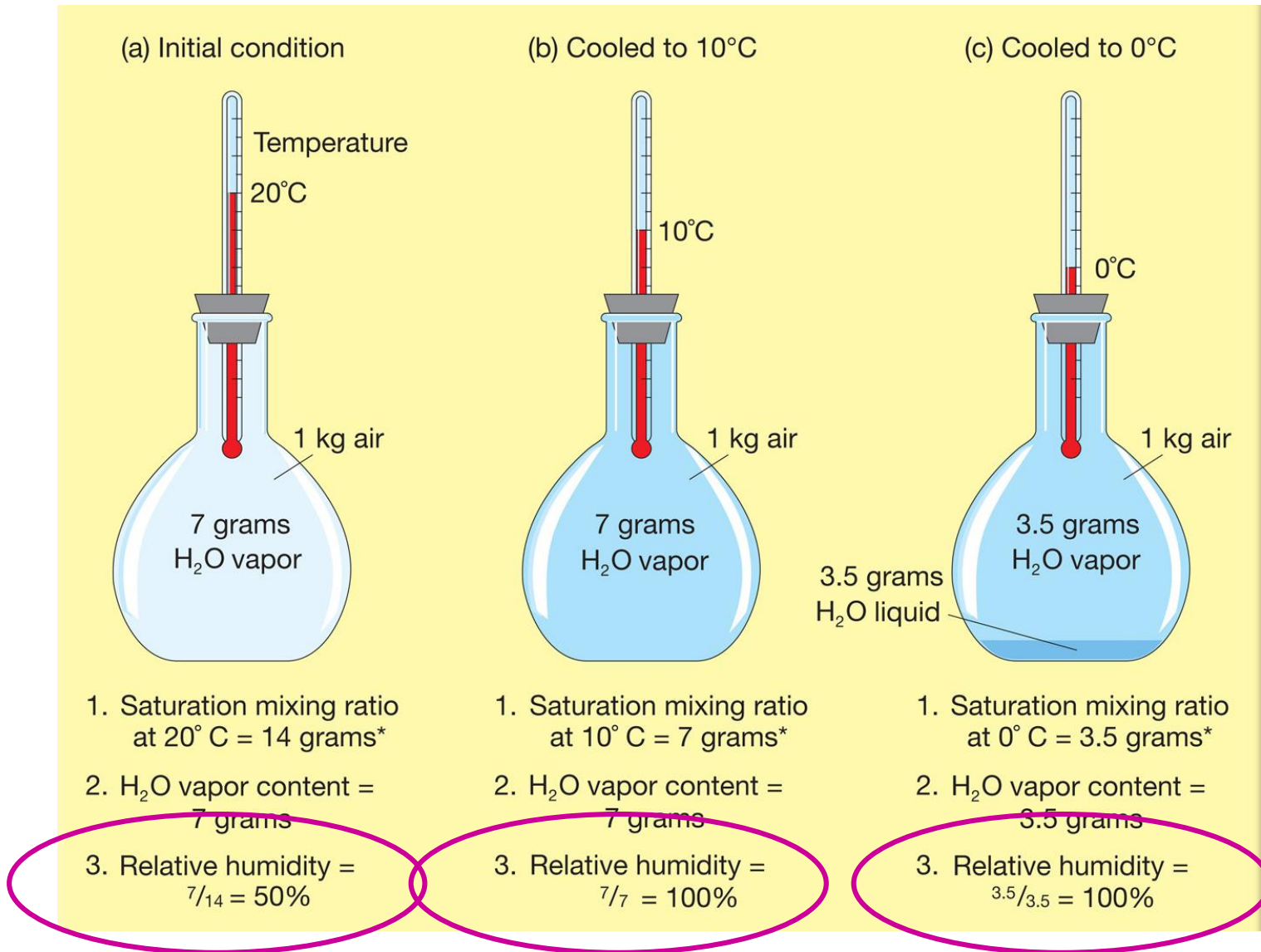
- What is the relative humidity if the mixing ratio of water vapor is 5 g/kg and the temperature is 25° C?

