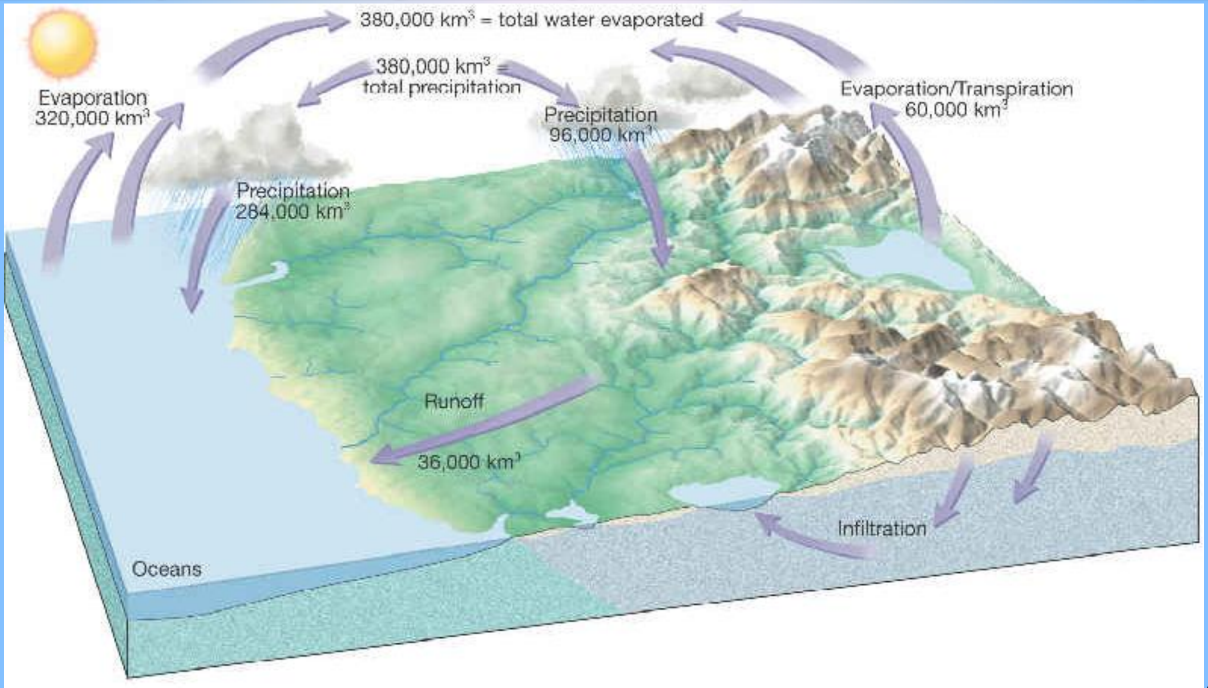
V. Moisture in the Atmosphere

A. The Hydrologic Cycle (or Water Cycle)



1. A huge system powered by Energy from the Sun in which the atmosphere is the link between ___oceans___ and ___continents___.
2. A continuous exchange of water among ___oceans___, the ___atmosphere___ and the ___continents___.
3. Water leaves Earth's surface by:
   a. ___Evaporation___ from surface water.
   b. ___Transpiration___ from plants
   c. ___Evapotranspiration___: The combined total of evaporation and transpiration for a region is usually used in climate data.
   d. Water returns to Earth's surface as ___precipitation___ (after cloud formation).

3. Water Budget (Balance)

a. A___quantitative (mathematical)___ depiction of the water cycle.

b. Amount of water cycled through the atmosphere yearly is immense (380,000 cubic kilometers) even though the amount of water vapor in the air is a___small___ fraction of this total water supply.

c. Average annual precipitation over Earth is___equal___ to the quantity of water evaporated.

(1) Over continents: precipitation is___greater___ than evaporation

(2) Over oceans:___evaporation___ is greater than ___precipitation___ (Runoff from land areas keeps the ocean level constant).

B. Change in Phase (State) of Water

1. Requires the **addition** or **loss** of heat

   a. **Calorie/Joule**: The amount of heat necessary to raise the temperature of one gram of water one degree Celsius.

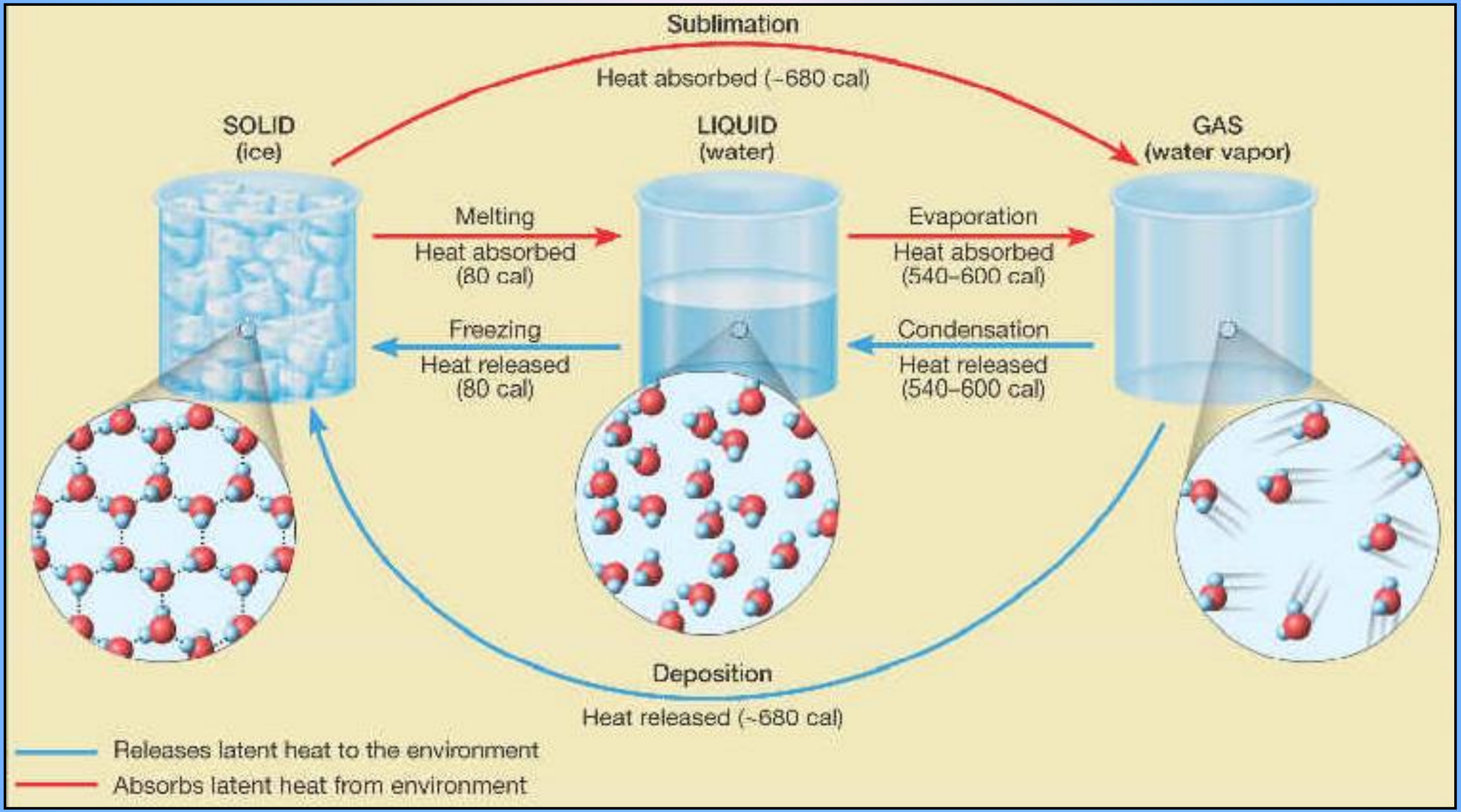
   Correct this in your notes

   b. **Latent** Heat:

   (1) Heat exchanged between water and its surroundings when water changes phase.

   (2) Latent refers to “hidden” heat.

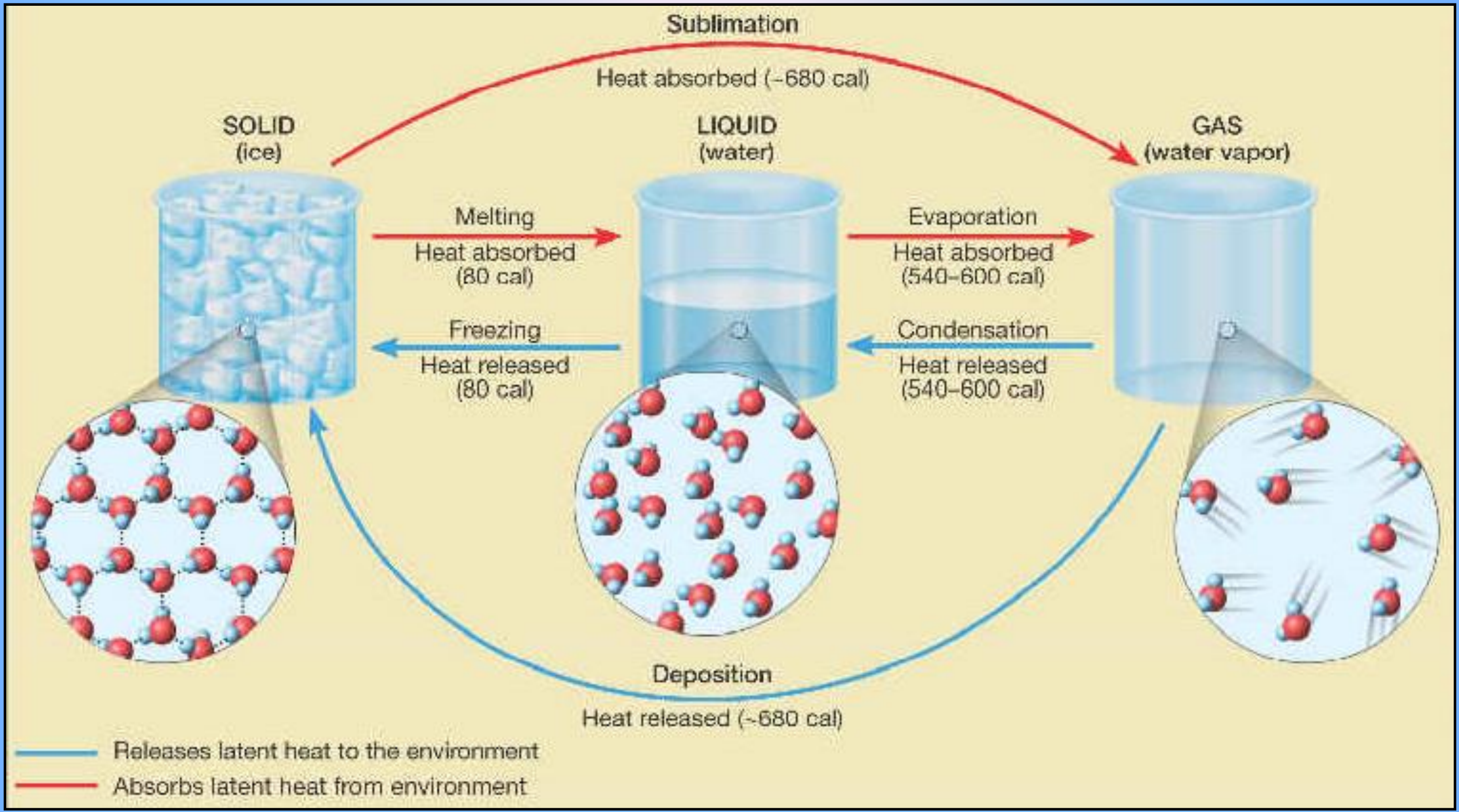
2. Changes in State



a. Melting:
   (1) __Solid__ water changes phase to __liquid__
   (2) Requires the __addition__ of heat which is stored as __latent heat of fusion (melting)__

b. Evaporation: (is a cooling process – removes heat from its environment)
   (1) __Liquid__ water changes phase to __water vapor__
   (2) Requires the __addition__ of heat which is stored as __latent heat of vaporization__

2. Changes in State



c. Condensation: (Warming process- releases heat back to the environment)

(1) _**Water vapor**_____changes phase to ___**liquid**__________

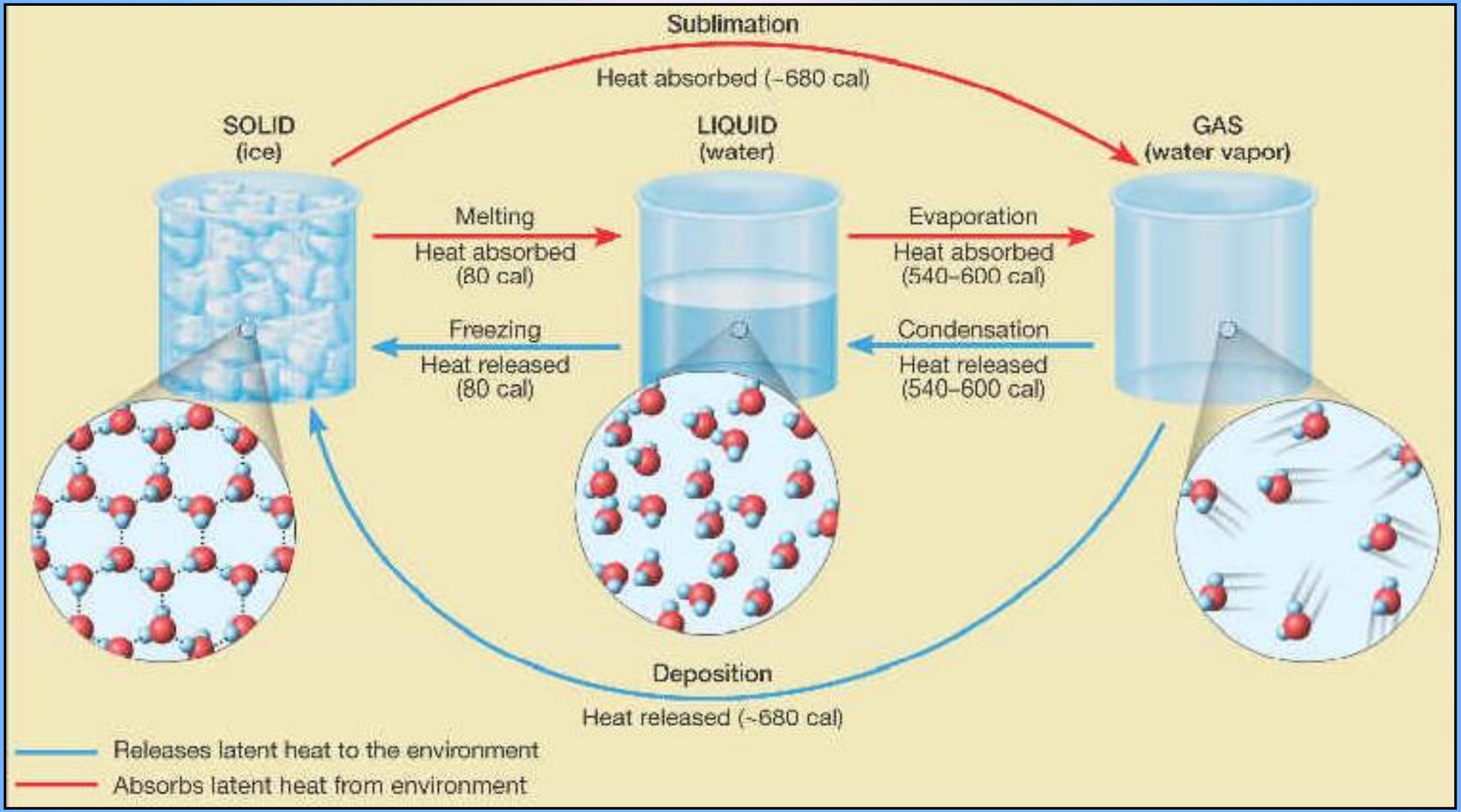
(2) Requires the _**loss** of heat which is released as_______**latent heat**____

d. Freezing:

(1) __**Liquid**_______water changes phase to __**solid (ice)**______

(2) Requires the __**loss**__ of heat ~~(cooling processes~~) which is released as _**latent heat**______

e. Sublimation and Deposition



(1) Sublimation is a phase change in which the **liquid phase is skipped**.

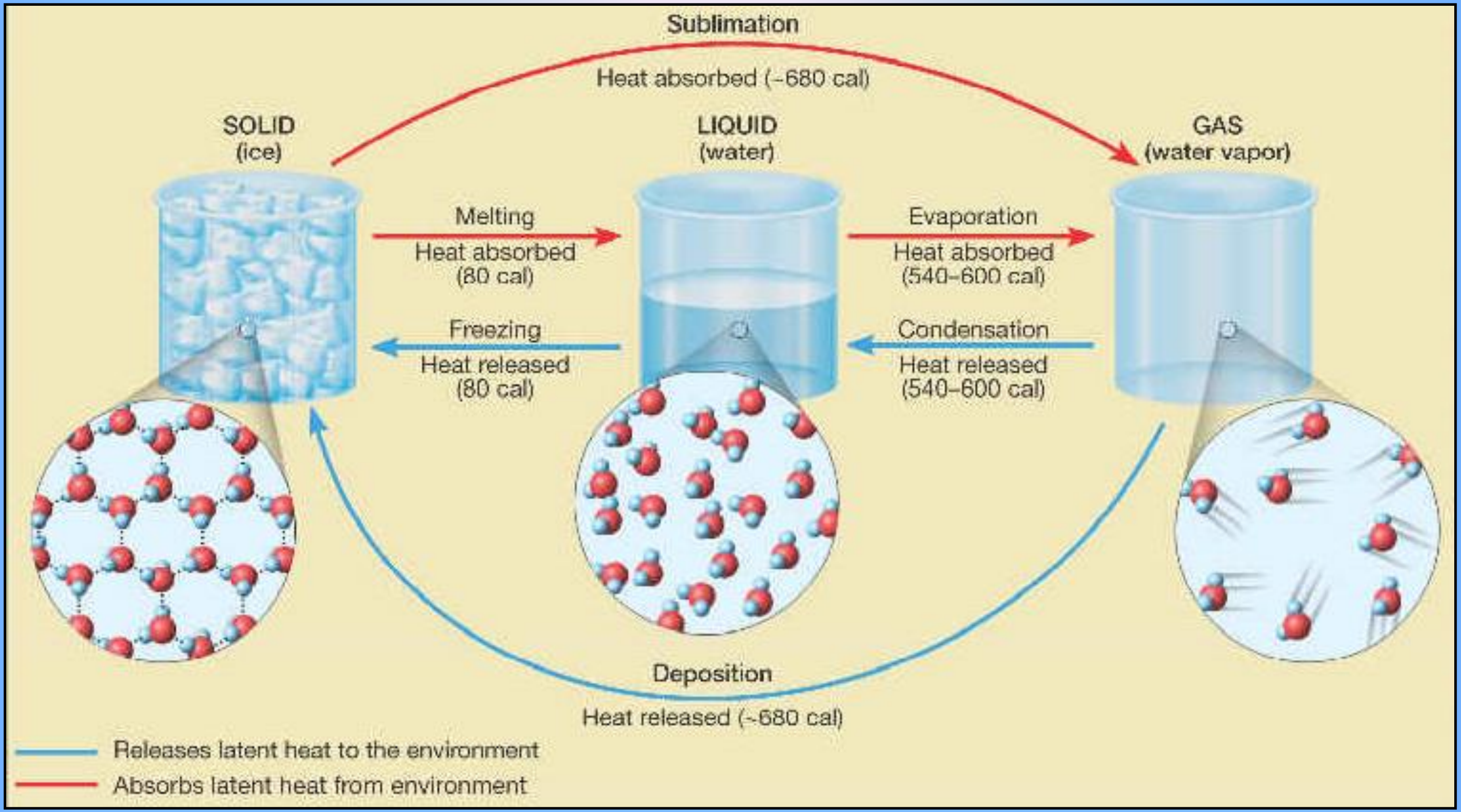
(2) Chemists use the term for:

  (a) Solid changing phase directly to gas

  (b) Gas changing phase directly to solid.

(3) Meteorologists use the term sublimation only for the phase change of **solid (ice) to liquid**.

(4) Deposition



(a) This is the term meteorologists use for gas changing phase directly to solid.

(b) Water vapor is deposited as ice on solid objects

- (i) Formation of “cold” clouds (temperatures below freezing).
- (ii) Frost

Latent Heat in the ESRT

The University of the State of New York • THE STATE EDUCATION DEPARTMENT • Albany, New York 12234 • www.nysed.gov

Reference Tables for Physical Setting/EARTH SCIENCE

Radioactive Decay Data

RADIOACTIVE ISOTOPE	DISINTEGRATION	HALF-LIFE (years)
Carbon-14	$^{14}C \rightarrow {}^{14}N$	5.7×10^3
Potassium-40	$^{40}K \rightarrow {}^{40}Ar$, ^{40}Ca	1.3×10^9
Uranium-238	$^{238}U \rightarrow {}^{206}Pb$	4.5×10^9
Rubidium-87	$^{87}Rb \rightarrow {}^{87}Sr$	4.9×10^{10}

Specific Heats of Common Materials

MATERIAL	SPECIFIC HEAT (Joules/gram • °C)
Liquid water	4.18
Solid water (ice)	2.11
Water vapor	2.00
Dry air	1.01
Basalt	0.84
Granite	0.79
Iron	0.45
Copper	0.38
Lead	0.13

Equations

$$\text{Eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}}$$

$$\text{Gradient} = \frac{\text{change in field value}}{\text{distance}}$$

$$\text{Rate of change} = \frac{\text{change in value}}{\text{time}}$$

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Properties of Water

Heat energy gained during melting . . . . 334 J/g
Heat energy released during freezing . . . . 334 J/g
Heat energy gained during vaporization . . . . . 2260 J/g
Heat energy released during condensation . . . 2260 J/g

Density at 3.98°C . . . . 1.0 g/mL

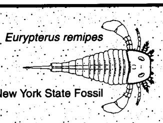
Average Chemical Composition of Earth's Crust, Hydrosphere, and Troposphere

ELEMENT (symbol)	CRUST		HYDROSPHERE	TROPOSPHERE
	Percent by mass	Percent by volume	Percent by volume	Percent by volume
Oxygen (O)	46.10	94.04	33.0	21.0
Silicon (Si)	28.20	0.88		
Aluminum (Al)	8.23	0.48		
Iron (Fe)	5.63	0.49		
Calcium (Ca)	4.15	1.18		
Sodium (Na)	2.36	1.11		
Magnesium (Mg)	2.33	0.33		
Potassium (K)	2.09	1.42		
Nitrogen (N)				78.0
Hydrogen (H)			66.0	
Other	0.91	0.07	1.0	1.0

2010 EDITION

This edition of the Earth Science Reference Tables should be used in the classroom beginning in the 2009–2010 school year. The first examination for which these tables will be used is the January 2010 Regents Examination in Physical Setting/Earth Science.

