Physics 221, March 23

Key Concepts:

- Temperature and pressure
- Heat
- Regulating heat flow
- Thermal properties of matter

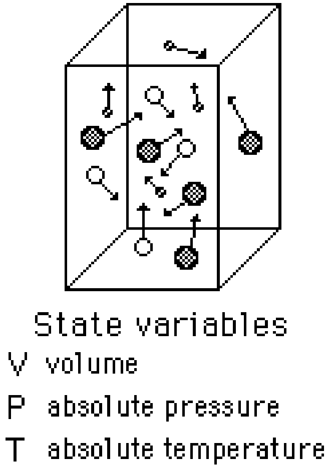
Temperature

The **average kinetic energy** of the random motion of the molecules of a substance is proportional to the **absolute temperature T** of the substance.

$\langle KE \rangle = \frac{1}{2}m\langle v^2 \rangle = (3/2)k_BT$, $k_B = 1.381 \times 10^{-23}$ J/K.

In SI units the scale of absolute temperature is **Kelvin** (K).

temperature in ^oC = temperature in K - 273.15.



Ideal gas law: $PV = Nk_BT = nRT$

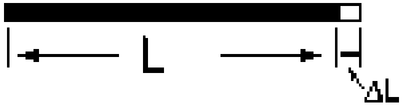
P = pressure, V = volume, T = absolute temperature,

N = number of molecules, n = number of moles,

R = universal gas constant, R = 8.31 J/(mol K).

For a gas: $V \propto T$ at constant pressure

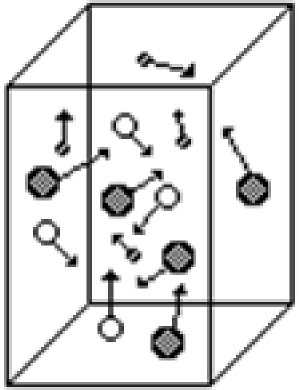
Solids and liquids also expand as the temperature increases.



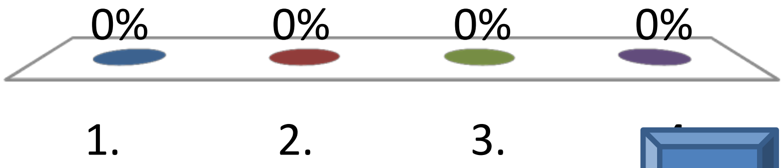
coefficient of linear expansion: $\Delta L = \alpha L \Delta T$ or , $\alpha = \Delta L/(L\Delta T)$.

volume expansion coefficient: $\Delta V = \beta V \Delta T$, $\beta = 3\alpha$.

Consider two specimens of ideal gas at the same temperature. The molecules in specimen #1 have greater molar mass than the molecules in specimen #2.
How do the root-mean-square or RMS speeds, $v_{rms} = \sqrt{\langle v^2 \rangle}$, of molecules and the average translational kinetic energy per molecule, $\langle KE \rangle = \frac{1}{2} m \langle v^2 \rangle$, compare in the two specimens?



1. v_{rms} and <KE> are both greater in specimen #2.
2. v_{rms} is greater in specimen #2; <KE> is the same in both specimens.
3. v_{rms} is greater in specimen #2; <KE> is greater in specimen #1.
4. v_{rms} and <KE> are the same in both specimens.



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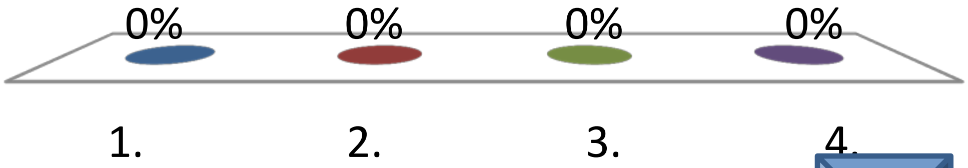
A steel bridge is built in several segments, each 20 m long. The gap between segments is 2 cm at 18 ^{o}C. What is the maximum temperature that the bridge can manage before buckling?

α(steel) = 13*10^{-6} /(^{o}C)

Hint:
$\Delta L = \alpha L \Delta T$).