Relative Humidity



Changes with Added Moisture

Relative Humidity



Changes with Temperature

Relative Humidity

Temperature °C (°F)	Saturation Mixing Ratio g/kg
5 (41)	5
10 (50)	7
15 (59)	10
20 (68)	14
25 (77)	20
30 (86)	26.5
35 (95)	35
40 (104)	47

Temp	Mixing Ratio (g/kg)	Saturation Mixing Ratio (g/kg)	Relative Humidity
15°C	5		
15°C	9		
25°C	5		
25°C	2		
35°C	7		

Relative Humidity

Temperature °C (°F)	Saturation Mixing Ratio g/kg
5 (41)	5
10 (50)	7
15 (59)	10
20 (68)	14
25 (77)	20
30 (86)	26.5
35 (95)	35
40 (104)	47

Temp	Mixing Ratio (g/kg)	Saturation Mixing Ratio (g/kg)	Relative Humidity
15°C	5	10	50%
15°C	9	10	90%
25°C	5	20	25%
25°C	2	20	10%
35°C	7	35	20%

Dew Point Temperature

Dew point is the temperature where condensation begins, or where the relative humidity would be 100% if the air was cooled.

When $T < \text{dew point}$

Condensation

When $T > \text{dew point}$

Evaporation

Dew point temperature (Td)

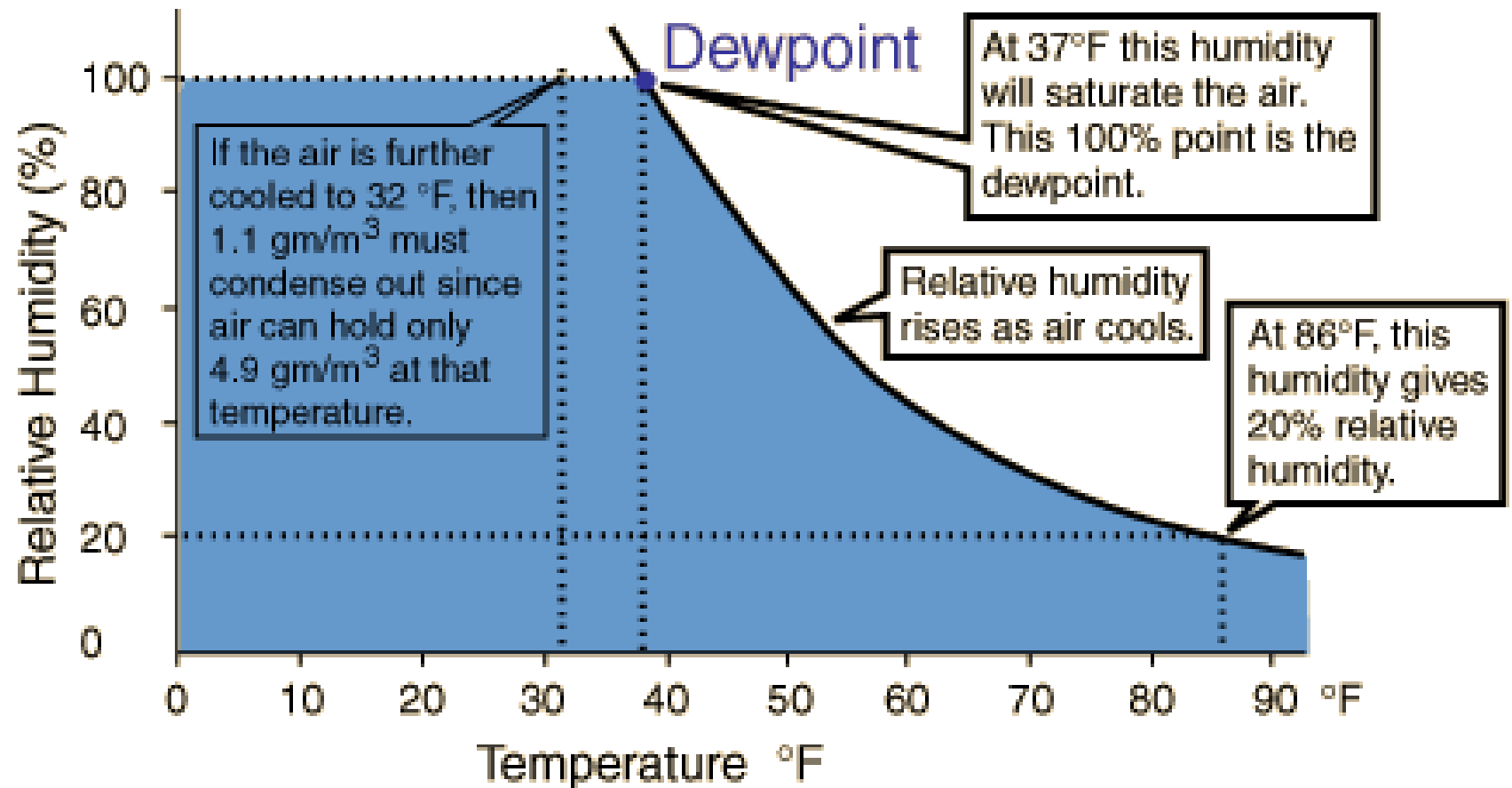
- The temperature at the air would become saturated (for water vapor to condense into water)if cooled at constant pressure.
- The dew point is a saturation point.
- For a given vapor pressure there is only one temperature at which air will be saturated.
- Hence Td is uniquely determined by the vapor pressure,