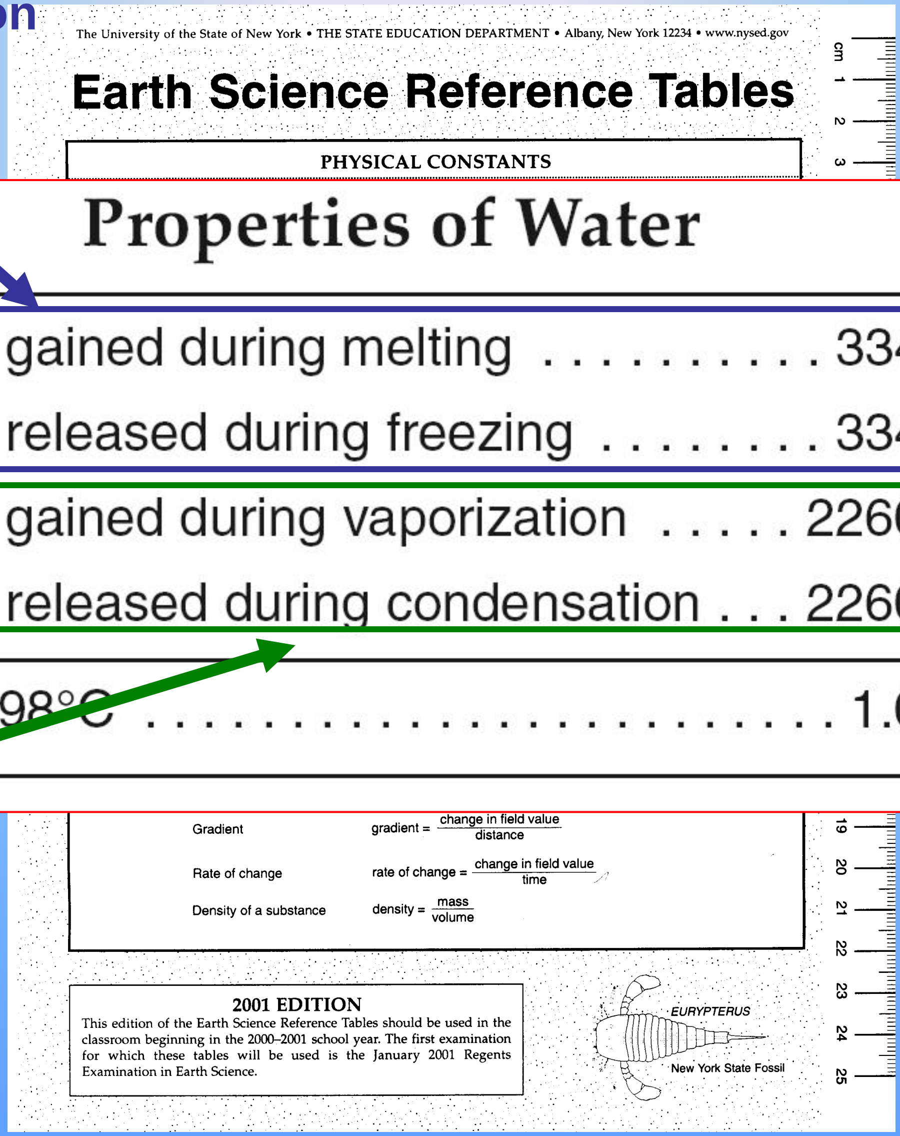
Eurypterus remipes



New York State Fossil

Latent Heat in the ESRT

Latent Heat of Fusion


The University of the State of New York • THE STATE EDUCATION DEPARTMENT • Albany, New York 12234 • www.nysed.gov

Earth Science Reference Tables

PHYSICAL CONSTANTS

Gradient gradient = $\frac{\text{change in field value}}{\text{distance}}$

Rate of change rate of change = $\frac{\text{change in field value}}{\text{time}}$

Density of a substance density = $\frac{\text{mass}}{\text{volume}}$

2001 EDITION

This edition of the Earth Science Reference Tables should be used in the classroom beginning in the 2000–2001 school year. The first examination for which these tables will be used is the January 2001 Regents Examination in Earth Science.

Properties of Water

Heat energy gained during melting	334 J/g
Heat energy released during freezing	334 J/g
Heat energy gained during vaporization	2260 J/g
Heat energy released during condensation	2260 J/g
Density at 3.98°C	1.0 g/mL

Latent Heat of Vaporization

Latent Heat Gained or Lost Can be Calculated Using the Following Equations

- Latent Heat for solid $\rightleftharpoons$ Liquid

$$Q = m \cdot H_f$$

  - Where:
    - Q = Heat Lost or Gained
    - m = Mass in grams
    - H_f = Latent Heat of Fusion
- Latent Heat for liquid $\rightleftharpoons$ gas

$$Q = m \cdot H_v$$

  - Where:
    - H_v = Latent Heat of Vaporization

Sample Problem

- How much heat energy is required to vaporize 10 grams of ice?
  - First determine the amount of heat necessary to melt the ice.

$Q = m \cdot H_f$

Grams cancel leaving calories

$$Q = (10\cancel{g})\left(\frac{334\ J}{\cancel{g}}\right)$$

$$\boxed{Q = 3{,}340\ J}$$

- Next determine how much additional heat must be added to the liquid water to change it from liquid to gas.

$$Q = m \bullet H_v$$

$$Q = (10\cancel{g})\left(\frac{2260\ J}{\cancel{g}}\right)$$

$$\boxed{Q = 22{,}600\ J}$$

- **Total Heat = Heat required to melt the ice plus the heat required to evaporate the water.**
- **$Q = 3{,}340\ J + 22{,}600\ J$**
- **$Q = 25{,}940\ J$**

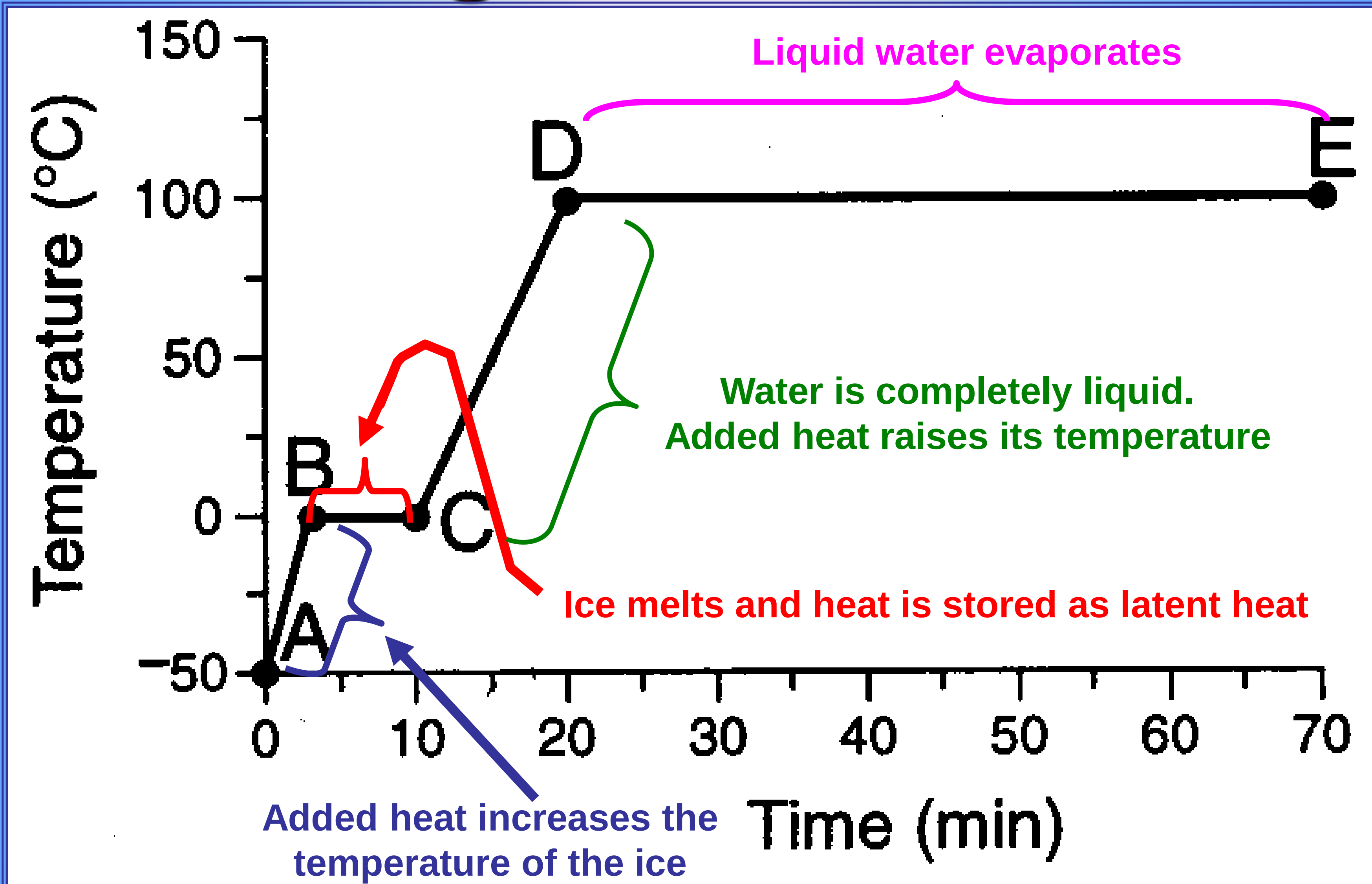
Good Morning ☺

- Please pass both Text HWs to the right..
- HW tonight…
  - ***"Atmospheric Moisture Wksht."***
    - 1. Finish Part A (UPCO RB -on Dew Point # 1-15)
    - 2. READ finding Rel. Humidity using Sat. Vap. Press.
    - 3. Complete Part B. (# 1-3)

Today:

- finding Rel. Humidity using Sat. Vap. Press.
- finding Cloud Base Altitude
- Can we make a cloud?
- Why is Seattle, WA so rainy?

Heating Curve for Water



- Try Properties of Water Questions (ESRT packet)

C. Humidity: Water Vapor in the Air

1. Humidity: The general term to describe the amount of water vapor in the air. Meteorologists use several methods to express the water-vapor content of air.

We will consider three methods to express the water vapor content of air

- **Mixing Ratio**
- **Specific Humidity**
- **Relative Humidity**

a. Mixing Ratio

(1) The **mass** of water vapor in a unit of air compared to the remaining mass of dry air.

(2) Expressed as:

$$\text{Mixing Ratio} = \frac{\text{mass of water vapor (grams)}}{\text{mass of dry air (kg)}}$$

(3) Not affected by changes in **pressure** or **temperature**

b. Specific Humidity

(1) Mass of water vapor in a unit mass of air *including* water vapor.

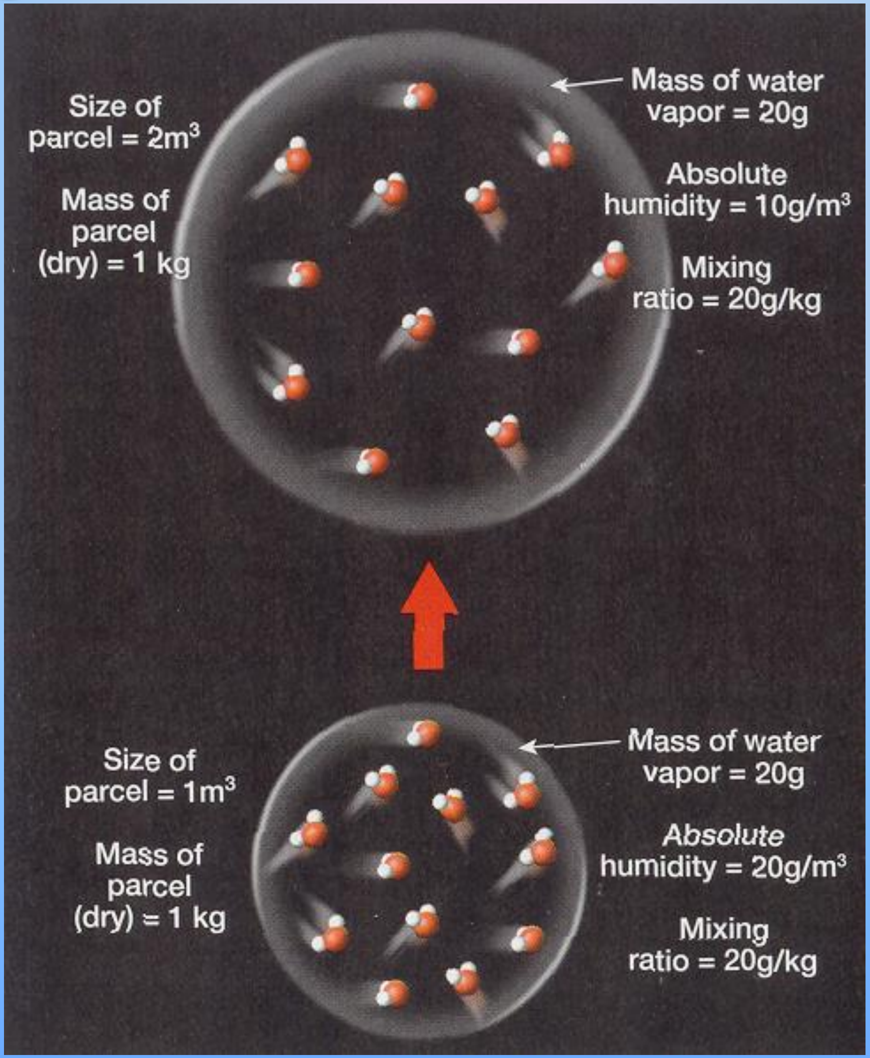
(2) Amount of water vapor is usually very low, only a few percent of the total mass.

(3) Considered the equivalent of <u>mixing ratio</u>

Absolute Humidity

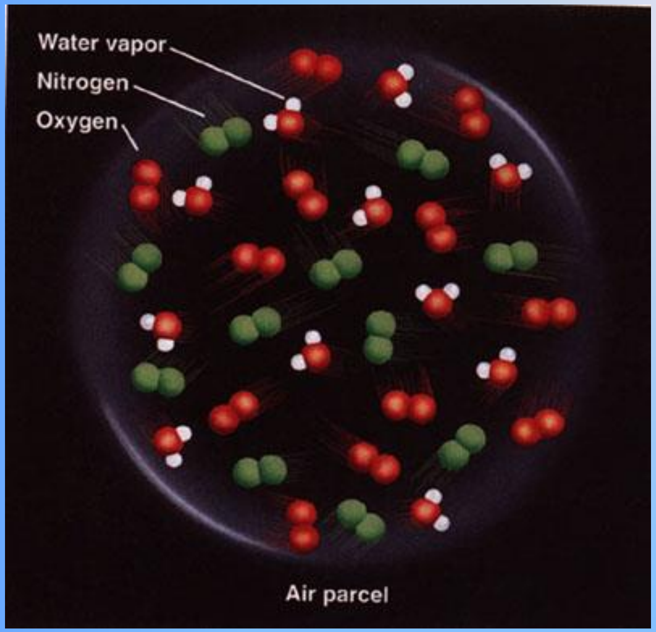
- The Ratio of **mass** of water vapor to the **volume** of air –water vapor mixture
- grams/meter^3
- Absolute humidity in air ranges from zero to roughly 30 grams per cubic meter when the air is saturated at 30 °C.

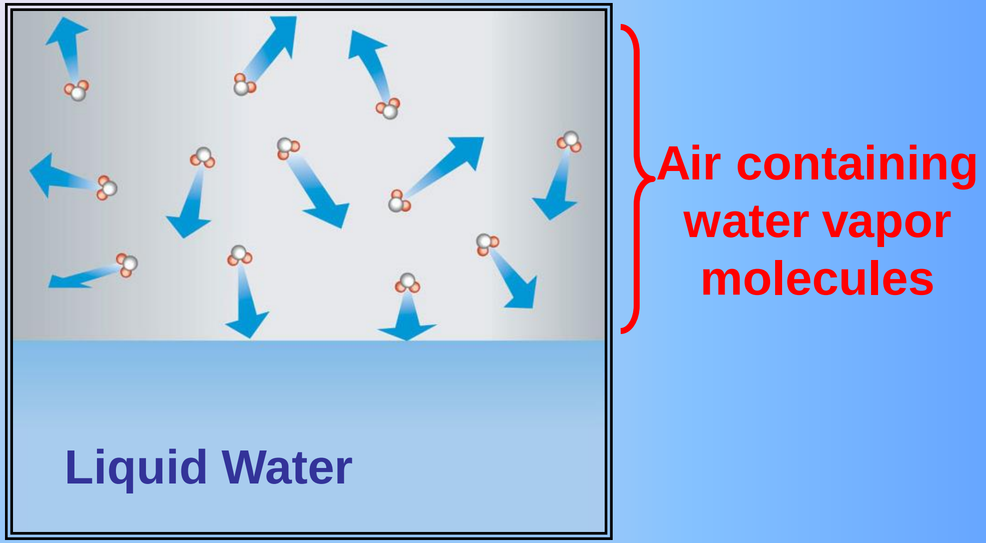
Mixing Ratio vs. Absolute Humidity



- Mixing ratio is not affected by changes in pressure as the parcel of air rises and expands.

2. Vapor Pressure and Saturation





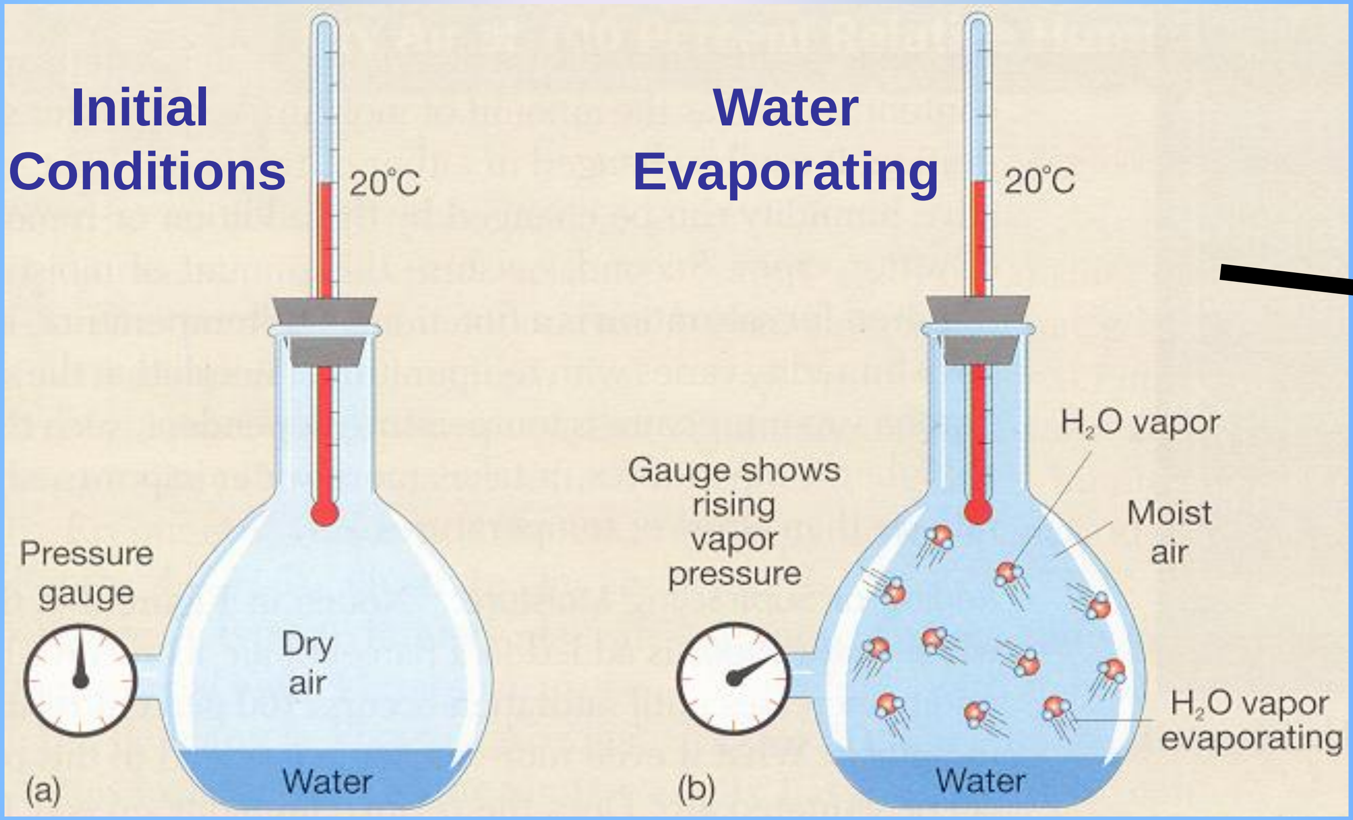
Vapor pressure may range from only 1 mb to 16 mb of the total air pressure reading.

a. Vapor Pressure:

(1) The _**partial**_ pressure that results from the addition of water vapor molecules.

(2) The part of the total atmospheric pressure due to _**water vapor**_ content.

b. Saturation (how does it occur?)



(1) Initially, many **more** molecules will leave the water surface than will **return**. (Evaporation occurs at a greater rate than condensation.)

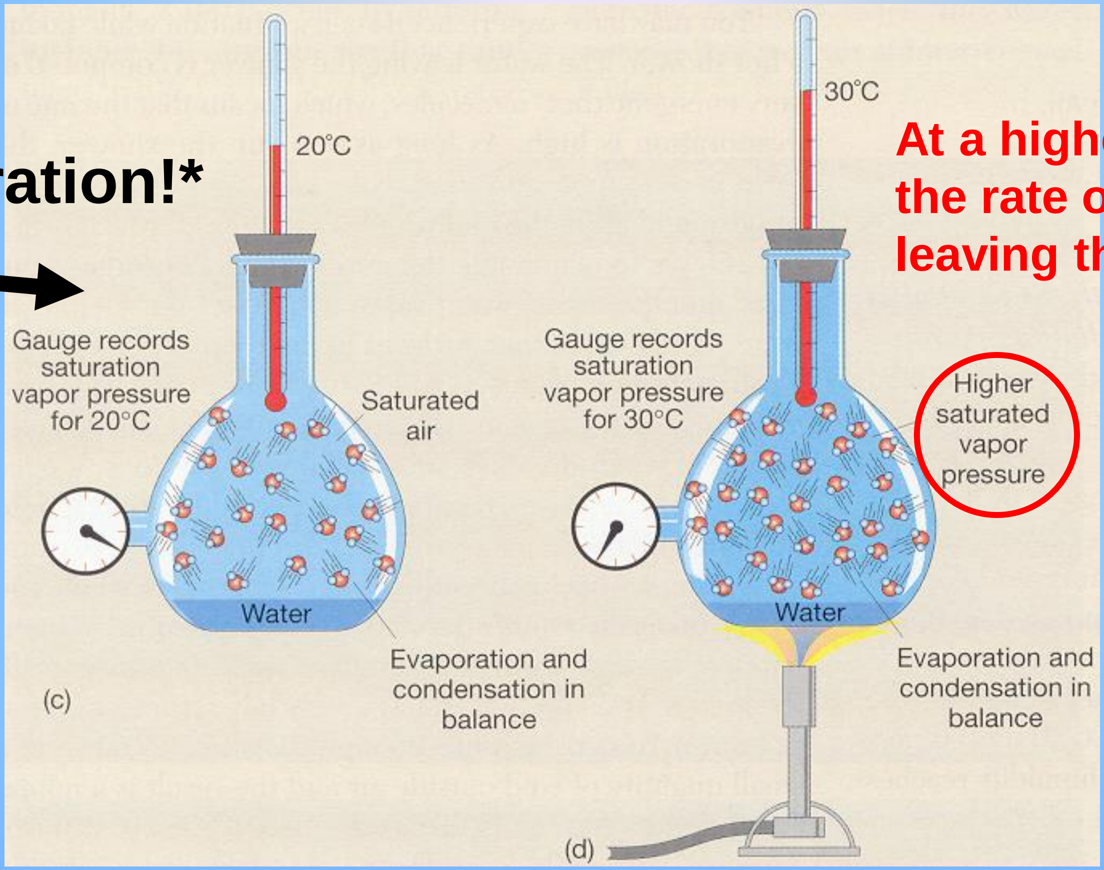
(2) As more water molecules evaporate and enter the air.

(a) Vapor pressure **increases** in the air **above** the liquid.

(b) This forces more water molecules to **return** **to the liquid (condense).**

3. The air is saturated when:

Saturation!

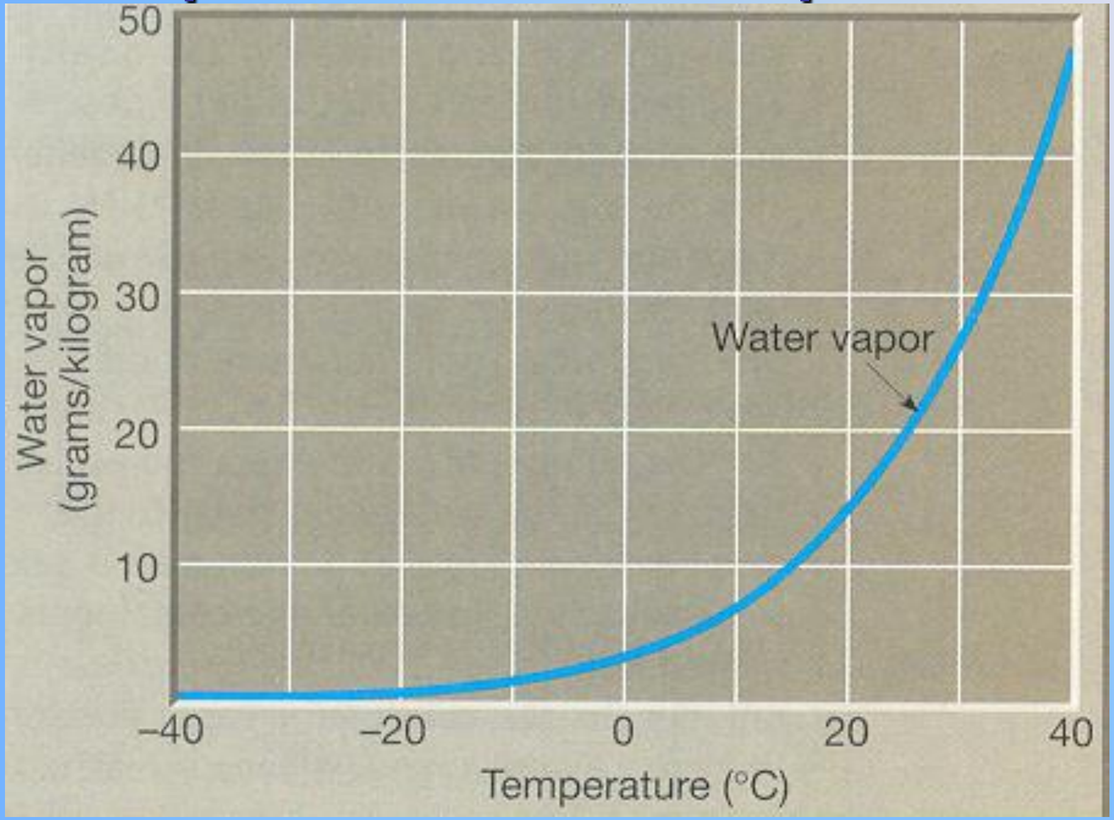


At a higher temperature the rate of water molecules leaving the liquid increases

a. The number of molecules of water returning to the liquid __balances__ the number leaving.

b. __Saturation__ Vapor Pressure: The partial vapor pressure exerted by the motion of the water vapor molecules when the air is saturated.