1. 95 ^{o}C
2. 77 ^{o}C
3. 28 ^{o}C
4. 38 ^{o}C



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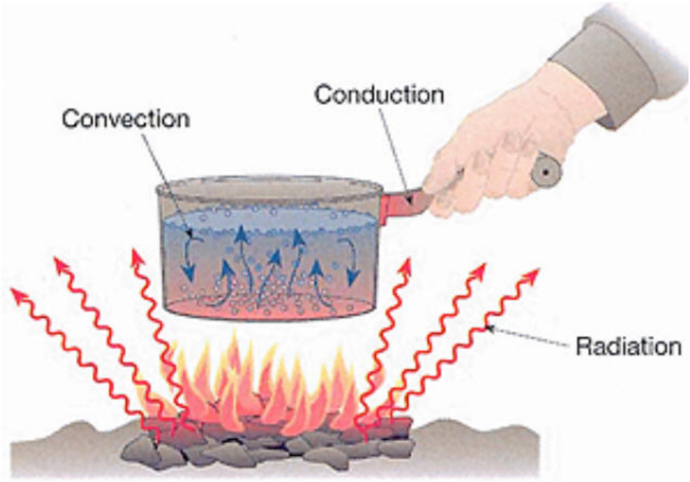
Heat

Two objects at the same temperature are in **thermal equilibrium** with each other.
When you bring two objects of different temperature together, energy will always be transferred from the hotter to the cooler object. We say that **heat** flows from the hotter to the cooler object.

Heat is energy on the move.

There are three different ways for heat to flow from one object to another.

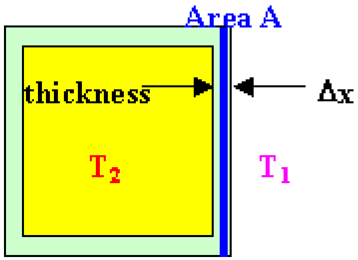
Conduction
Convection
Radiation



Conduction and convection

law of heat conduction:

$$\frac{\Delta Q}{\Delta t} = -kA\,\frac{\Delta T}{\Delta x}$$



$\Delta Q/\Delta t$ = rate at which heat flows across area A through a layer (J/s)

$\Delta T = (T_2 - T_1)$ = difference in temperature between side 2 and side 1 (K or °C)

Δx = the thickness of the layer (m)

k = thermal conductivity (material property) (J/s)/(°C m)

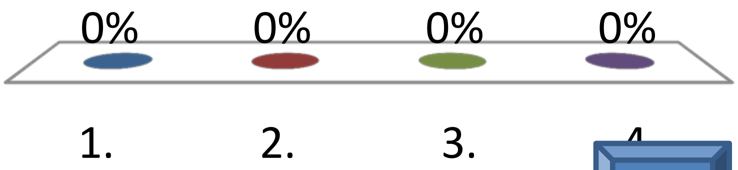
Convection (in fluids):

forced: wind, fan, etc

natural: thermal expansion → density change → buoyancy

Why are good thermal conductors generally good electric conductors also?

1. Heat and electricity are the same things.
2. The molecules in both don’t move around very much.
3. Electron motion is responsible for determining both properties.
4. The answer depends on the specific metal.



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Radiation

The **Wien Law** gives the wavelength of the peak of the radiation distribution, $\lambda_{max} = 3*10^6/T$.

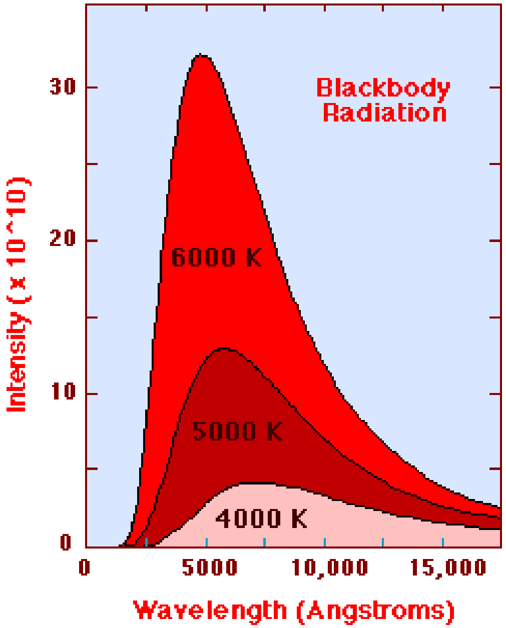
λ is measured in units of nm = 10^{-9} m and T in Kelvin.