$$RH = \frac{e_s \text{ at } T_d}{e_s \text{ at air temperature}} \times 100$$

e_s - Saturation vapor pressure

Dewpoint

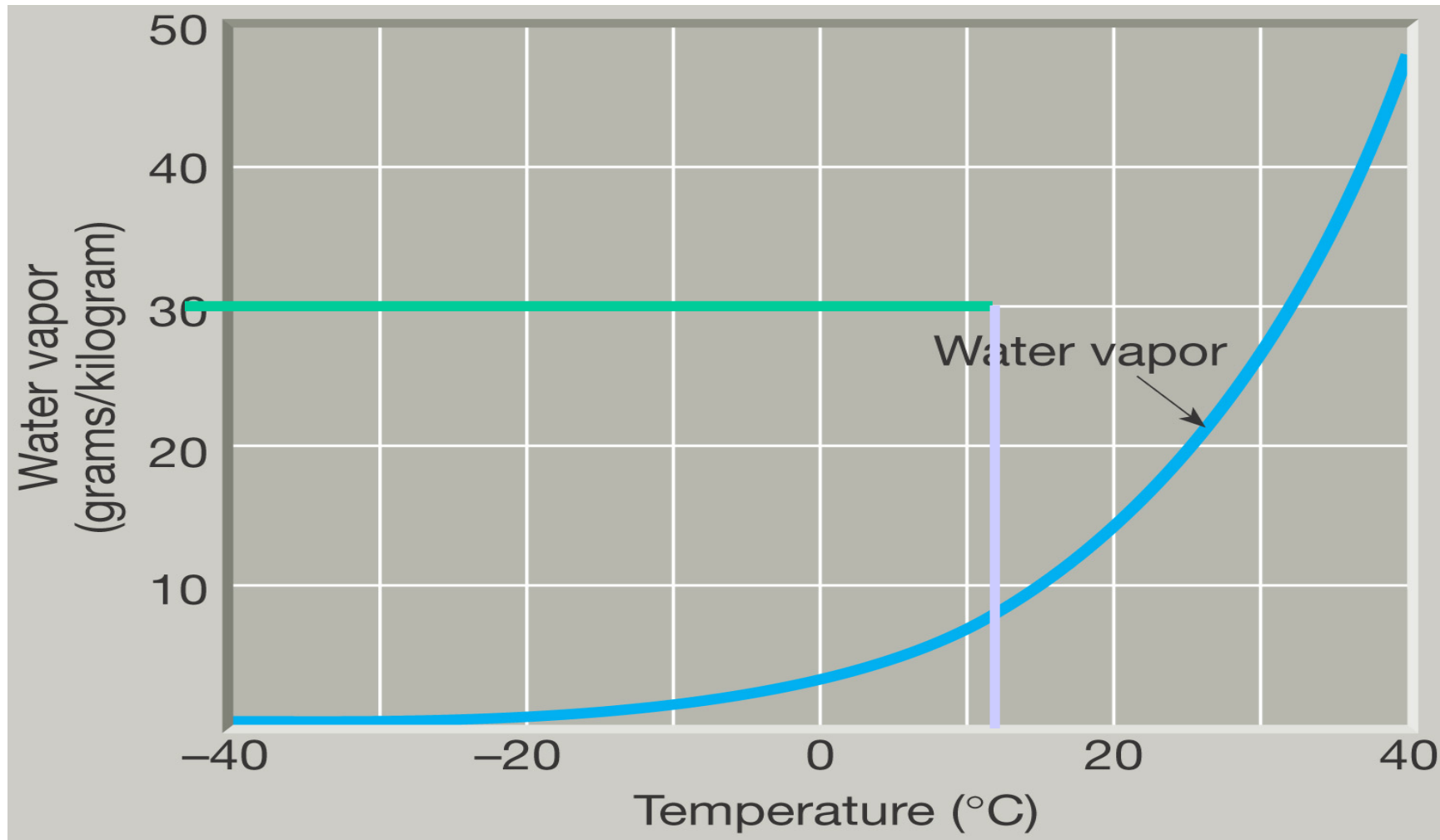
If the air is gradually cooled while maintaining the moisture content constant, the relative humidity will rise until it reaches 100%. This temperature, at which the moisture content in the air will saturate the air, is called the dew point. If the air is cooled further, some of the moisture will condense.