(c) Saturation Vapor Pressure is Temperature Dependent



(i) As temperature **increases**, the rate at which water molecules leave the liquid **increases**.

(ii) Vapor pressure in the air above increases until a new **equilibrium** is reached.

(iii) Therefore, at **higher** temperatures it takes **more** water vapor to saturate the air.

3. Relative Humidity

a. Ratio of the air's __**actual**__ water vapor content compared with the amount of water vapor required for ____**saturation**________ at that temperature.

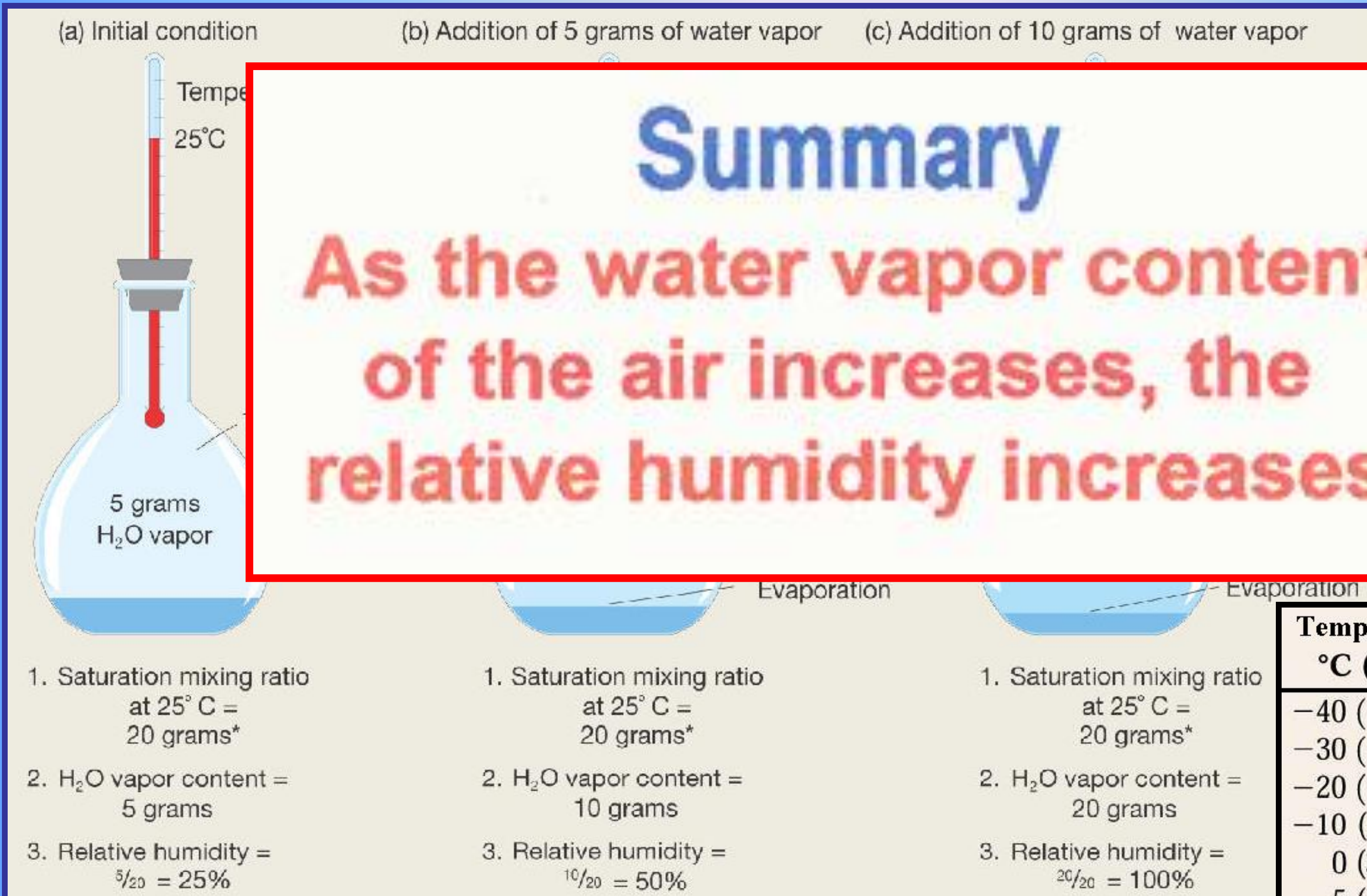
b. Saturated air has a relative humidity of __**100**__percent.

c. Relative humidity can change as a result of:

(1) Changing the amount of moisture in the air

(2) Temperature change of the air

Changing the Amount of Moisture



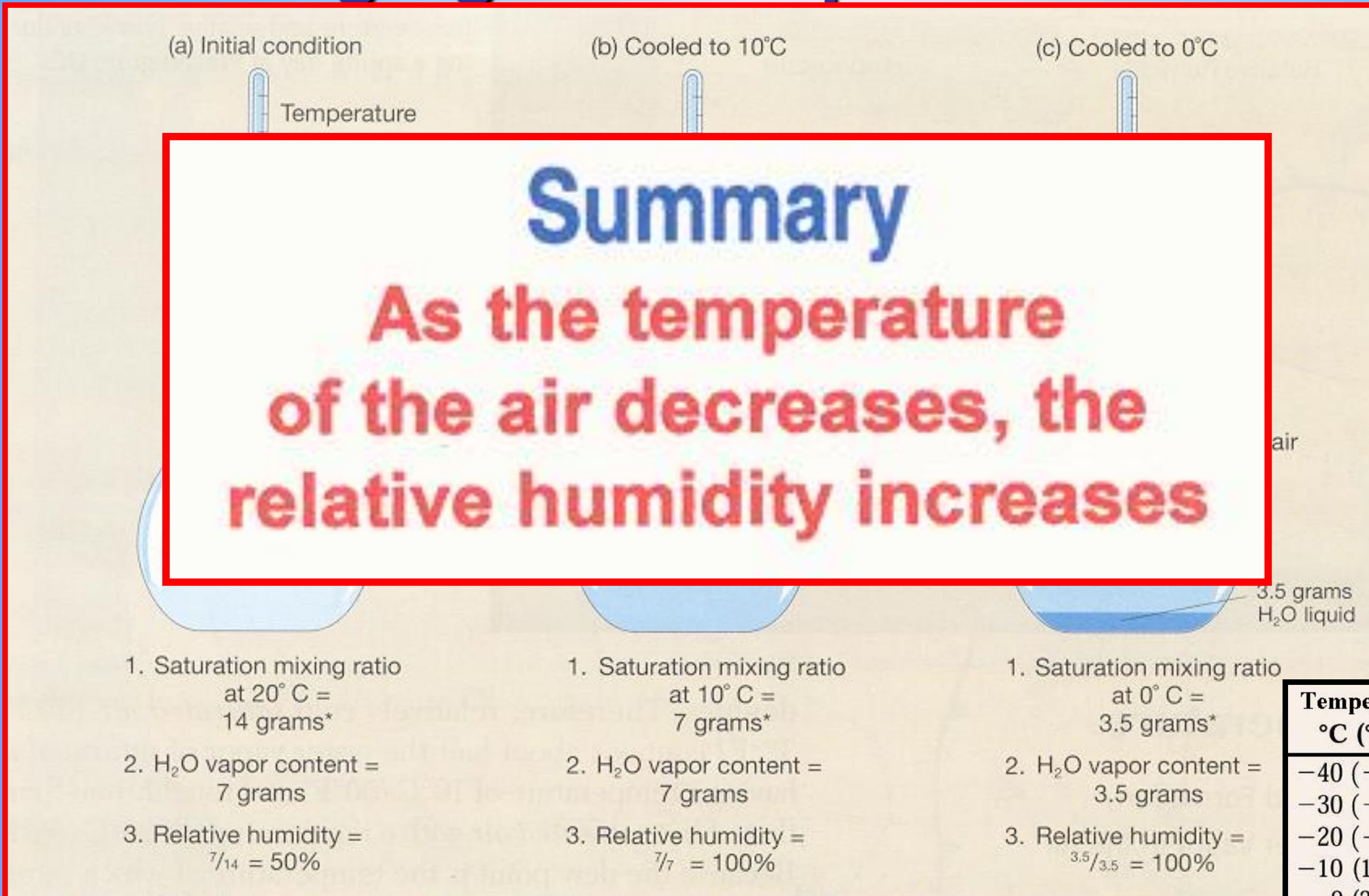
Summary

As the water vapor content of the air increases, the relative humidity increases

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

$$\text{Relative Humidity} = \frac{\text{Water Vapor Content}}{\text{Water Vapor Needed to Saturate the Air}}$$

Changing the Temperature of the Air



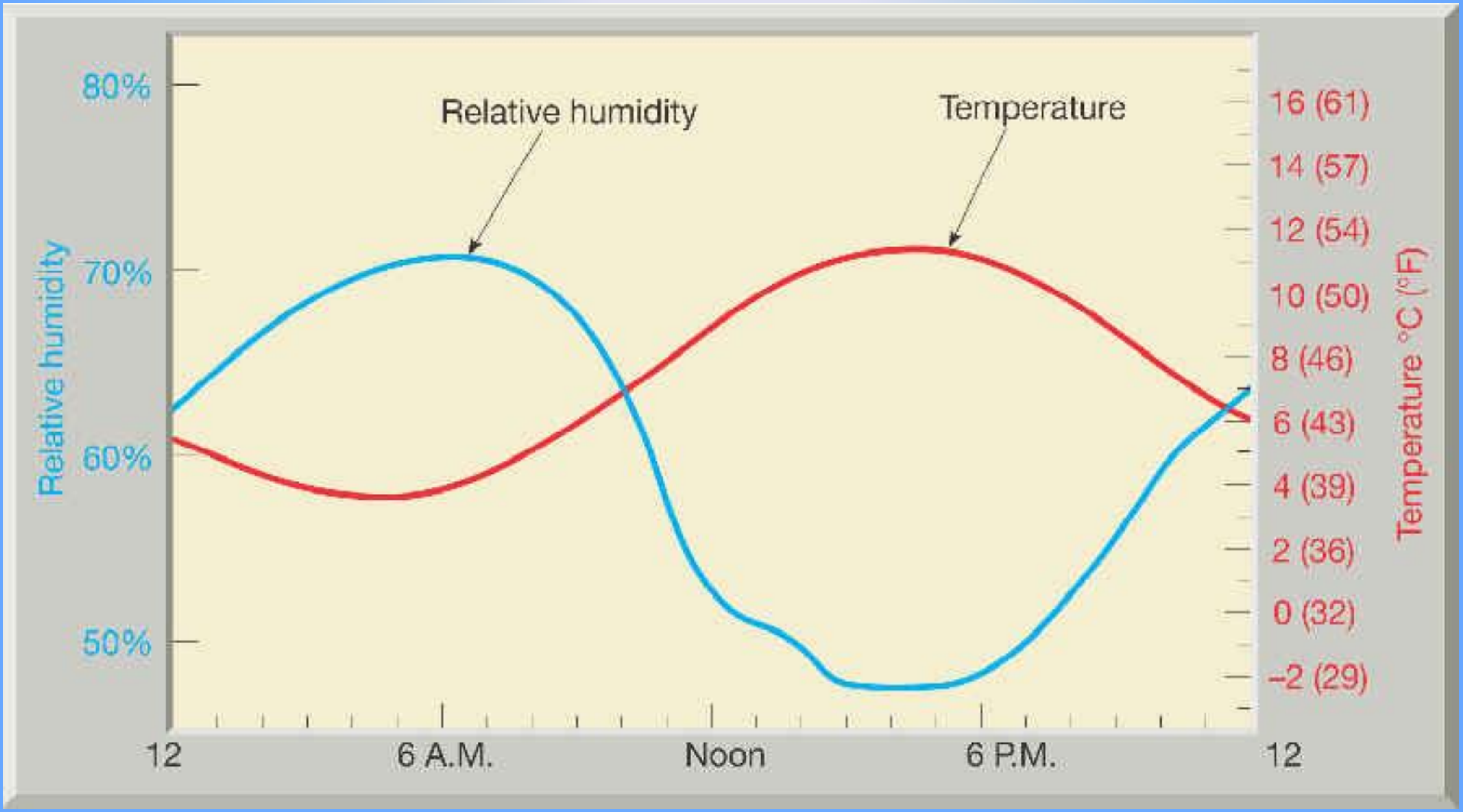
Summary

As the temperature of the air decreases, the relative humidity increases

$$\text{Relative Humidity} = \frac{\text{Water Vapor Content}}{\text{Water Vapor Needed to Saturate the Air}}$$

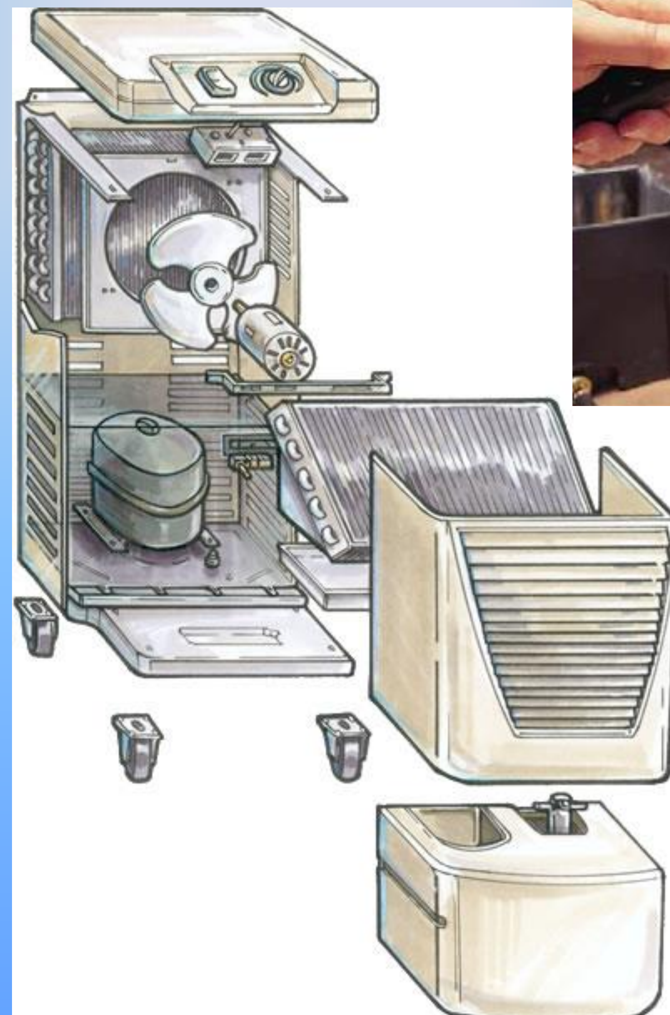
Temperature °C (°F)	Saturation Mixing Ratio (g/kg)
−40 (−40)	0.1
−30 (−22)	0.3
−20 (−4)	0.75
−10 (14)	2
0 (32)	3.5
5 (41)	5
10 (50)	7
15 (59)	10
20 (68)	14
25 (77)	20
30 (86)	26.5
35 (95)	35
40 (104)	47

Daily Changes in Relative Humidity

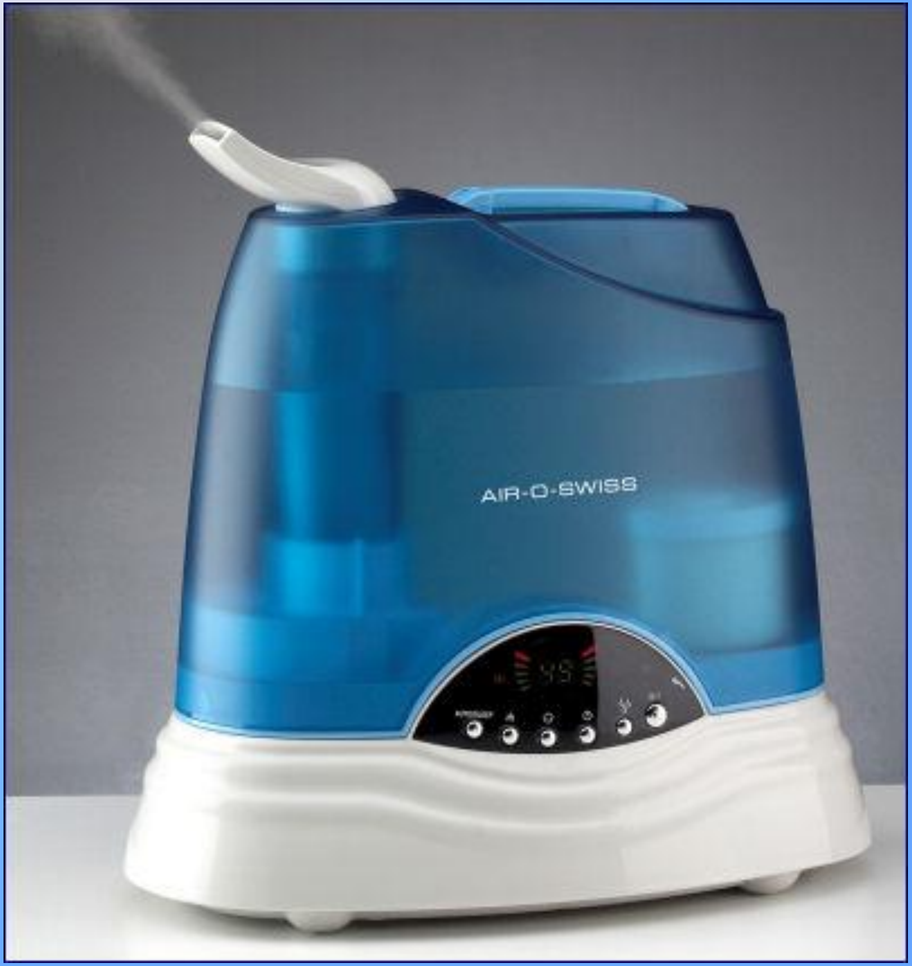


Typical daily variation in temperature and relative humidity on a spring day in a middle latitude location

Dehumidifiers



Humidifiers



Heat Index

Relative Humidity (%)

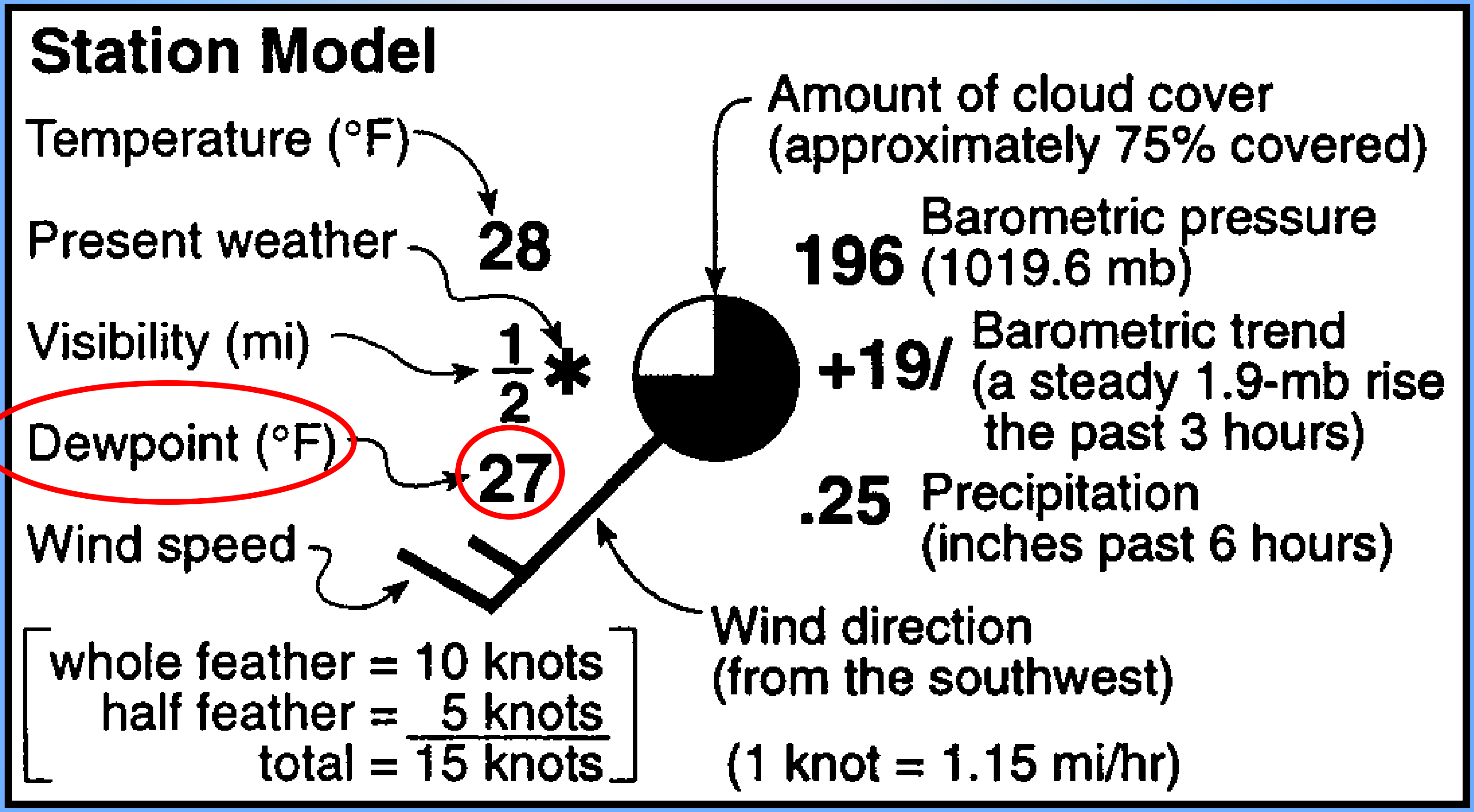
Air Temperature (°F)	40	45	50	55	60	65	70	75	80	85	90	95	100
110	136												
108	130	137											
106	124	130	137										
104	119	124	131	137									
102	114	119	124	130	137								
100	109	114	118	124	129	136							
98	105	109	113	117	123	128	134						
96	101	104	108	112	116	121	126	132					
94	97	100	102	106	110	114	119	124	129	135			
92	94	96	99	101	105	108	112	116	121	126	131		
90	91	93	95	97	100	103	106	109	113	117	122	127	132
88	88	89	91	93	95	98	100	103	106	110	113	117	121
86	85	87	88	89	91	93	95	97	100	102	105	108	112
84	83	84	85	86	88	89	90	92	94	96	98	100	103
82	81	82	83	84	84	85	86	88	89	90	91	93	95
80	80	80	81	81	82	82	83	84	84	85	86	86	87

With prolonged exposure and/or physical activity
Extreme danger Heat stroke or sunstroke highly likely
Danger Sunstroke, muscle cramps, and/or heat exhaustion likely
Extreme caution Sunstroke, muscle cramps, and/or heat exhaustion possible
Caution Fatigue possible

D. Dew Point Temperature

1. The temperature to which a parcel of air must be cooled to reach__saturation___.
2. As air cools to this temperature, condensation or deposition occurs.
3. Formation of _clouds_, _fog_, _dew_, or _frost_.
4. Dew point is a good measure of the amount of water vapor in the air.
   a. Directly related to the _actual amount_of water vapor in the air.
   b. It's easy to determine.
   c. It's plotted on the weather map station model.
5. The closer the dew point temperature is to the__air temperature__, the higher the relative humidity.
6. Dew point temperature will not _exceed___the air temperature.