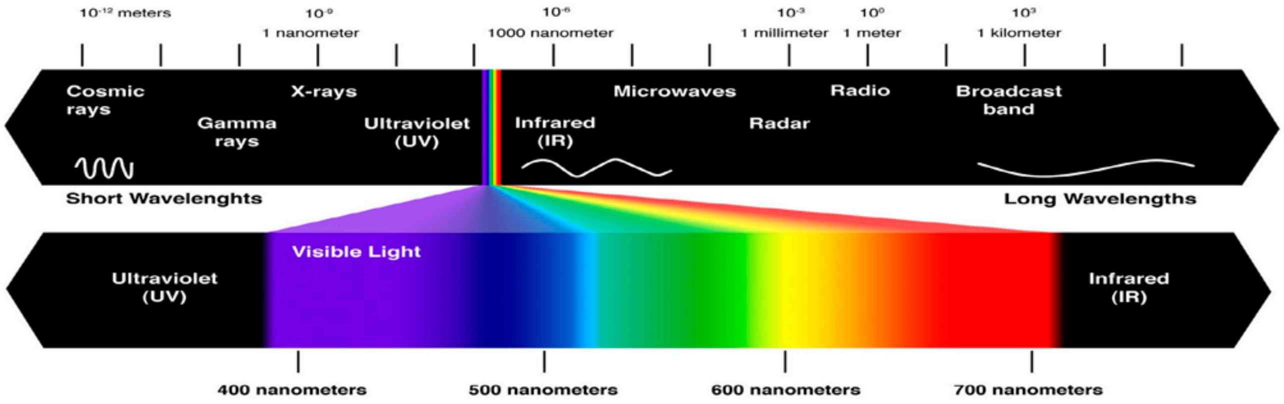
The **Stefan-Boltzmann Law** gives the total energy being emitted at all wavelengths by the body.

Radiated power = emissivity * σ * T^4 * Area

$\sigma = 5.67*10^{-8} W/(m^2K^4)$ is the **Stefan-Boltzmann constant**, and the temperature is measured in Kelvin.

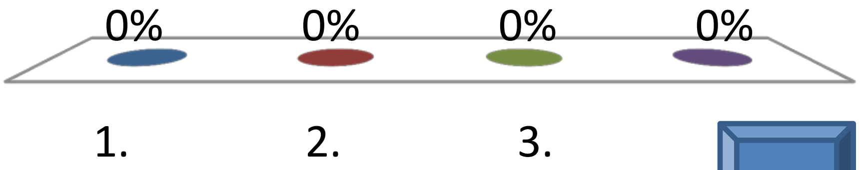
Planck Radiation Law.





In the constellation Orion, you can easily observe the difference between the reddish looking star Betelgeuse and the bluish looking star Rigel. Which of the two has the cooler surface temperature?

1. Rigel
2. Betelgeuse
3. They have the same surface temperature, since they are in the same constellation.
4. There is no way to tell since we do not know the exact distance to those stars.



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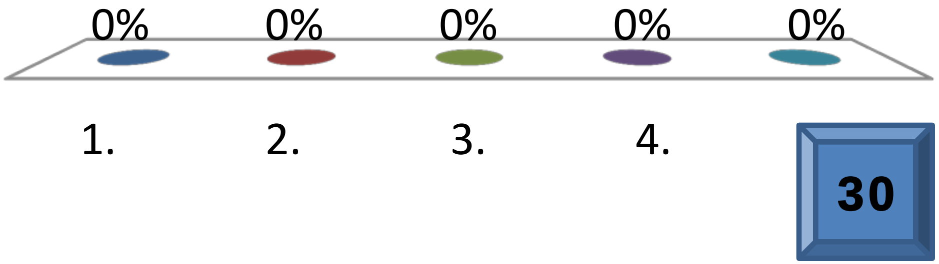
Assume that a naked human body has a surface area of 1.5 m^2 and a surface temperature of 32°C. If the surroundings are at a temperature of 16°C, calculate the net rate of heat loss by the body due to radiation. Assume an emissivity of 1.

Heat loss = **$\sigma * T^4_{body} * Area$,** Heat gain = **$\sigma * T^4_{surrounding} * Area$,**
Net loss = **$\sigma * (T^4_{body} - T^4_{surrounding}) * Area$**

1. 0.083 W
2. $9.8*10^5$ W
3. 105 W
4. 95 W
5. 143 W



People fighting forest fires carry emergency tents that have shiny aluminum outer surfaces. If there is trouble, a fire fighter can lie under the tent to block the heat from burning trees overhead. The tent helps because

1. conduction carries heat downward toward the fire fighter and the aluminum tent conducts that heat harmlessly into the ground .
2. radiation carries heat downward toward the fire fighter and the aluminum tent reflects most of that radiation.
3. convection carries heat downward toward the fire fighter and the aluminum tent blocks most of the heat carried by convection.
4. both conduction and radiation carry heat downward toward the fire fighter and the aluminum tent blocks most of that heat.

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Thermal properties of matter

How much heat does a substance absorb or release?