Saturation and dew point

- For some temperature, T :
 - **Saturation mixing ratio** = *How much water vapor at equilibrium?*
- For some mixing ratio M :
 - **Dewpoint** = *For what temperature would M be saturated?*

Determining dew point



- What is dewpoint for a mixing ratio of 30 g/kg?

7/5/2019 – Around 32°C

How to find dew point

Temperature °C (°F)	Saturation Mixing Ratio g/kg
−40 (−40)	0.1
−30 (−22)	0.3
−20 (−4)	0.75
−10 (14)	2
0 (32)	3.5
5 (41)	5
10 (50)	7
15 (59)	10
20 (68)	14
25 (77)	20
30 (86)	26.5
35 (95)	35
40 (104)	47

- What is the dew point if the mixing ratio of water vapor is 10 g/kg?

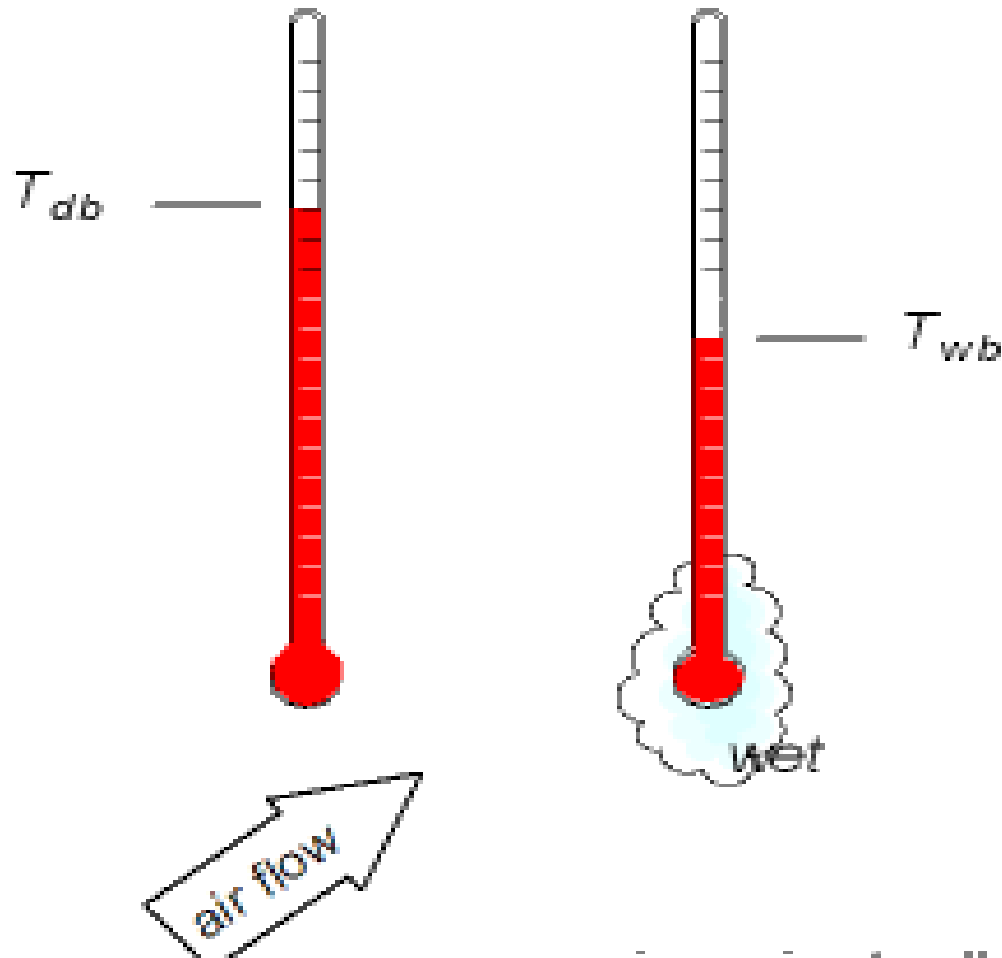
Frost point T_f [$^{\circ}\text{C}$ or $^{\circ}\text{F}$]