Dew Point Temperature on the Station Model

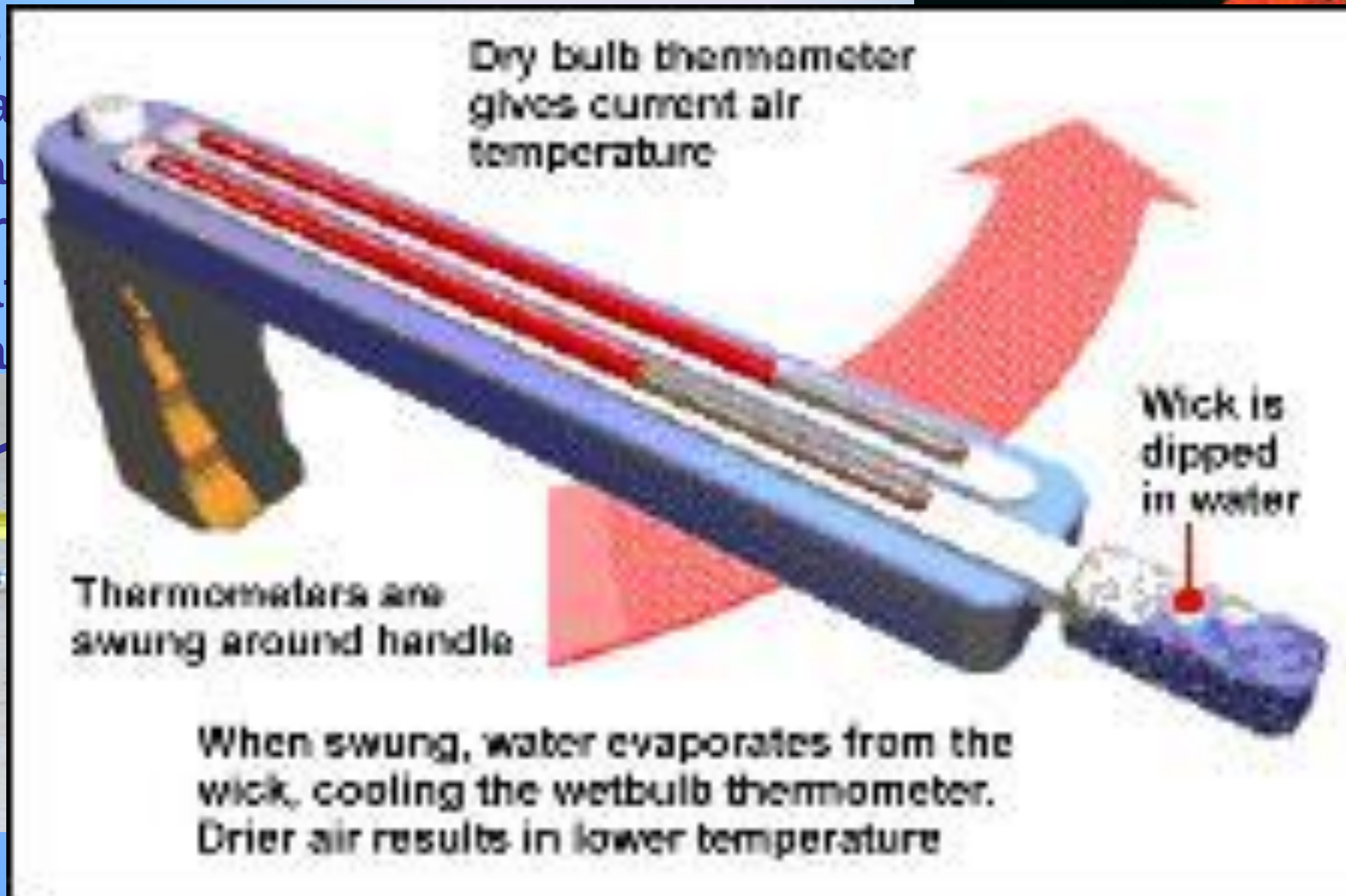


E. *Measuring Humidity*

Hygrometers **are Instruments Used to Measure Humidity**

1. Sling Psychrometer

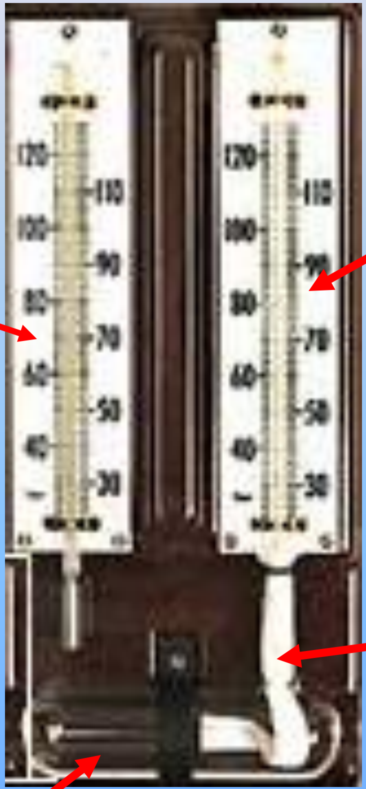
- Wet-Bulb indicates the moisture Content
- Evapora tempera
- Drier air evapora tempera



Dry-Bulb Thermometer indicates the air temperature

Hygrometer

Dry-Bulb Thermometer

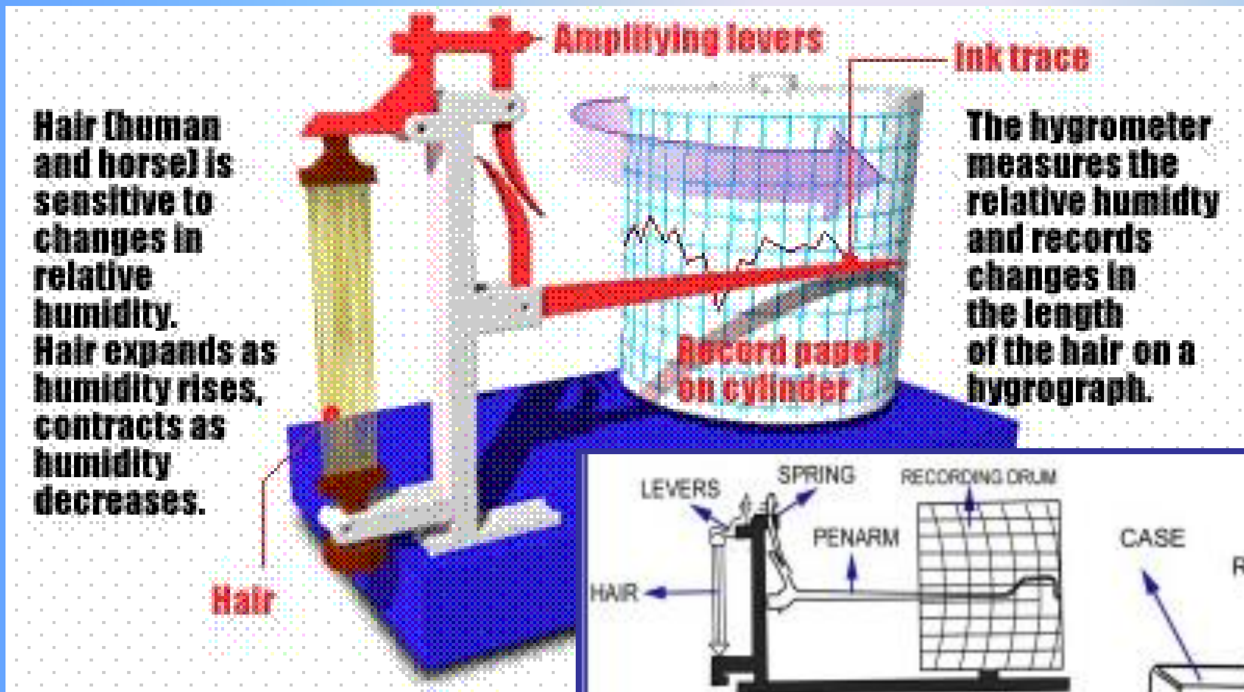


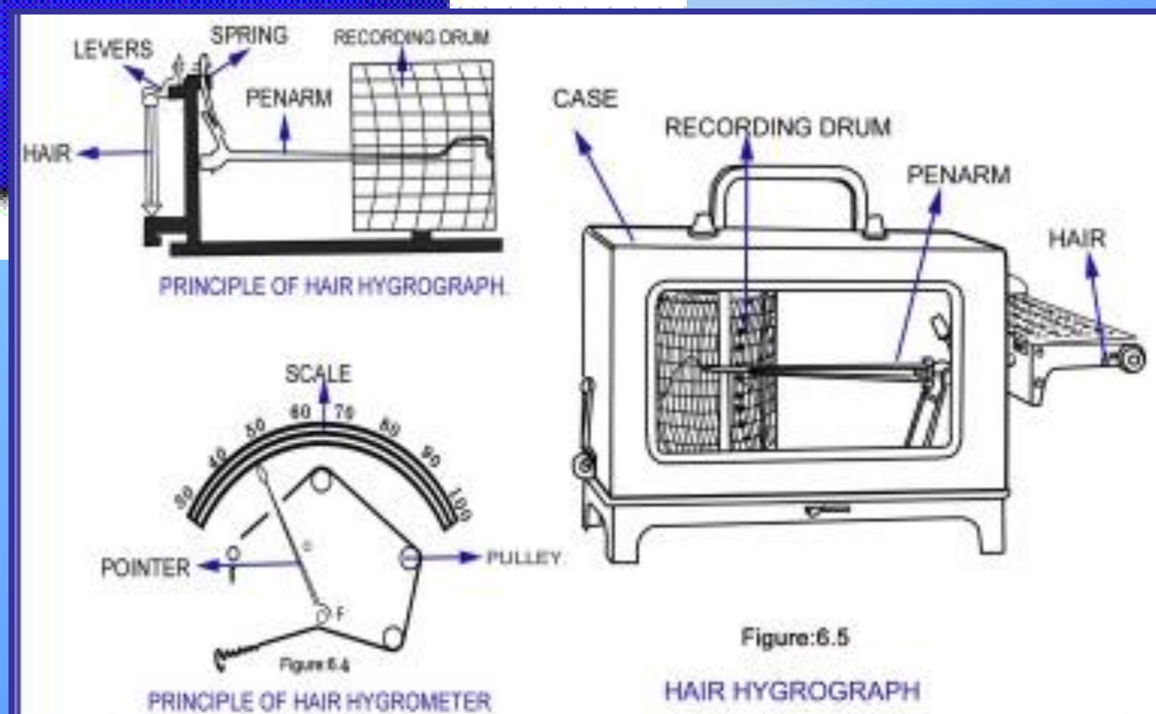
Wet-Bulb Thermometer

Wick

Water Reservoir

The Hair Hygrometer





Determining Relative Humidity Using a Psychrometer and the *ESRT*

Dewpoint (°C)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	−20	−33														
−18	−18	−28														
−16	−16	−24														
−14	−14	−21	−36													
−12	−12	−18	−28													
−10	−10	−14	−22													
−8	−8	−12	−18	−29												
−6	−6	−10	−14	−22												
−4	−4	−7	−12	−17	−29											
−2	−2	−5	−8	−13	−20											
0	0	−3	−6	−9	−15	−24										
2	2	−1	−3	−6	−11	−17										
4	4	1	−1	−4	−7	−11	−19									
6	6	4	1	−1	−4	−7	−13	−21								
8	8	6	3	1	−2	−5	−9	−14								
10	10	8	6	4	1	−2	−5	−9	−14	−28						
12	12	10	8	6	4	1	−2	−5	−9	−16						
14	14	12	11	9	6	4	1	−2	−5	−10	−17					
16	16	14	13	11	9	7	4	1	−1	−6	−10	−17				
18	18	16	15	13	11	9	7	4	2	−2	−5	−10	−19			
20	20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19		
22	22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19	
24	24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

Relative Humidity (%)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	100	28														
−18	100	40														
−16	100	48														
−14	100	55	11													
−12	100	61	23													
−10	100	66	33													
−8	100	71	41	13												
−6	100	73	48	20												
−4	100	77	54	32	11											
−2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

Determining Relative Humidity Using a Psychrometer and the *ESRT*

Dry-Bulb = 20º C

Relative Humidity (%)

Wet-Bulb = 12º C

Dry-Bulb Tempera-ture (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
–20	100	28														
–18	100	40														
–16	100	48														
–14	100	55	11													
–12	100	61	23													
–10	100	66	33													
–8	100	71	41	13												
–6	100	73	48	20												
–4	100	77	54	32	11											
–2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

RH = 36 %

Determining Relative Humidity Using a Psychrometer and the *ESRT*

Dry-Bulb = 20º C

Wet-Bulb = 18º C

Relative Humidity (%)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
–20	100	28														
–18	100	40														
–16	100	48														
–14	100	55	11													
–12	100	61	23													
–10	100	66	33													
–8	100	71	41	13												
–6	100	73	48	20												
–4	100	77	54	32	11											
–2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

RH = 82 %

Determining Dew Point Temperature Using a Psychrometer and the *ESRT*

Dewpoint (°C)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	−20	−33														
−18	−18	−28														
−16	−16	−24														
−14	−14	−21	−36													
−12	−12	−18	−28													
−10	−10	−14	−22													
−8	−8	−12	−18	−29												
−6	−6	−10	−14	−22												
−4	−4	−7	−12	−17	−29											
−2	−2	−5	−8	−13	−20											
0	0	−3	−6	−9	−15	−24										
2	2	−1	−3	−6	−11	−17										
4	4	1	−1	−4	−7	−11	−19									
6	6	4	1	−1	−4	−7	−13	−21								
8	8	6	3	1	−2	−5	−9	−14								
10	10	8	6	4	1	−2	−5	−9	−14	−28						
12	12	10	8	6	4	1	−2	−5	−9	−16						
14	14	12	11	9	6	4	1	−2	−5	−10	−17					
16	16	14	13	11	9	7	4	1	−1	−6	−10	−17				
18	18	16	15	13	11	9	7	4	2	−2	−5	−10	−19			
20	20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19		
22	22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19	
24	24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

Relative Humidity (%)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	100	28														
−18	100	40														
−16	100	48														
−14	100	55	11													
−12	100	61	23													
−10	100	66	33													
−8	100	71	41	13												
−6	100	73	48	20												
−4	100	77	54	32	11											
−2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

Determining Dew Point Temperature Using a Psychrometer and the *ESRT*

Dry-Bulb = 20º C | **Dewpoint (°C)** | **Wet-Bulb = 12º C**

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
–20	–20	–33														
–18	–18	–28														
–16	–16	–24														
–14	–14	–21	–36													
–12	–12	–18	–28													
–10	–10	–14	–22													
–8	–8	–12	–18	–29												
–6	–6	–10	–14	–22												
–4	–4	–7	–12	–17	–29											
–2	–2	–5	–8	–13	–20											
0	0	–3	–6	–9	–15	–24										
2	2	–1	–3	–6	–11	–17										
4	4	1	–1	–4	–7	–11	–19									
6	6	4	1	–1	–4	–7	–13	–21								
8	8	6	3	1	–2	–5	–9	–14								
10	10	8	6	4	1	–2	–5	–9	–14	–28						
12	12	10	8	6	4	1	–2	–5	–9	–16						
14	14	12	11	9	6	4	1	–2	–5	–10	–17					
16	16	14	13	11	9	7	4	1	–1	–6	–10	–17				
18	18	16	15	13	11	9	7	4	2	–2	–5	–10	–19			
20	20	19	17	15	14	12	10	7	4	2	–2	–5	–10	–19		
22	22	21	19	17	16	14	12	10	8	5	3	–1	–5	–10	–19	
24	24	23	21	20	18	16	14	12	10	8	6	2	–1	–5	–10	–18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	–4	–9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	–3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

DP Temp. = 4º C

Determining Dew Point Temperature Using a Psychrometer and the *ESRT*

Dry-Bulb = 20º C

Dewpoint (°C)

Wet-Bulb = 18º C

DP Temp. = 17º C

Dry-Bulb Tempera-ture (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
–20	–20	–33														
–18	–18	–28														
–16	–16	–24														
–14	–14	–21	–36													
–12	–12	–18	–28													
–10	–10	–14	–22													
–8	–8	–12	–18	–29												
–6	–6	–10	–14	–22												
–4	–4	–7	–12	–17	–29											
–2	–2	–5	–8	–13	–20											
0	0	–3	–6	–9	–15	–24										
2	2	–1	–3	–6	–11	–17										
4	4	1	–1	–4	–7	–11	–19									
6	6	4	1	–1	–4	–7	–13	–21								
8	8	6	3	1	–2	–5	–9	–14								
10	10	8	6	4	1	–2	–5	–9	–14	–28						
12	12	10	8	6	4	1	–2	–5	–9	–16						
14	14	12	11	9	6	4	1	–2	–5	–10	–17					
16	16	14	13	11	9	7	4	1	–1	–6	–10	–17				
18	18	16	15	13	11	9	7	4	2	–2	–5	–10	–19			
20	20	19	17	15	14	12	10	7	4	2	–2	–5	–10	–19		
22	22	21	19	17	16	14	12	10	8	5	3	–1	–5	–10	–19	
24	24	23	21	20	18	16	14	12	10	8	6	2	–1	–5	–10	–18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	–4	–9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	–3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

- Find the relative humidity and dew point outside with the student psychrometers.

Finding Relative Humidity Using Saturation Vapor Pressure

- Vapor pressure increases as relative humidity increases.
  - Air with a relative humidity of 25%
    - Has 25% as many water vapor molecules as when it's saturated
  - If the vapor content doubles to 50%
    - Vapor pressure also doubles to 50%

Finding Relative Humidity Using Saturation Vapor Pressure

- Relative humidity is a measure of how close the air is to saturation.
  - It’s expressed as a ratio of:
    - water vapor content in the air to
    - the maximum amount of water vapor it could hold at a given temperature.
- Relative humidity can be calculated if we know the:
  - Actual Vapor pressure (determined by the vapor present in the air) at a given temperature
  - Saturation Vapor Pressure at that temperature.

Saturation Vapor Pressure

Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)
30	41.9	13	14.8	-4	4.3
29	39.7	12	13.9	-5	4.0
28	37.6	11	13.0	-6	3.8
27	35.5	10	12.2	-7	3.5
26	33.4	9	11.4	-8	3.2
25	31.4	8	10.7	-9	2.9
24	29.6	7	10.0	-10	2.6
23	27.8	6	9.3	-11	2.4
22	26.1	5	8.7	-12	2.2
21	24.6	4	8.1	-13	2.0
20	23.2	3	7.5	-14	1.8
19	21.8	2	7.0	-15	1.7
18	20.5	1	6.5	-16	1.5
17	19.2	0	6.1	-17	1.4
16	18.0	-1	5.6	-18	1.3
15	16.9	-2	5.1	-19	1.1
14	15.8	-3	4.7	-20	1.0

Finding Relative Humidity Using Saturation Vapor Pressure

- The ratio of the actual water vapor content to it's saturation vapor pressure can be expressed using the following equation:

$$\boxed{\text{Relative Humidity} = \frac{\text{Actual Vapor Pressure}}{\text{Saturation Vapor Pressure}} \times 100}$$

- The *dew point temperature* is used to find the *actual vapor pressure.*
  - Dewpoint is determined by the water vapor content of the air at a given temperature.

Sample Problem

- Given:
  - Air temperature = 20^{o} C
  - Dewpoint temperature = 15^{o} C

- Step 1: Find the *actual vapor pressure.*
  - Use the saturation vapor pressure of the dewpoint temperature.
  - From the chart, this value is 16.9 mb.

Saturation Vapor Pressure

Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)
30	41.9	13	14.8	-4	4.3
29	39.7	12	13.9	-5	4.0
28	37.6	11	13.0	-6	3.8
27	35.5	10	12.2	-7	3.5
26	33.4	9	11.4	-8	3.2
25	31.4	8	10.7	-9	2.9
24	29.6	7	10.0	-10	2.6
23	27.8	6	9.3	-11	2.4
22	26.1	5	8.7	-12	2.2
21	24.6	4	8.1	-13	2.0
20	23.2	3	7.5	-14	1.8
19	21.8	2	7.0	-15	1.7
18	20.5	1	6.5	-16	1.5
17	19.2	0	6.1	-17	1.4
16	18.0	-1	5.6	-18	1.3
15	16.9	-2	5.1	-19	1.1
14	15.8	-3	4.7	-20	1.0

Sample Problem Continued . . .

- Step 2: Find the *saturation vapor pressure* of the *actual* air temperature.
  - This will indicate what the vapor pressure would be if the air was saturated.
  - From the chart, this value is 23.2 mb.

Saturation Vapor Pressure

Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)	Temperature (ºC)	Saturated Vapor Pressure (mb)
30	41.9	13	14.8	-4	4.3
29	39.7	12	13.9	-5	4.0
28	37.6	11	13.0	-6	3.8
27	35.5	10	12.2	-7	3.5
26	33.4	9	11.4	-8	3.2
25	31.4	8	10.7	-9	2.9
24	29.6	7	10.0	-10	2.6
23	27.8	6	9.3	-11	2.4
22	26.1	5	8.7	-12	2.2
21	24.6	4	8.1	-13	2.0
20	23.2	3	7.5	-14	1.8
19	21.8	2	7.0	-15	1.7
18	20.5	1	6.5	-16	1.5
17	19.2	0	6.1	-17	1.4
16	18.0	-1	5.6	-18	1.3
15	16.9	-2	5.1	-19	1.1
14	15.8	-3	4.7	-20	1.0

Sample Problem Continued . . .

- Step 3: Substitute the values determined in steps 1 and 2 into the equation for relative humidity.

Vapor pressure of the dew point temperature

$$\text{Relative Humidity} = \frac{\text{Actual Vapor Pressure}}{\text{Saturation Vapor Pressure}} \times 100$$

Vapor pressure of the Dry-bulb temperature

Sample Problem Continued . . .

- <u>Step 3</u>: Substitute the values determined in steps 1 and 2 into the equation for relative humidity.

$$\text{Relative Humidity} = \frac{\mathbf{16.9\ mb}}{\mathbf{23.2\ mb}} \times 100$$

Relative Humidity = 73% (rounded to the *nearest whole number*)

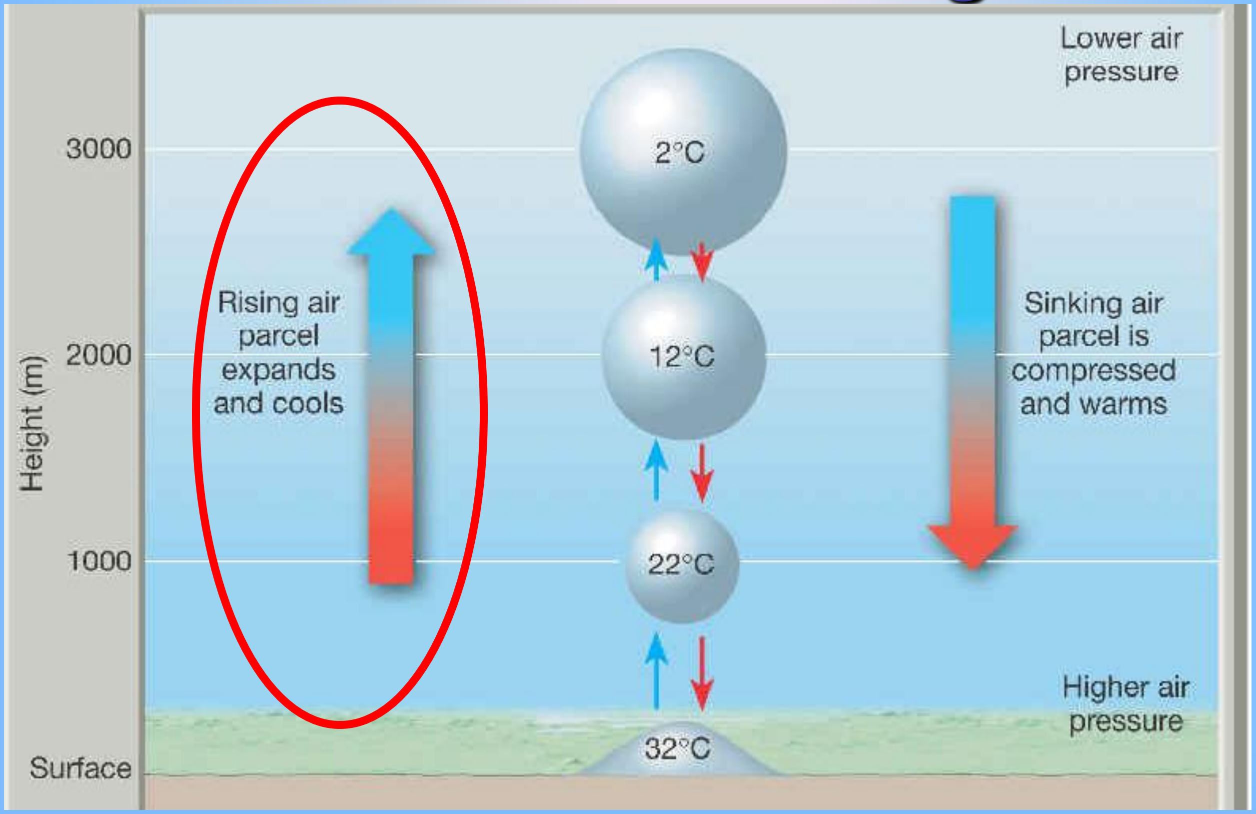
F. Adiabatic Changes and Cloud Formation

1. **Adiabatic changes**

   a. Temperature changes without __**exchange**__ of heat with the surroundings.

   - Temperature rises without the addition of heat.
   - Temperature falls without the loss of heat.

Adiabatic Cooling



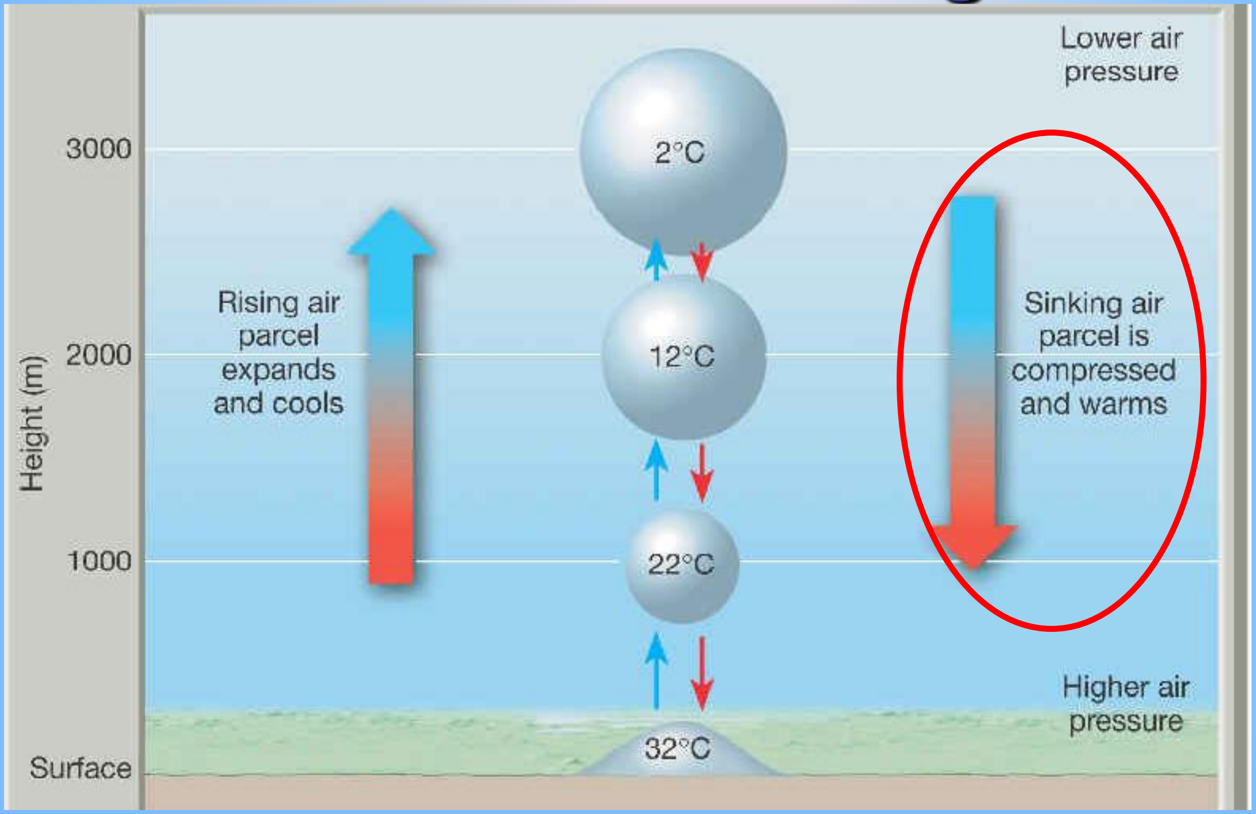
b. Expansion of air:

(1) Causes gas molecules to move ___less rapidly___.

(2) Air temperature ___decreases___.

(3) Caused by air ___expanding___ (as it rises) and the ___decreasing___ air pressure around the parcel of air.

Adiabatic Heating



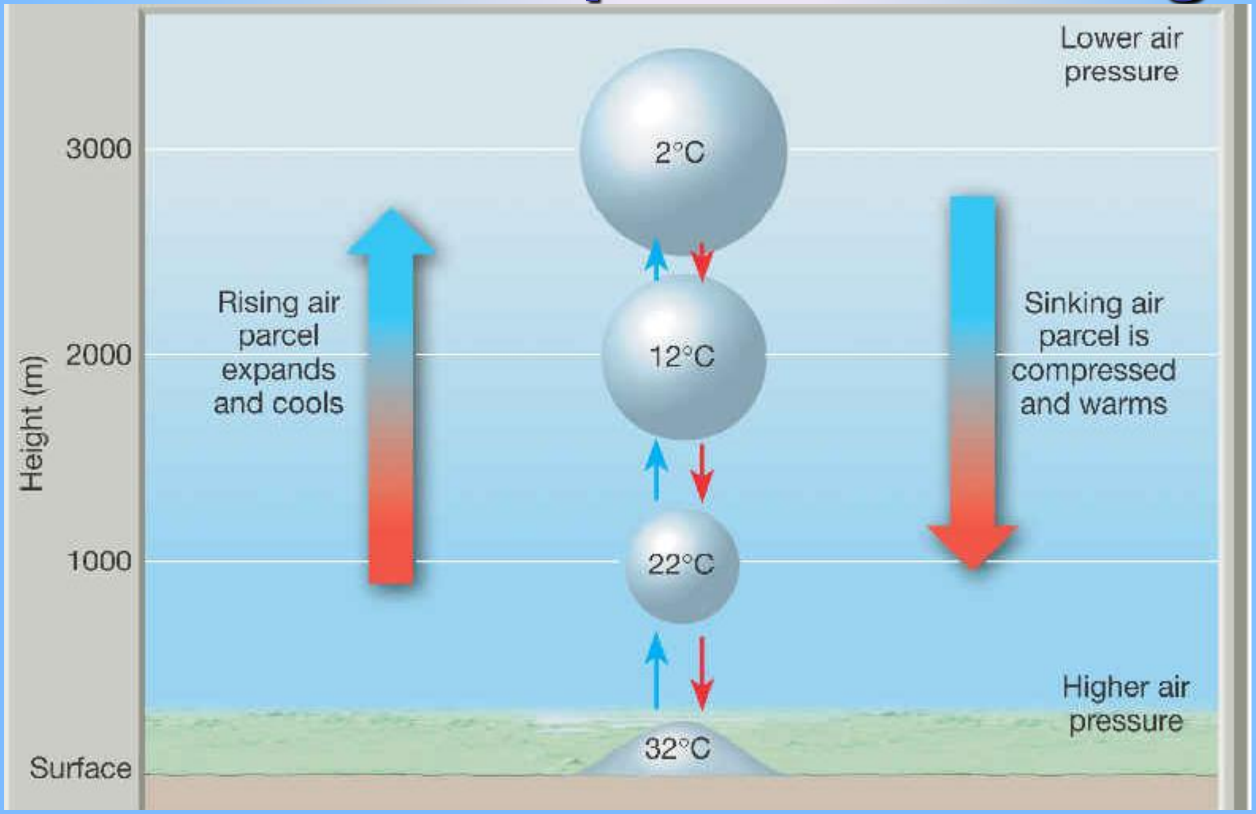
b. **Compression of air:**

(1) **Gas molecules more** more rapidly.

(2) **Air temperature** increases.

(3) **Caused by air being** compressed **(as it sinks) by the** higher **air pressure around the parcel of air.**

Adiabatic Temperature Change

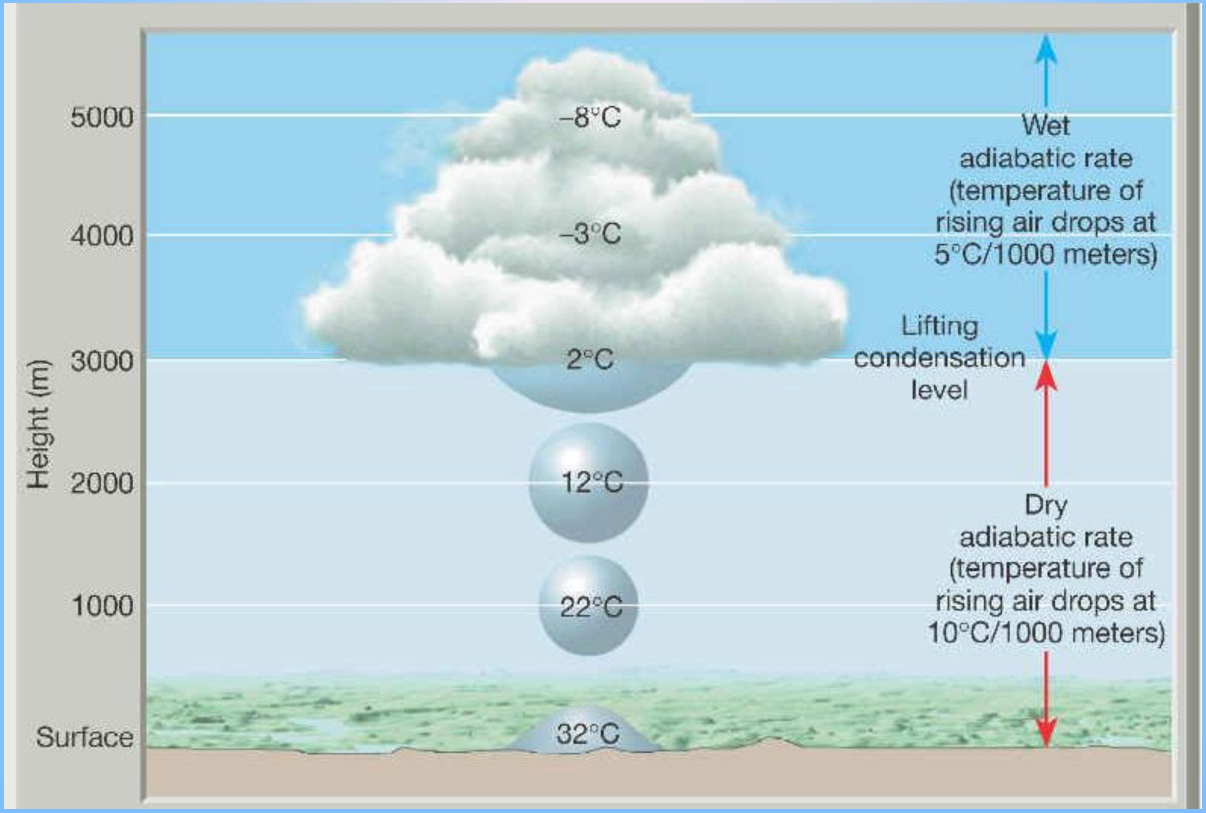


2. <u>Dry Adiabatic Lapse Rate</u>

a. Applies to __**unsaturated**__ air

b. Ascending air __**expands**__ causing __**cooling**__ at 10º C/km.

3. Wet Adiabatic Lapse Rate



a. As saturated air rises latent heat is __released__ by condensation.

b. The added heat __slows__ down the rate of cooling as the air rises

c. The wet adiabatic lapse rate varies with __moisture__ content (varying amounts of latent heat released)

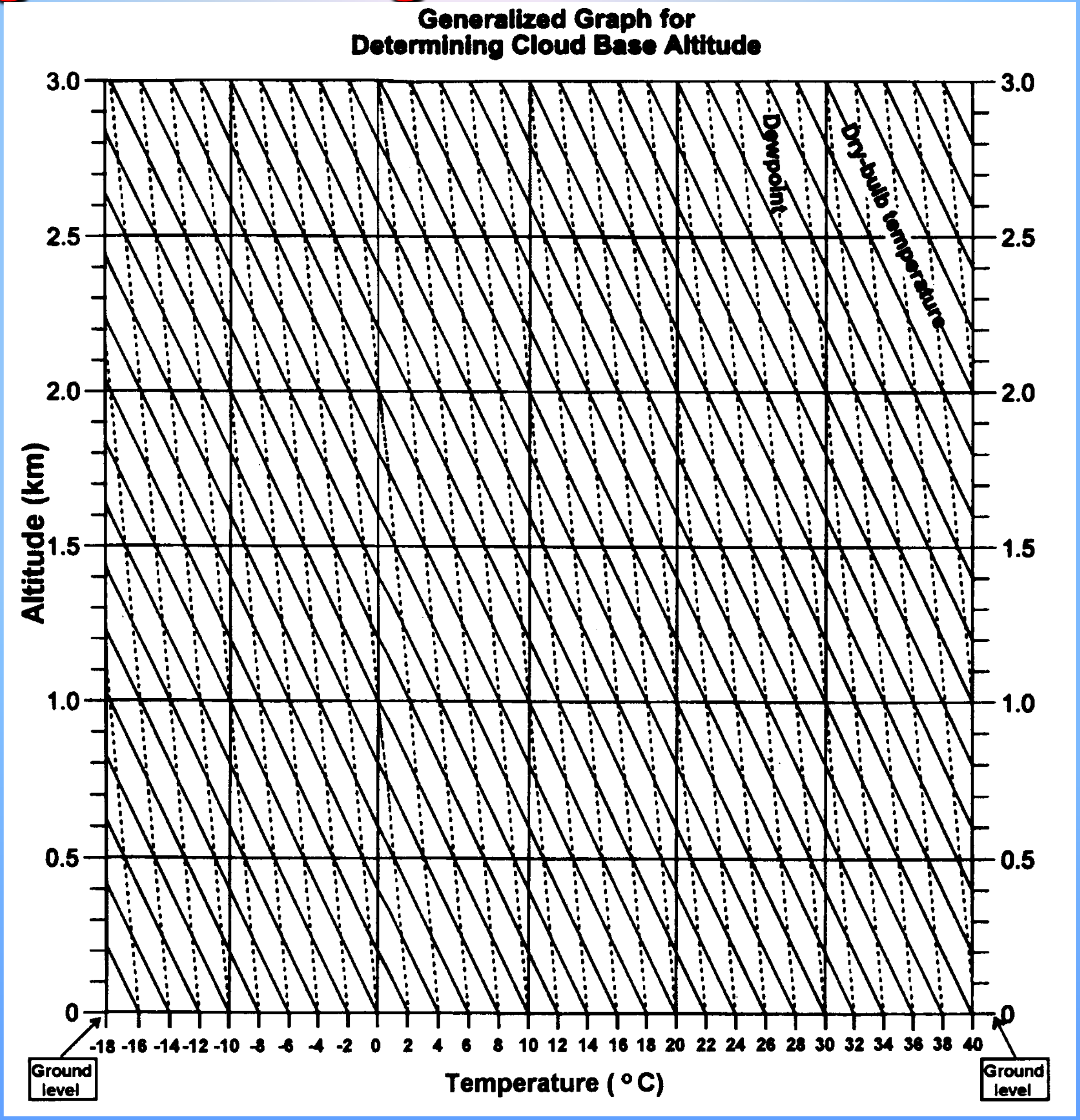
4. Lifting Condensation Level or (Cloud Base Altitude)

a. Altitude at which rising air has cooled to its **dew point** temperature.

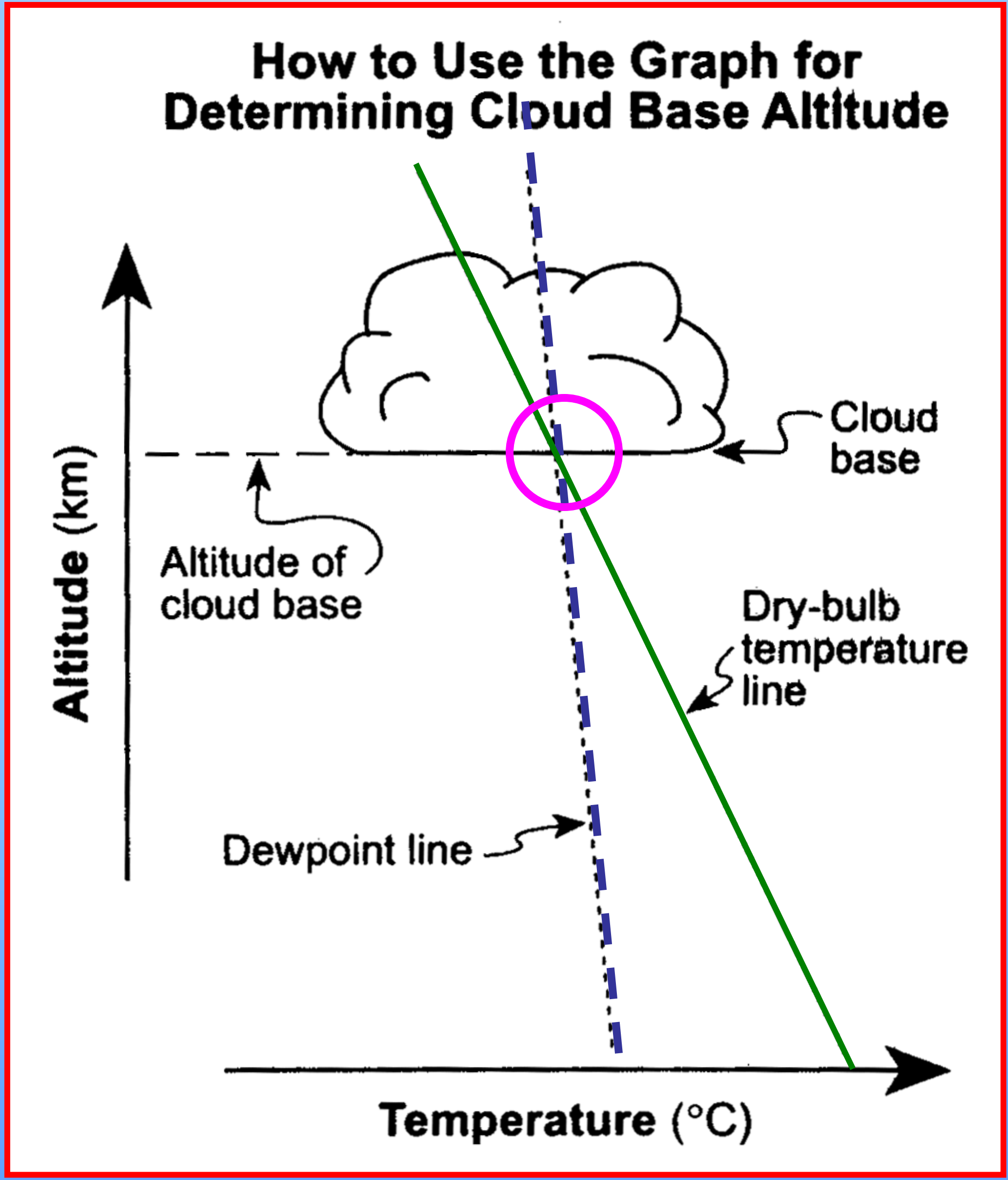
b. The lifting condensation level will be the altitude of the **cloud base**.