Wet bulb and Dry bulb temperature

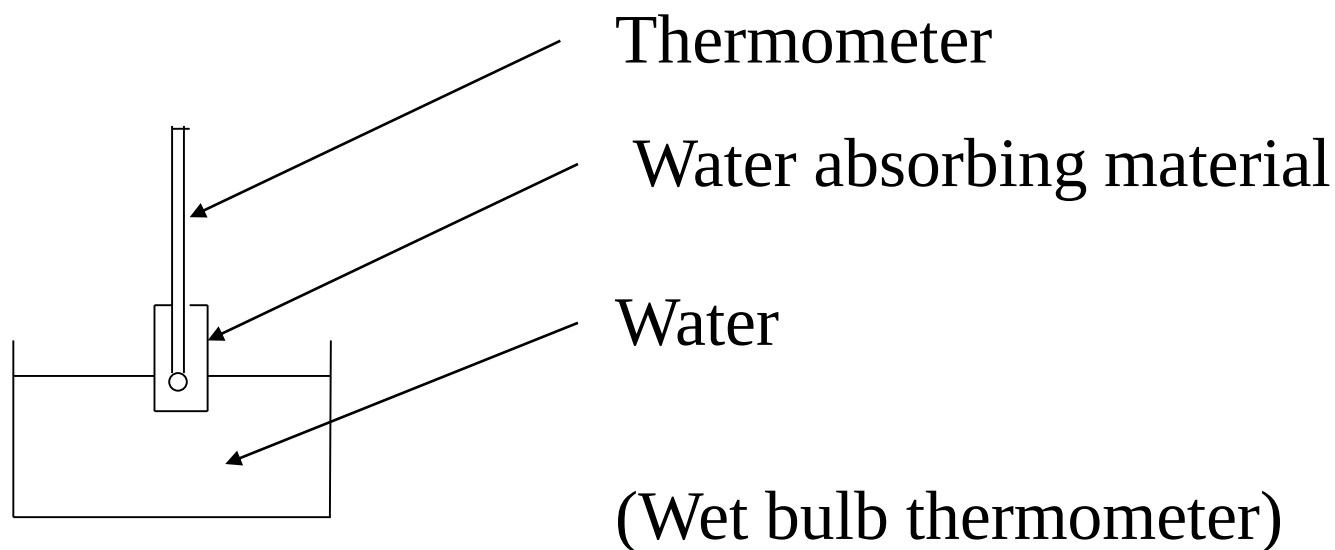
- The Dry Bulb Temperature refers basically to the ambient air temperature.
- It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air.
- The Wet Bulb temperature is the temperature of adiabatic saturation. This is the temperature indicated by a moistened thermometer bulb exposed to the air flow.
- The rate of evaporation from the wet bandage on the bulb, and the temperature difference between the dry bulb and wet bulb, depends on the humidity of the air. The evaporation is reduced when the air contains more water vapor.

- As water evaporates, it consumes heat. This cooling effect depends on the ambient temperature and the difference between the water vapor pressure of the ambient air and the saturation pressure at that temperature.
- By measuring the cooling effect, it is therefore possible to determine the ambient relative humidity.
- The cooling effect is measured with a psychrometer, an instrument with two thermometers, one of which is covered by a wet cloth.
- The reading of this thermometer is called the wet bulb temperature. Wet bulb temperature can also be calculated from the temperature, pressure and relative humidity.

- The wet bulb temperature is always lower than the dry bulb temperature but will be identical with 100% relative humidity.



- In here dry bulb temperature gives normal air temperature
 $=T_d = T$.
- Wet bulb temperature gives saturation air temperature. (T_w)





THANK YOU