VEL 0.01km/h
Earth
DST 6390.46km
h 11514m

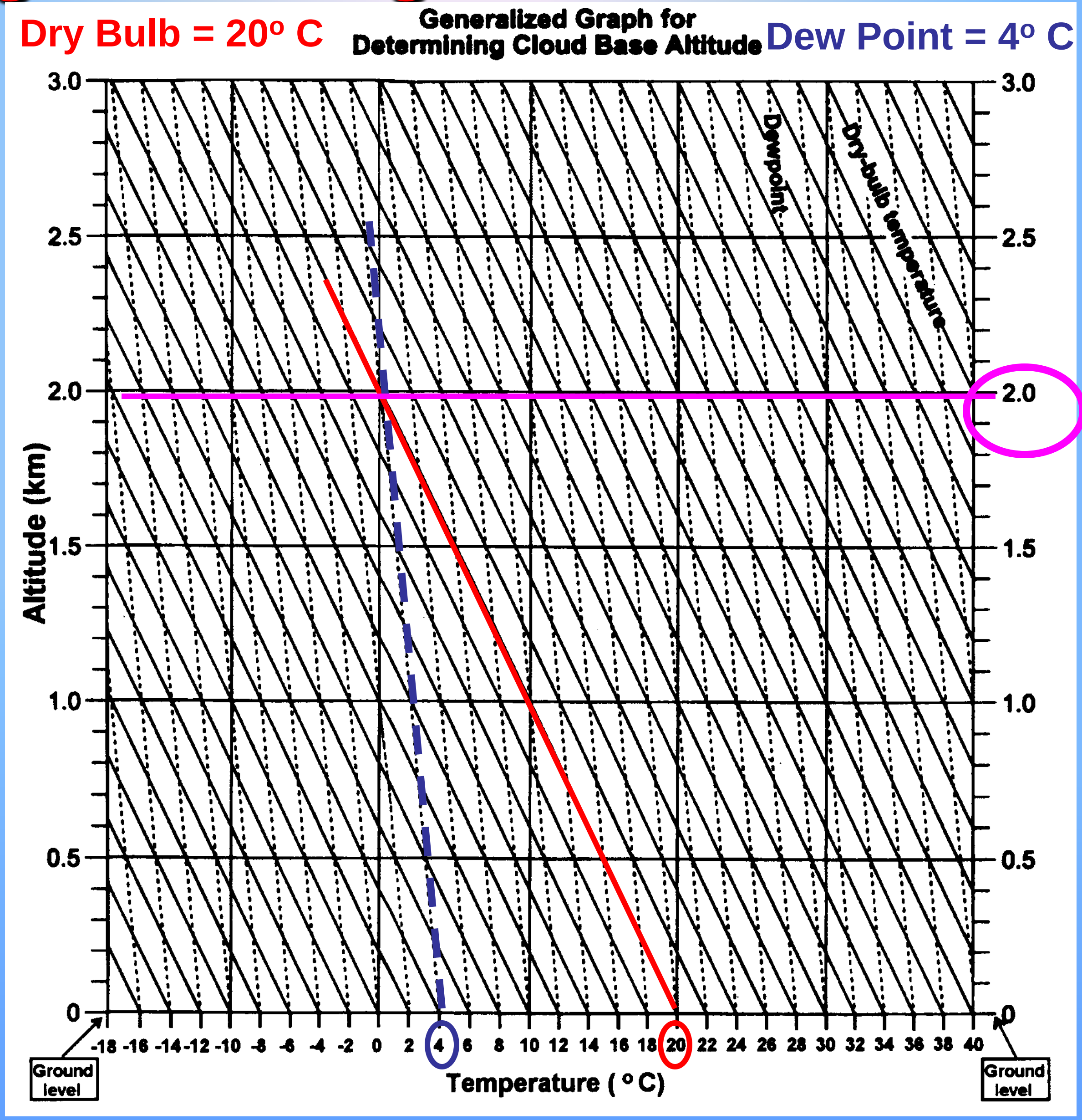
Finding the Lifting Condensation Level



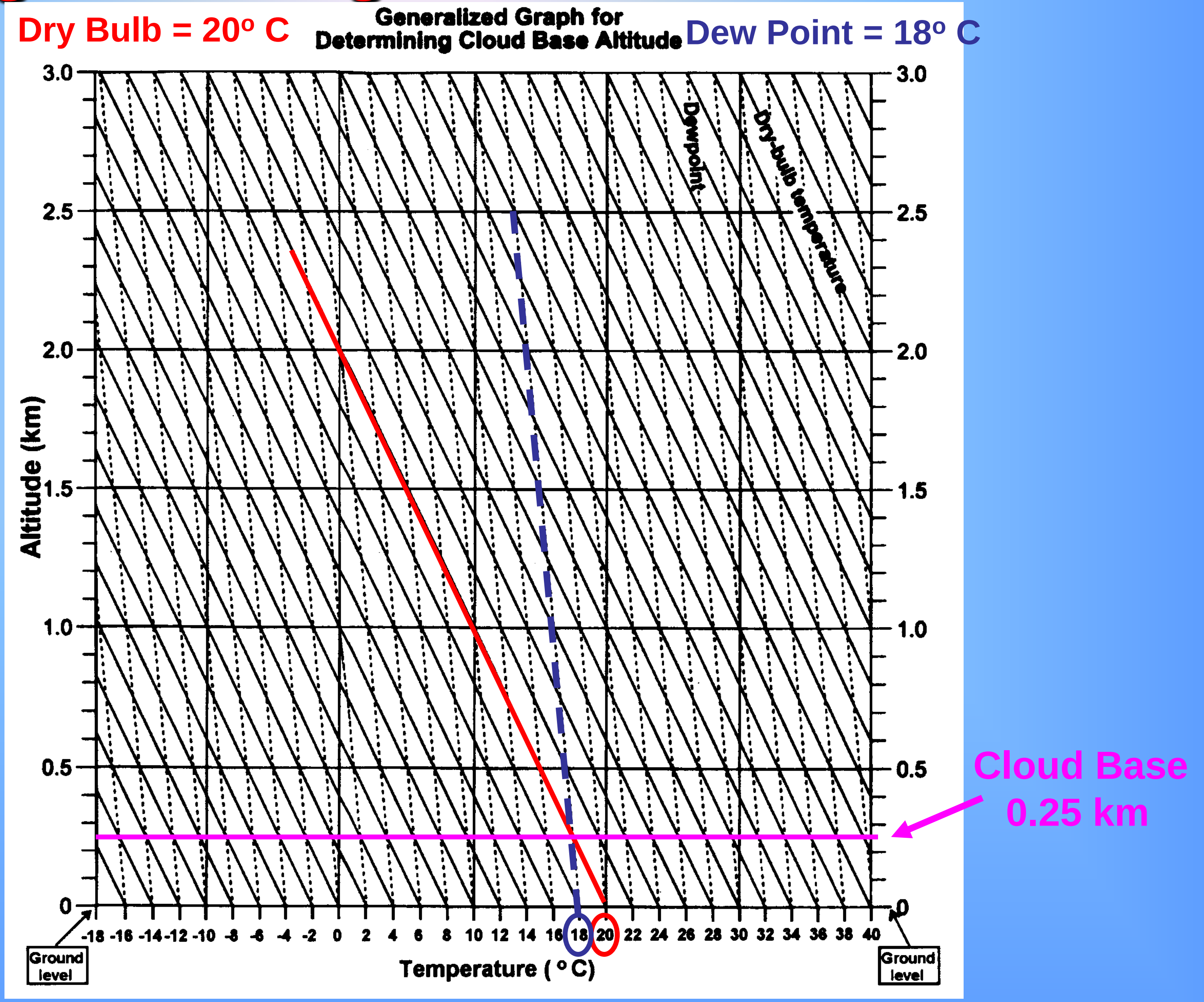
Finding the Lifting Condensation Level



Finding the Lifting Condensation Level



Finding the Lifting Condensation Level



5. Requirements for Cloud Formation

a. __**Humid**__ air

b. __**Condensation**__ (hydroscopic) Nuclei

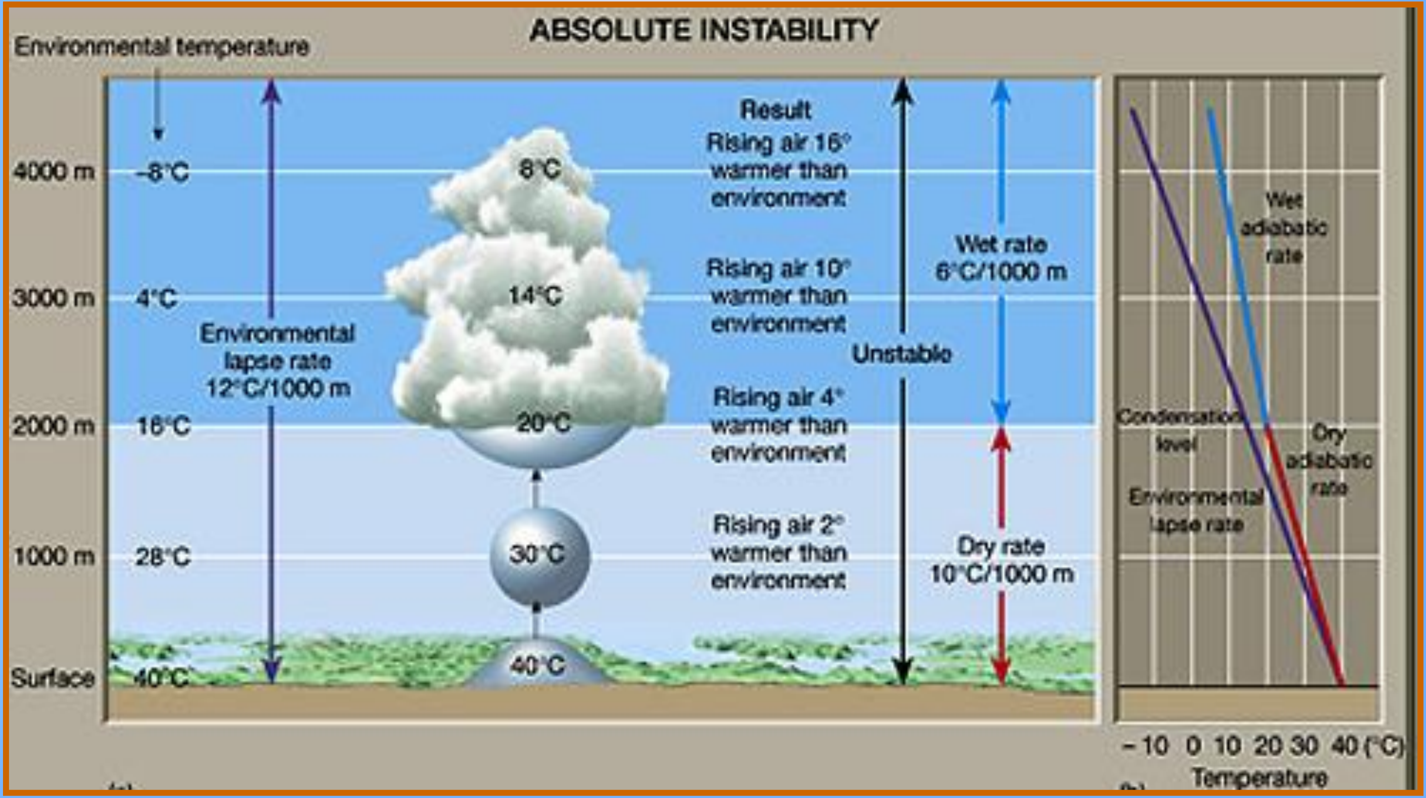
Salt particles from ocean spray, volcanic dust, pollen, smoke, etc.

c. __**Cooling**__ temperatures: Most often caused by unstable air.

- So, what is the difference between <u>unstable</u> air and <u>stable</u> air?

(1) Unstable Air

The lowermost portion of the atmosphere is warmed to a higher temperature than the air aloft.

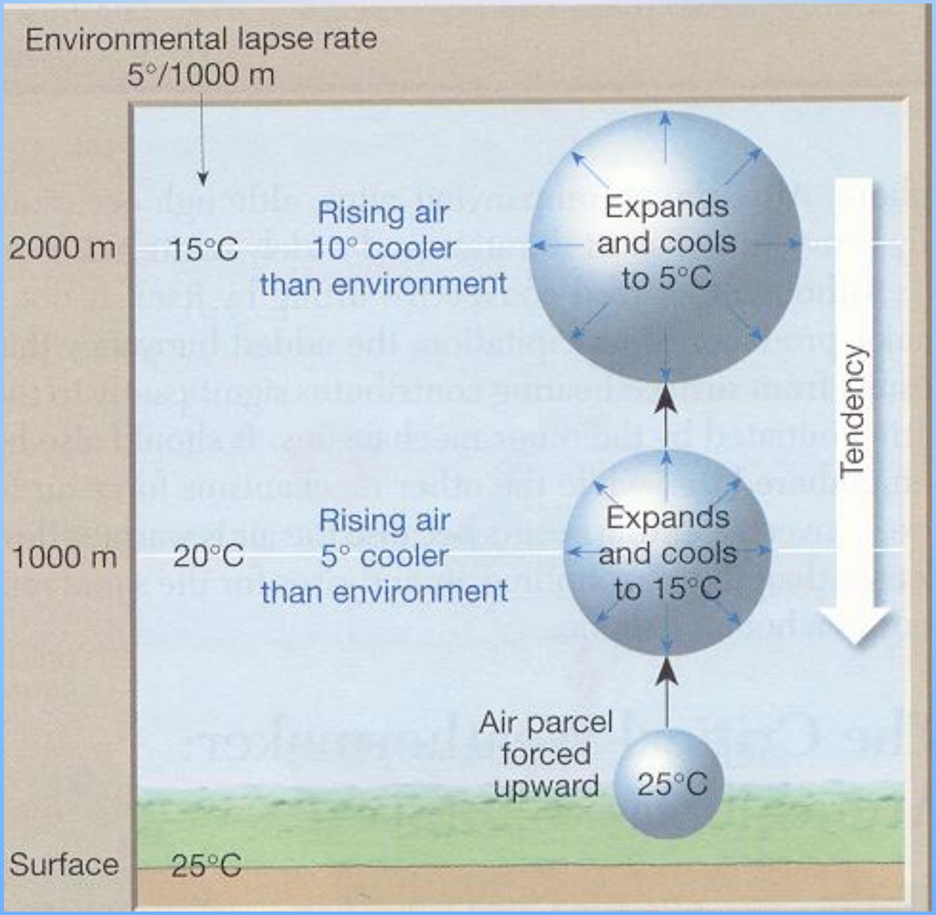


(a) Air that has a tendency to __rise______.

(b) It will rise until it reaches an altitude where its temperature is equal to that of the surrounding air.

(c) As it rises it will cool adiabatically.

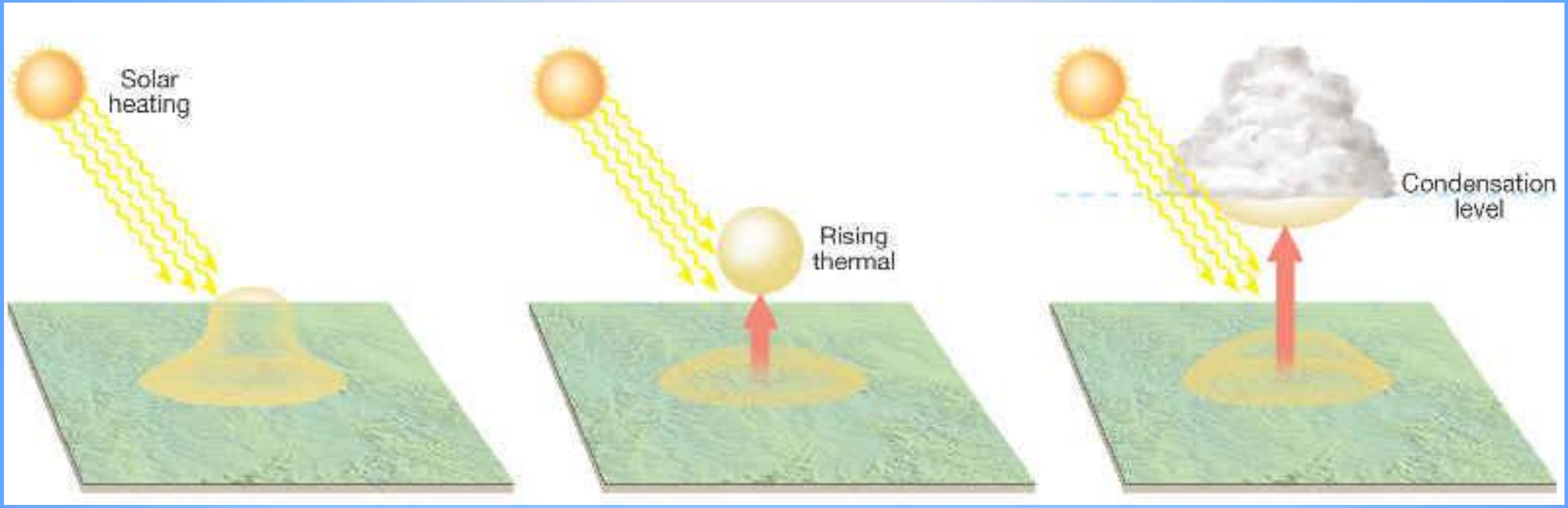
(2) Stable Air



(a) Tends to __**remain**____in its original position or if forced to rise will tend to sink.

(b) It’s cooler (and denser) than the surrounding air

(3) Causes of Lifting

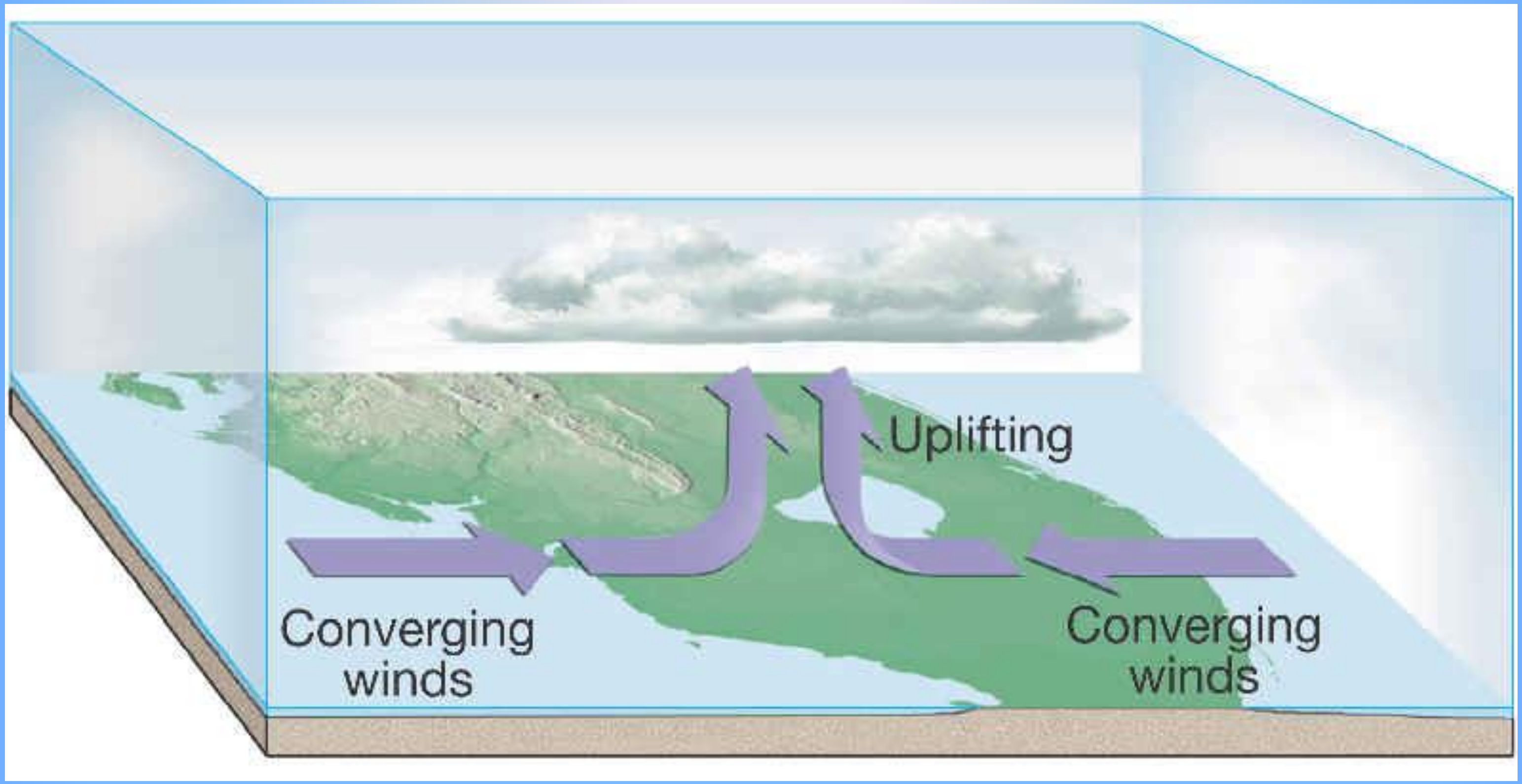


(a) Localized Convective Lifting

(i) ___Unequal___ heating of Earth's surface causes pockets of air to become warmer than its surroundings.

(ii) The parcels rise, causing ___thermals___.

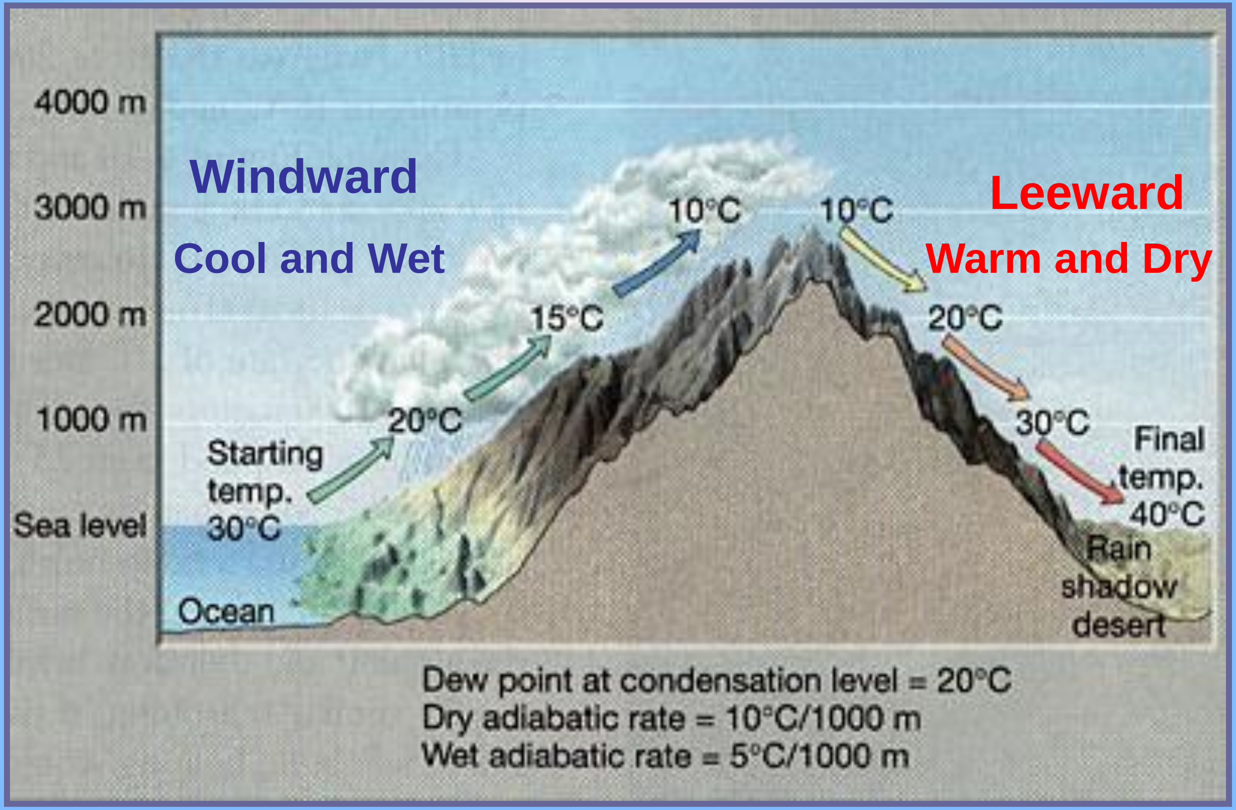
(b) Convergence



(i) Air in the lower troposphere flows **together**.

(ii) Lifting results as air piles up.

(c) Orographic Lifting



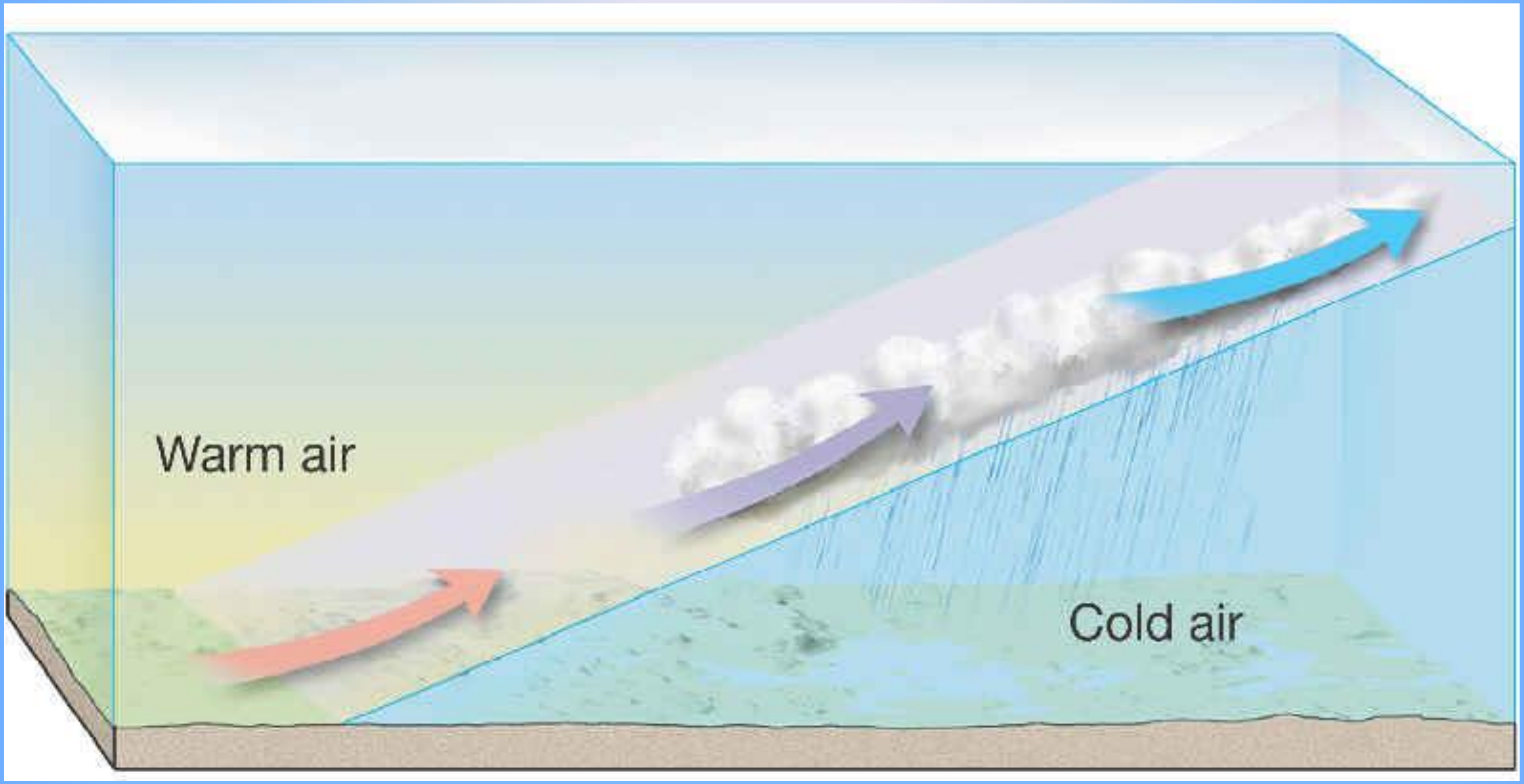
(i) Mountain barriers force air to rise on the _***windward***__side.

(ii) Air becomes_**unstable**_.

(iii) Air descends on the _***leeward***_side and heats by compression (dry adiabatic rate)

(iv) _**Rainshadow**__deserts result on the *leeward side.*

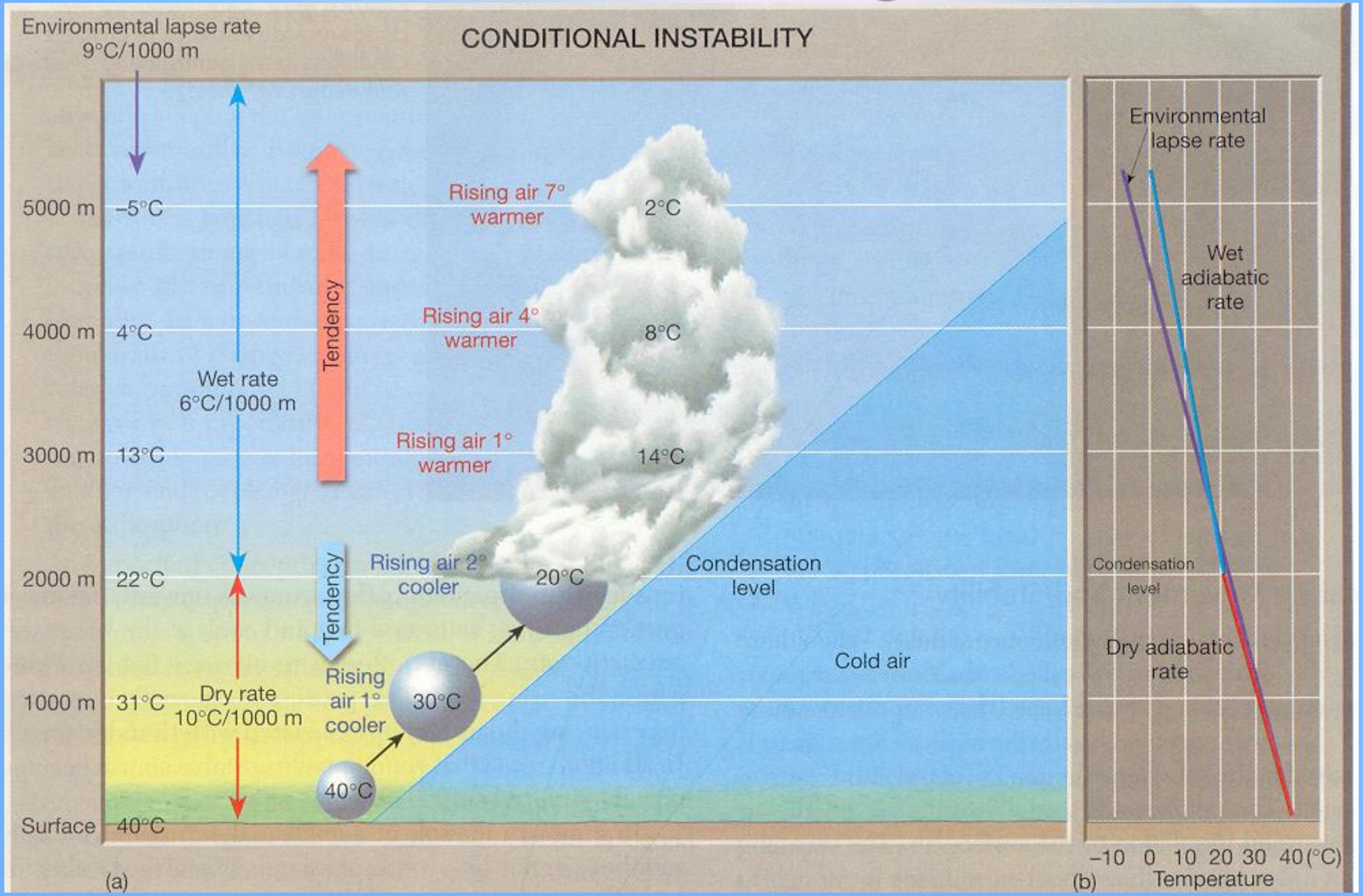
(d) Frontal Wedging



(i) ~~Boundaries (fronts)~~ produced by collision of warm and cold air masses.

(ii) Warm air forced **over** cooler air, forming middle-latitude cyclones (*wave cyclones*).

Warm Air is Forced to Rise Along a Frontal Boundary



- The parcel of air is cooler than the surrounding air up to nearly 3,000 m and has a tendency to sink (stability)
- Above 3,000 m the parcel is warmer than the surrounding air and will rise. (It’s unstable.)
- The result can be towering cumulus clouds.

6. Classification of Clouds

a. Classification by Cloud Form

(1) Cirrus

- (a) High altitude clouds made primarily of ice crystals.
- (b) Are thin and white due to small amount of water vapor at high altitudes.

(2) Cumulus

- (a) Individual masses and often form on clear days.
- (b) Often develop into vertical domes or towers.

(3) Stratus

- (a) A uniform layer that frequently covers much of the sky.
- (b) Layered clouds due to horizontal air flow

6. Classification by Height

a. High Clouds: Above 6000 meters (20,000 ft): Clouds in this “family” are thin, white, and composed primarily of ice crystals due to small amounts of water vapor and low temperatures

b. Middle Clouds: Altitude range of 2000 to 6000 meters (6500 to 20,000 ft)

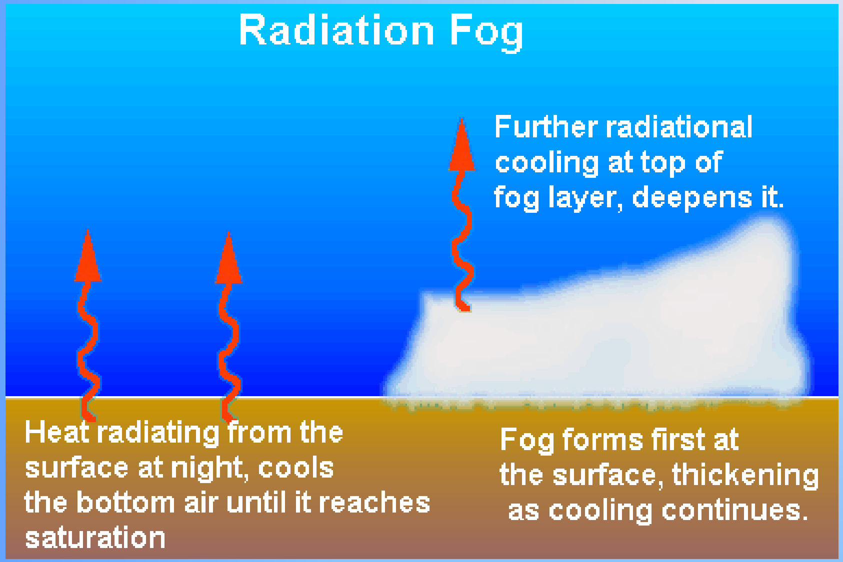
c. Low Clouds: Base below 2000 m (6500 ft)

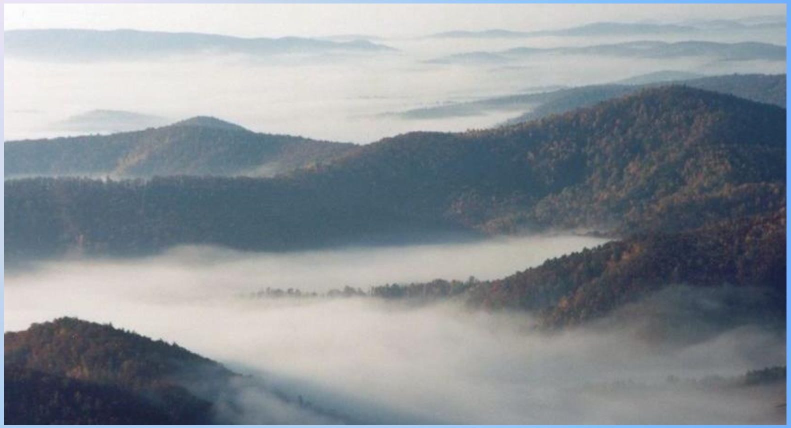
d. Clouds of Vertical Development
   (1) Do not fit into any of the three height families of clouds
   (2) Bases are low and tops extend to the middle or high altitude range and are associated with unstable air.

G. *Fog*

1. A cloud with its base at or very near the **ground**.
2. Physically, there is **no** difference between fog and a cloud.
3. The basic difference is the **method** and place of **formation**.
   a. Clouds form when air rises and cools **adiabatically**.
   b. Fog forms from **cooling** or the addition of enough water vapor to cause **saturation**.

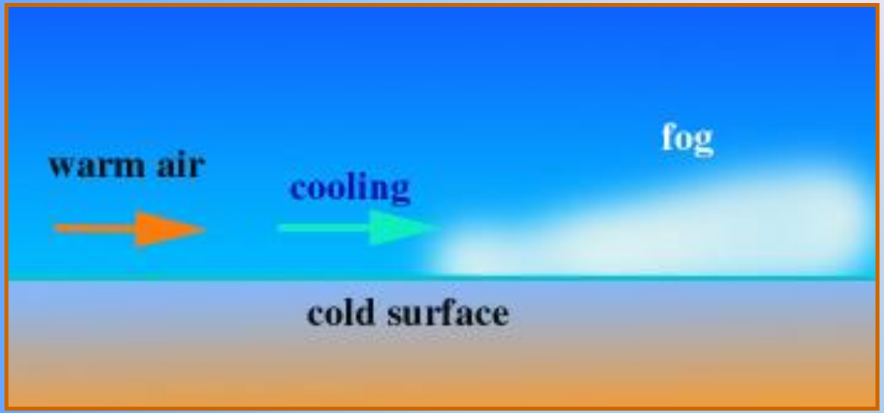
Radiation Fog

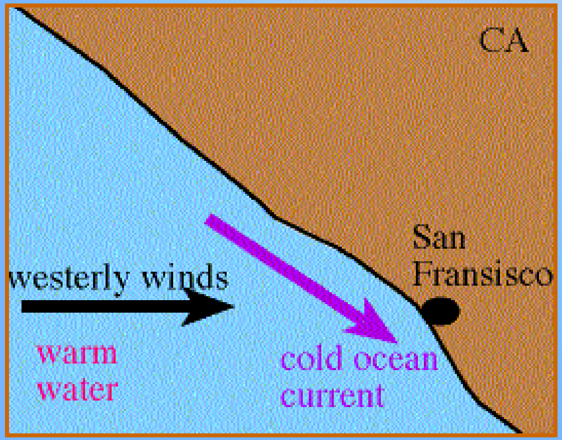


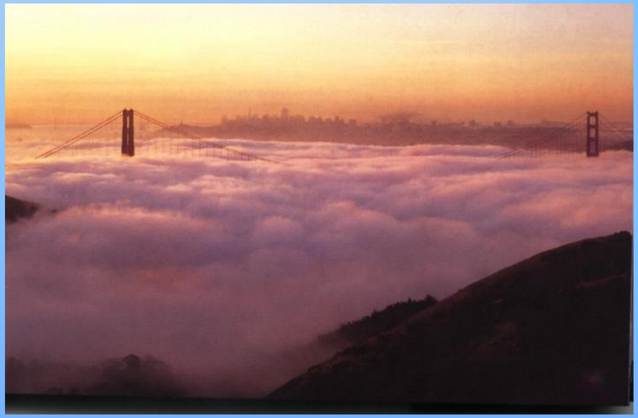


- Results from radiational cooling.
- Occurs at night.
- Requires clear skies and a high relative humidity
- The cold and dense air tends to flow downslope and is often thickest in mountain valleys
- After sunrise it dissipates (often said to “lift” or “burn off”). Fog evaporates from the bottom up (due to heating of the ground).

Advection Fog

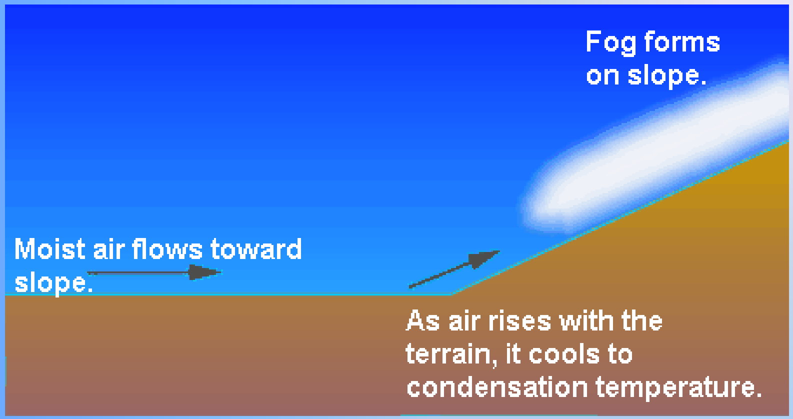






- Results from warm air being blown over a cold surface.
- Common in San Francisco, Cape Disappointment, Washington, winter months in central eastern North America

Upslope Fog



Rocky Mountains

- Formed when humid air moves up a gradual sloping plain or a steep mountain slope.
- The upward movement of the air causes it to expand and cool adiabatically. (This is the only type of fog that forms adiabatically.)

Steam Fog

- Air just above warm water becomes saturated as cool air moves over it.
- Air has a “steaming” appearance and is shallow (it re-evaporates in unsaturated air above)
- Arctic Sea Smoke is steam fog formed in winter when cold air moves off continents and ice shelves of the north into the open ocean.

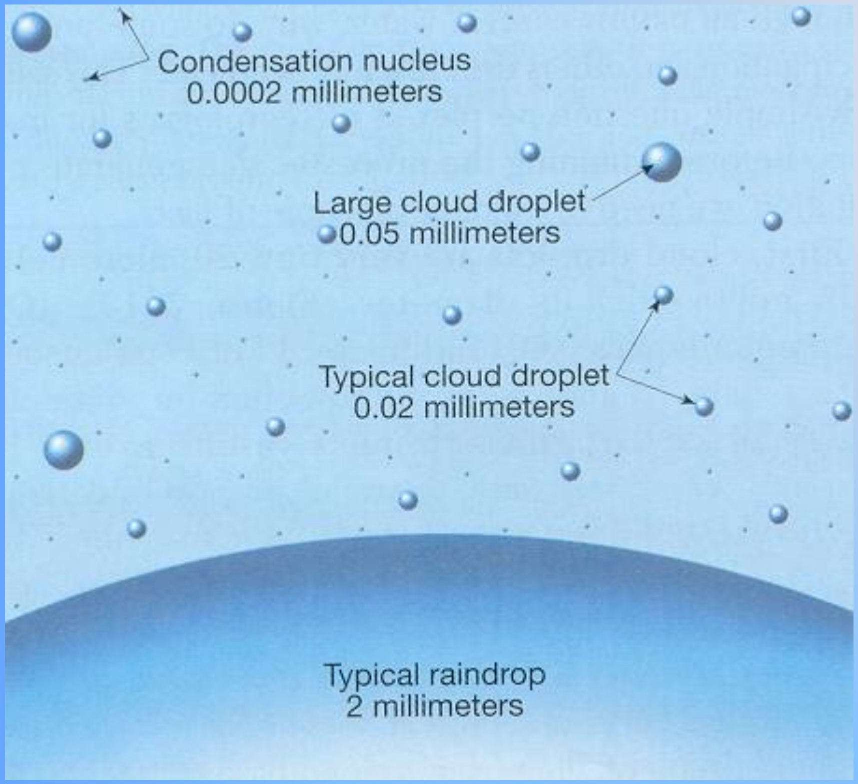
H. Dew and Frost

1. __Dew__
   a. Temperature next the ground cools to its dew point
   b. Water condenses on surfaces
2. Frost____
   a. Air temperature is _below_ freezing.
   b. Deposition occurs on surfaces.

l Precipitation: Moisture falling to Earth's __surface__ from clouds.

1. Formation

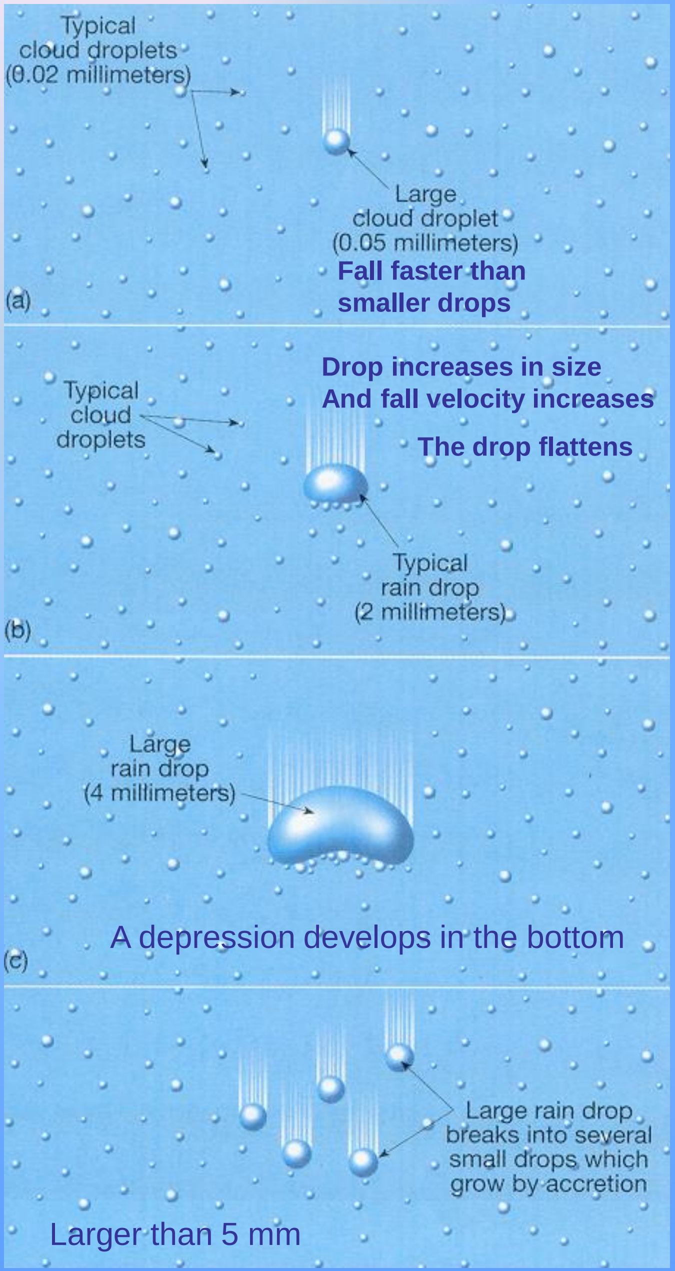
a.**Collision-Coalescence** in _**Warm**_ Clouds (above freezing)



(1) Larger drops __**collide**____with smaller ones, therefore growing in size

(2) Drop has to survive water loss due to frictional drag (function of surface tension).

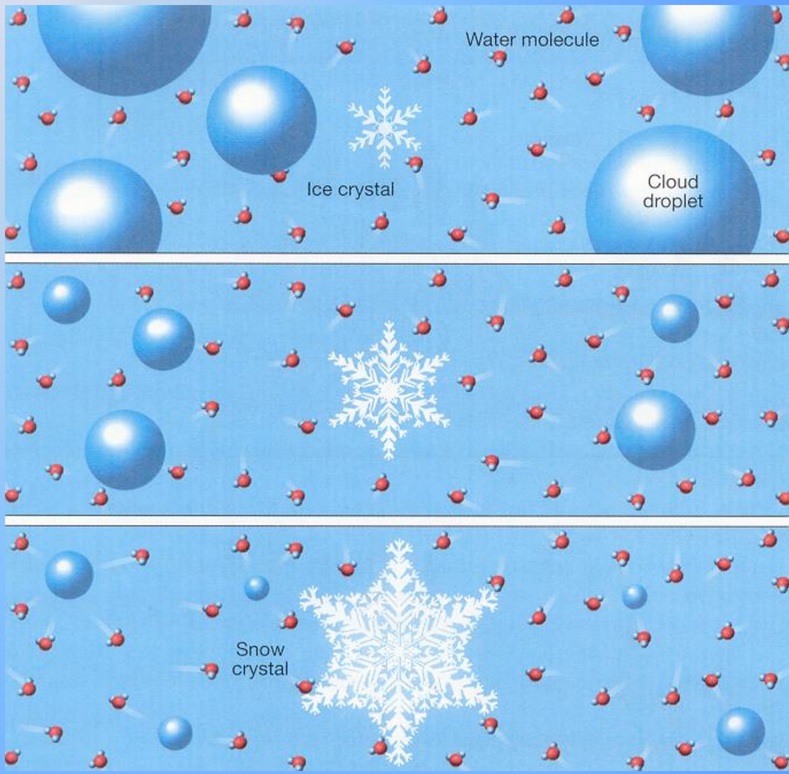
(3) Large drops may __**splinter**__into small ones which in turn grow by collision and coalescence.



b. **Bergeron Process** in Cold Clouds (Below Freezing)

***Ice crystals grow at the expense of supercooled water drops*.**

(1) <u>Supercooled Drops</u>: A liquid below its standard freezing point will crystallize in the presence of a seed crystal or nucleus around which a crystal structure can form. However, lacking any such nucleus, the liquid phase can be maintained.



(a) Pure water drops suspended in air freeze at -40º C (-40º F)

(b) Freeze on contact with solid particles with a crystal structure resembling ice (called *freezing nuclei*)

(c) Between 0º C and -10º C clouds consist of mainly supercooled water because freezing nuclei are sparse and don't become active until -10º C or lower.

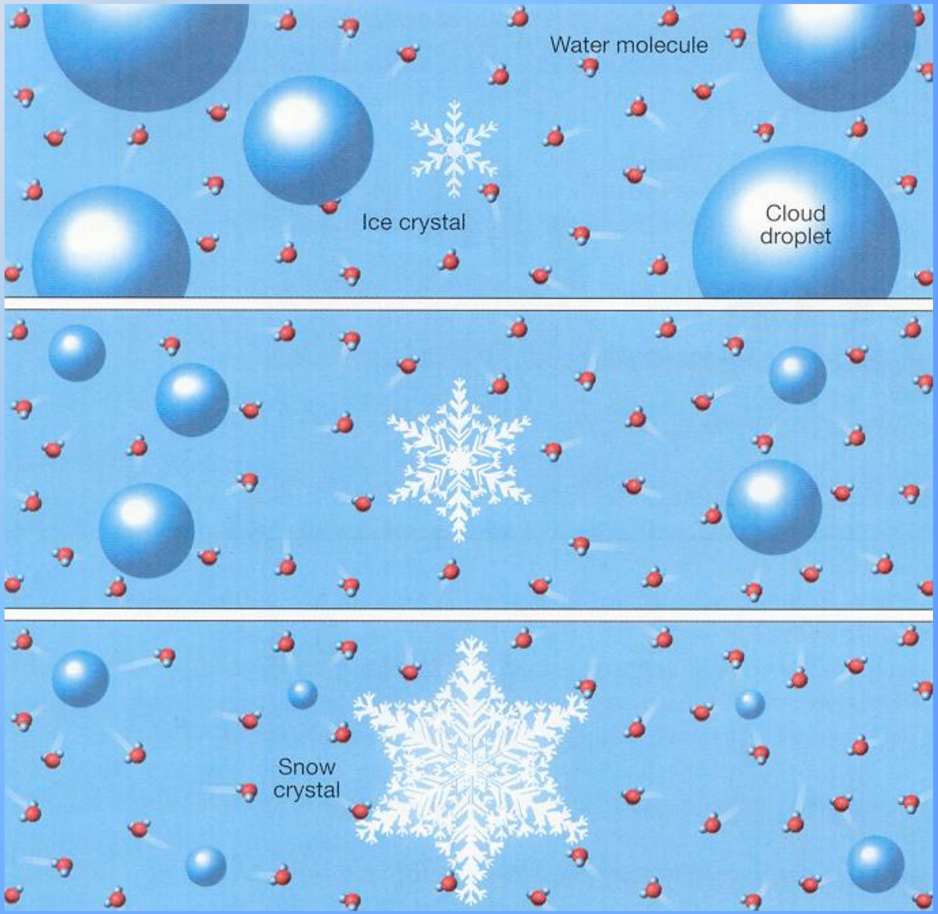
(d) Between -10º C and -20º C supercooled drops coexist with ice crystals

The Bergeron Process

- proposed by the Swedish meteorologist Tor Bergeron
- takes place when ice crystals form high in the cloud tops.
- microscopic ice crystals attract more water vapor, causing them to increase in size.
- as the ice crystals increase in size, the vapor pressure drops (relative humidity decreases).
- this allows surrounding water droplets to evaporate, becoming smaller and smaller as the ice crystals grow.
- eventually these ice crystals become large and heavy enough that they begin to fall towards the Earth's surface.
- they pass through the lower warmer portion of clouds, attracting even more water vapor, and growing larger still.

2. Saturation Vapor Pressure of Supercooled Water vs. Ice Crystals

(a) Ice crystals have a lower saturation vapor pressure above them.
(b) Supercooled water drops loose water molecules at a greater rate than ice crystals which are solid.
(c) When air is saturated with supercooled liquid droplets it is supersaturated with respect to ice crystals.

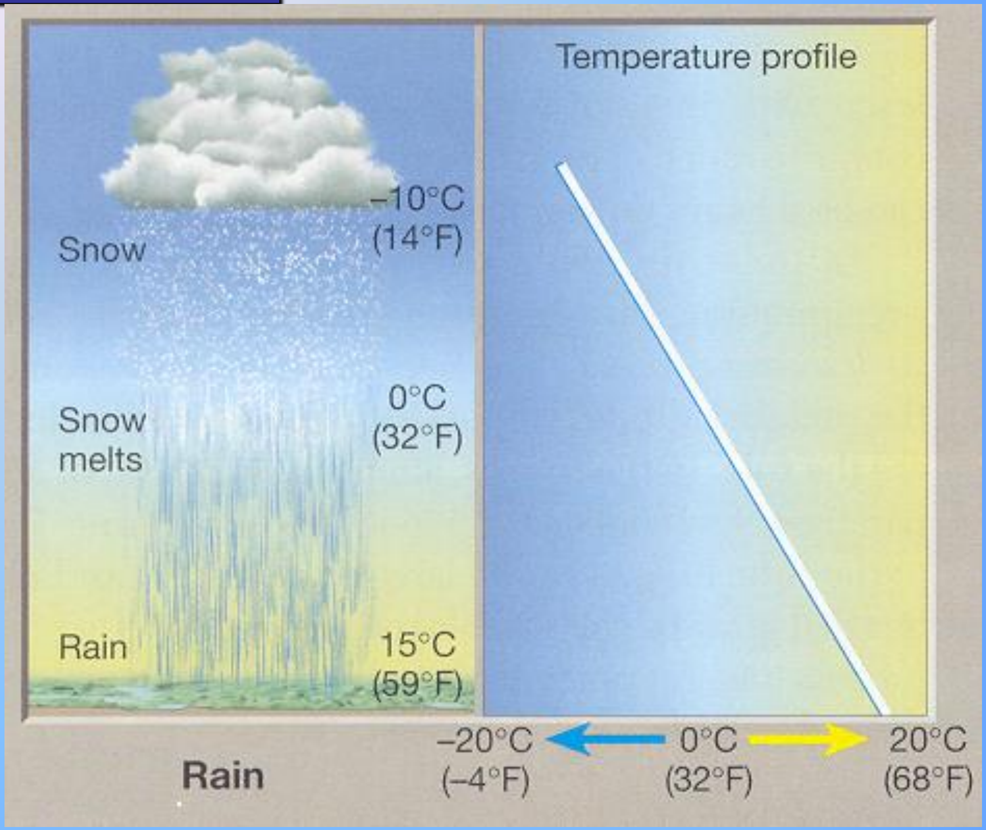


3. Ice serve as freezing nuclei

(Similar to condensation nuclei for condensation)

(a) Become heavy and fall, break up (air movement) and form more crystals
(b) Become large snowflakes that usually melt before they reach the ground resulting in rain.

2. Forms of Precipitation



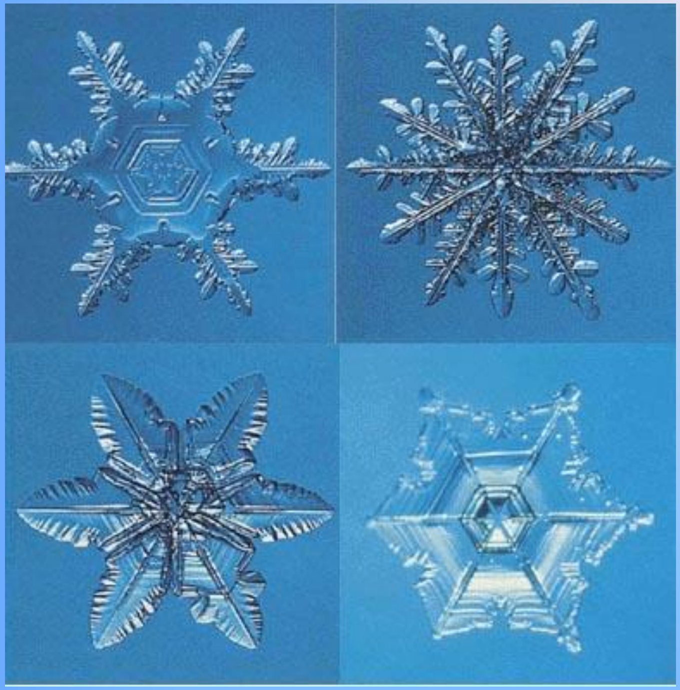
a. **Rain**

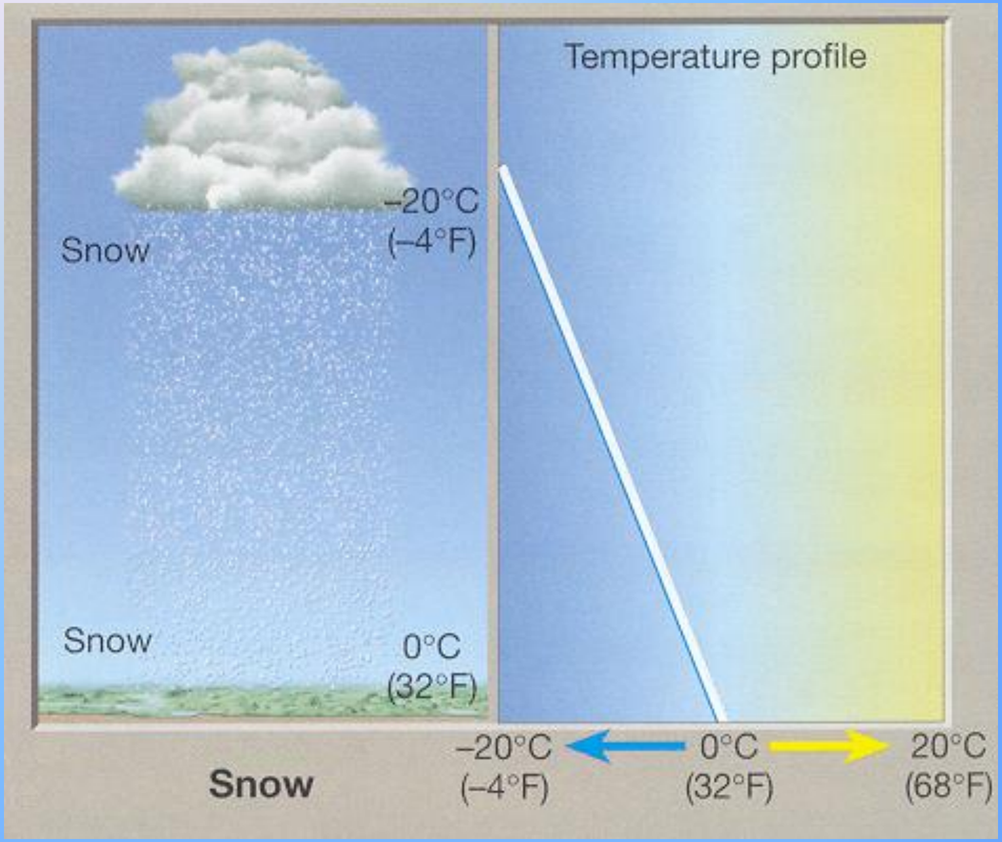
(1) __Liquid__ drops with a diameter of at least 0.5 mm (usually not larger than 5 mm)

(2) Often begins as __snow__ at high altitudes

b. __Drizzle__ is composed of uniform droplets with diameters less than 0.5 mm.

c. Snow

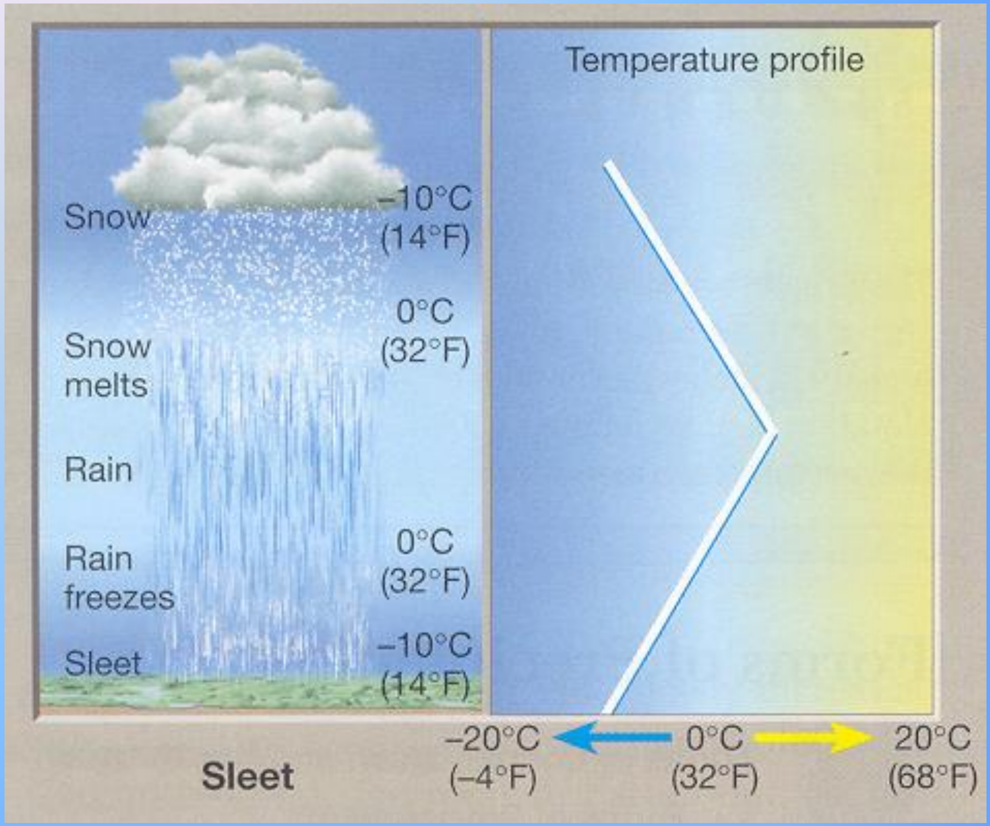




(1) Ice Crystals that have grown as they traverse the cloud.

(2) At temperatures greater than about -5º C, crystals usually stick together forming snowflakes

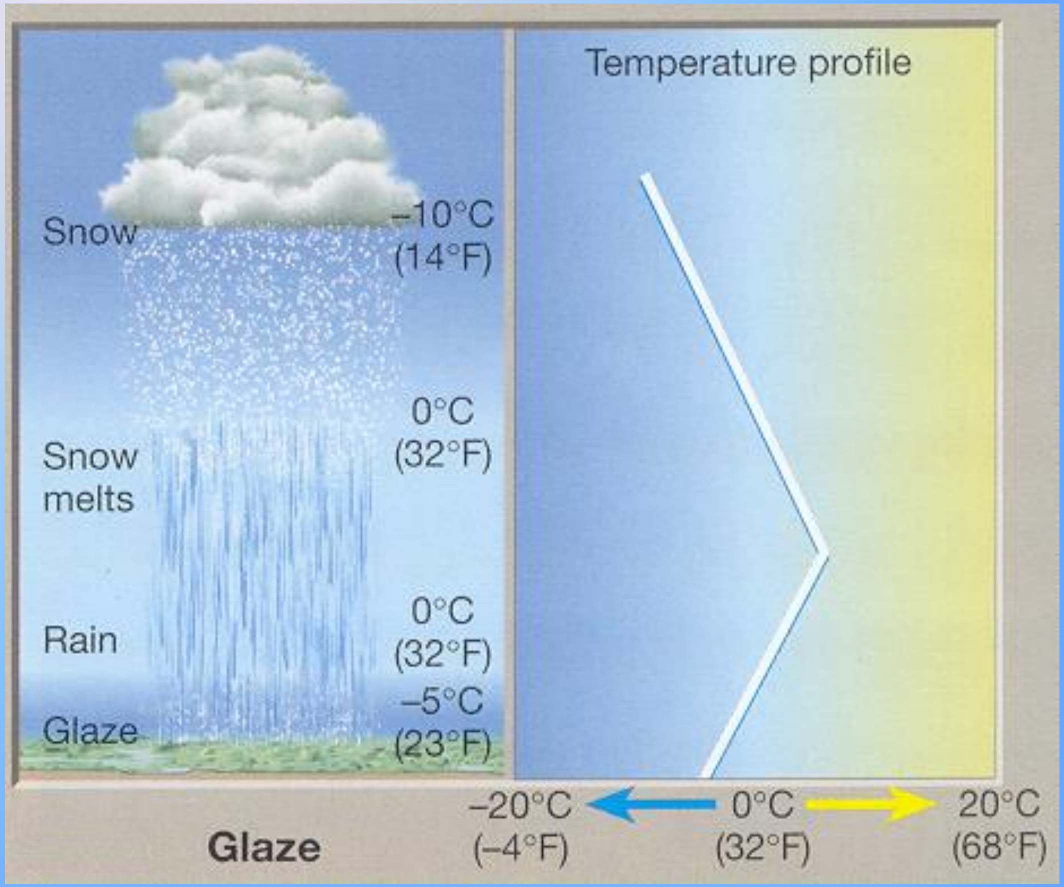
d. Sleet



(1) Transparent or translucent, quasi-spherical ice (diameter less than 5 mm)

(2) Originate either as raindrops or snowflakes that have melted en route to the ground and are frozen as the move through a cold air layer near the ground.

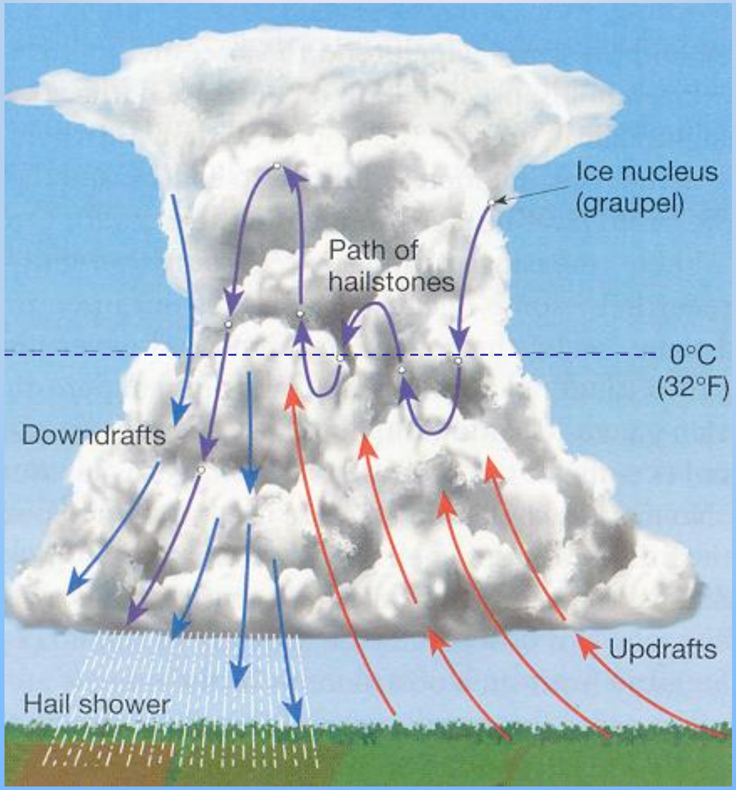
e. Freezing Rain (Also Called *glaze*)



(1) Rain or drizzle that freezes on impact with the ground or objects.

(2) Subfreezing air near the ground is not thick enough for liquid drops to freeze although the liquid drops become supercooled.

F.__**Hail**__: Formed in large cumulonimbus clouds

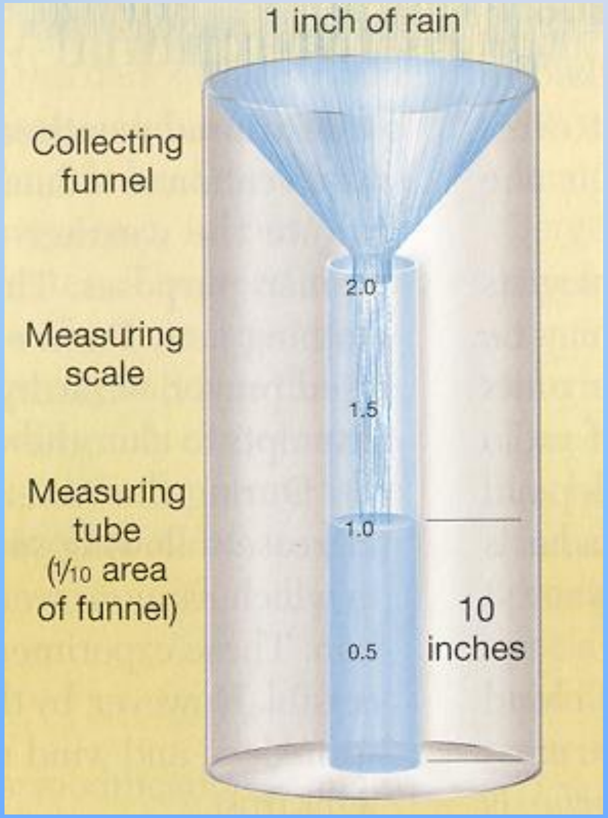


(1) **Small balls or chunks of ice with a diameter of 5 to 75 mm (largest on record fell in Coffeyville, Kansas on Sept. 3, 1970 and was 140 mm in diameter).**

(2) **Produced by successive accretion of water drops around a small kernel of ice moving through a thick cloud. Produces several layers resulting in an onion-like cross section**

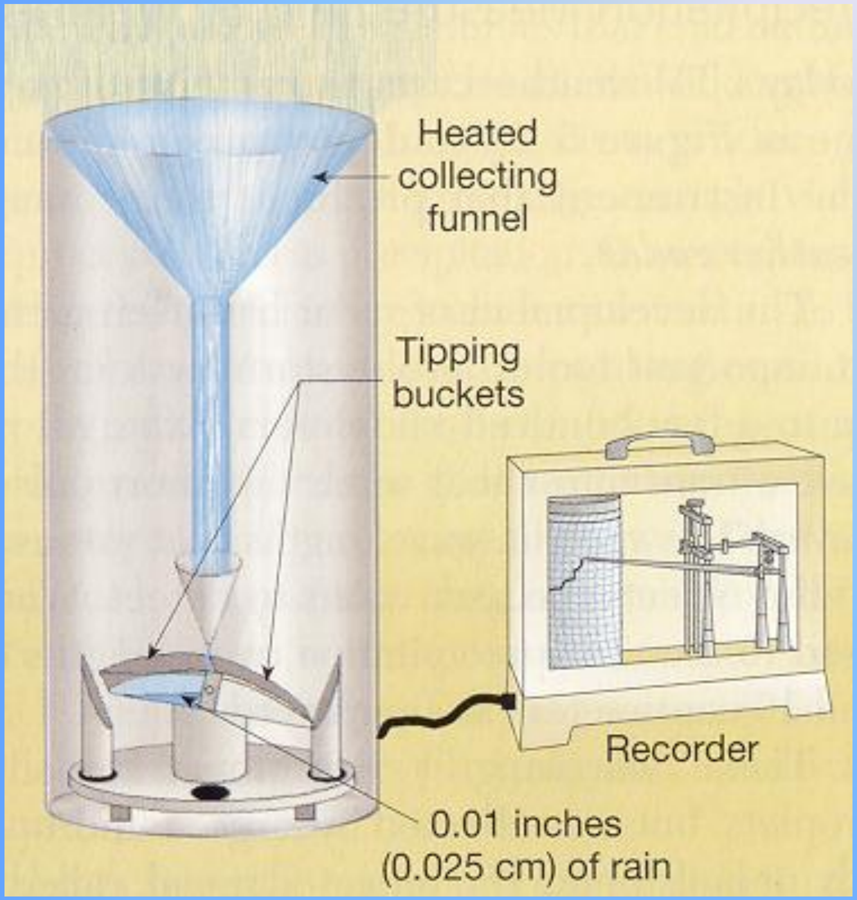
3. Measuring Precipitation

a. Rainfall



Standard Rain Gauge

Tipping Bucket Rain Gauge

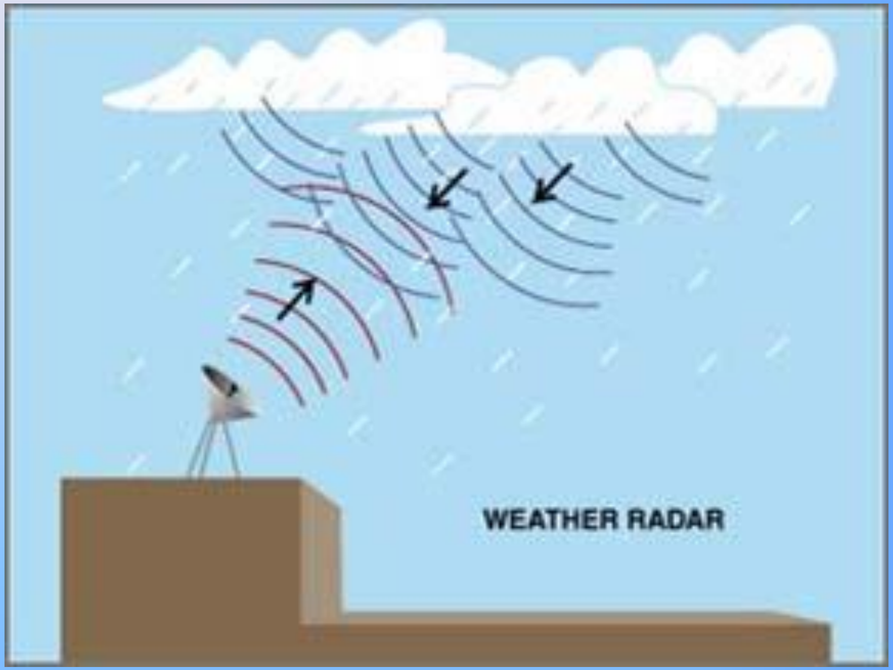


b. Snow Records

(1) Snow depth is measured

(2) Liquid equivalent is determined

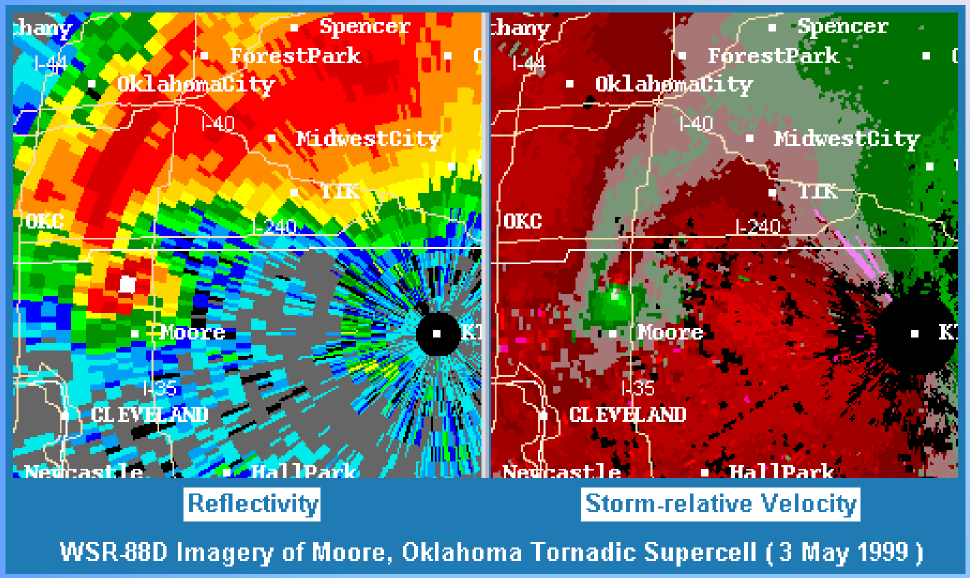
5. Weather Radar



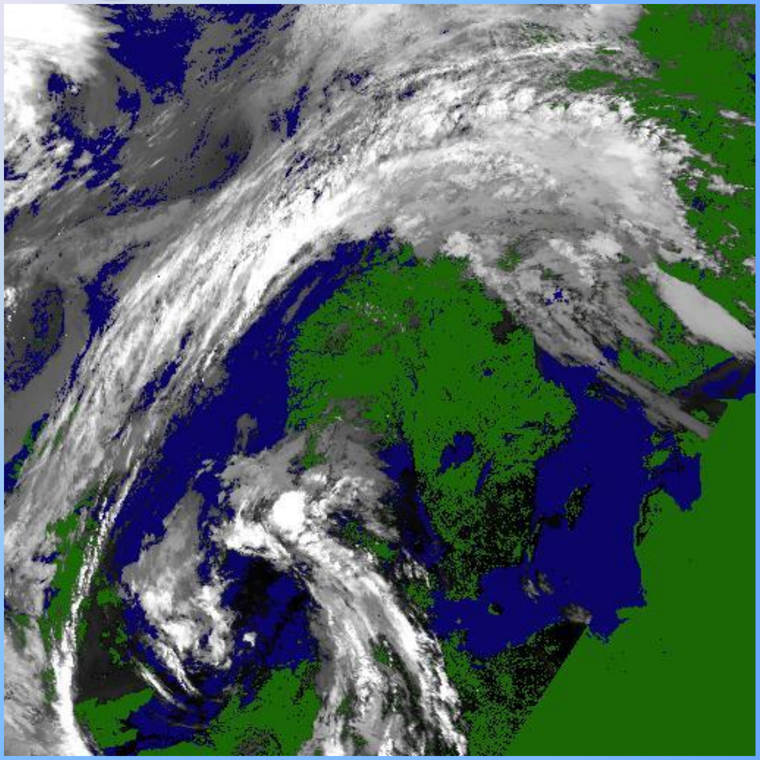
(1) Specific wavelengths are reflected by larger raindrops, ice crystals, or hailstones (penetrate small cloud droplets.

(2) Echo results (reflected signal)

Radar Images



Doppler Radar



Conventional Radar

Conventional radars can show the intensity of a storm, but only in regards to precipitation.

The Doppler radar measures the *speed* and direction of the wind in addition to precipitation, and receives a more comprehensive view of a storm.