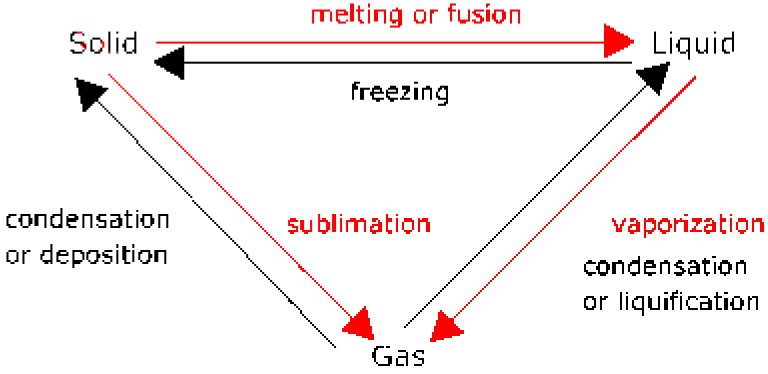
- Specific heat capacity c: $c = \frac{\Delta Q}{m\Delta T}$ kcal/(kg ^{o}C)
- latent heat of melting or latent heat of fusion (L_f) kcal/kg
- latent heat of vaporization (L_V) kcal/kg

Water:

$c = 1$ kcal/(kg ^{o}C)

$L_f = 80$ kcal/kg

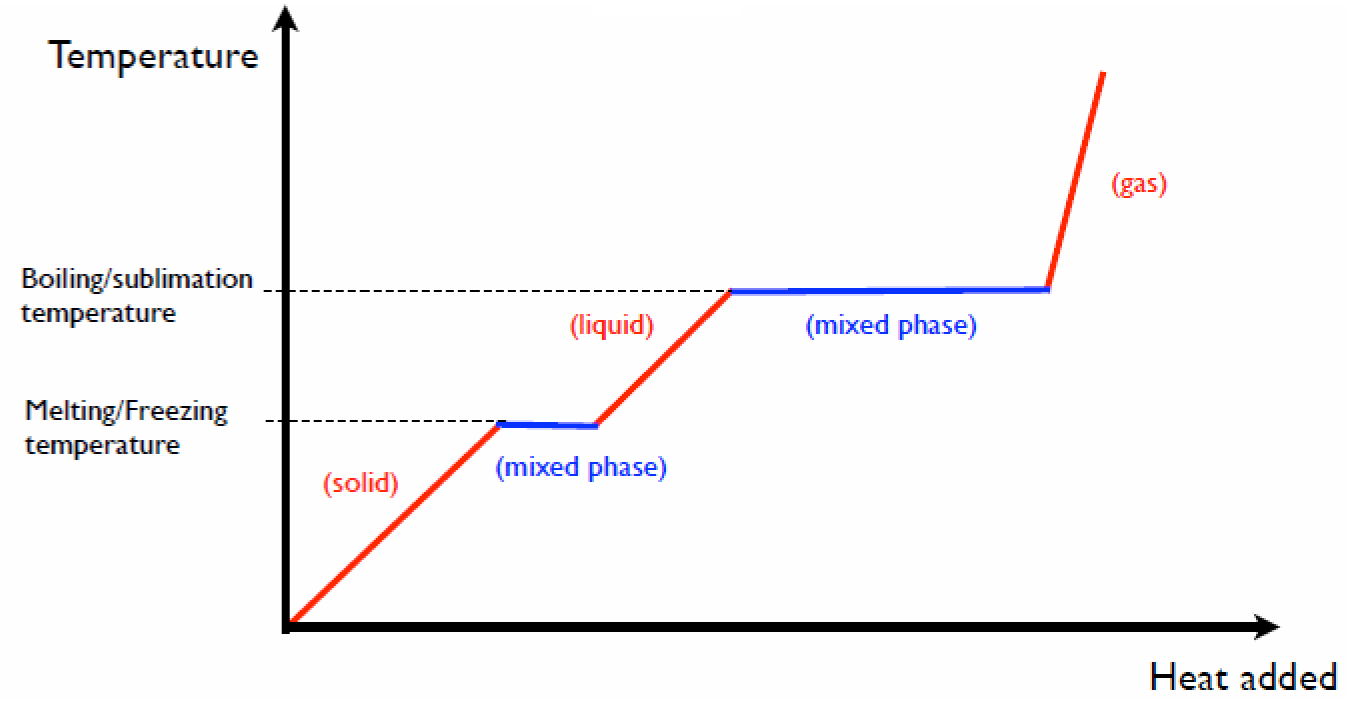
$L_v = 540$ kcal/kg



The processes represented by the **red** arrows require energy input.

The processes represented by the **black** arrows release energy.

Phases of matter



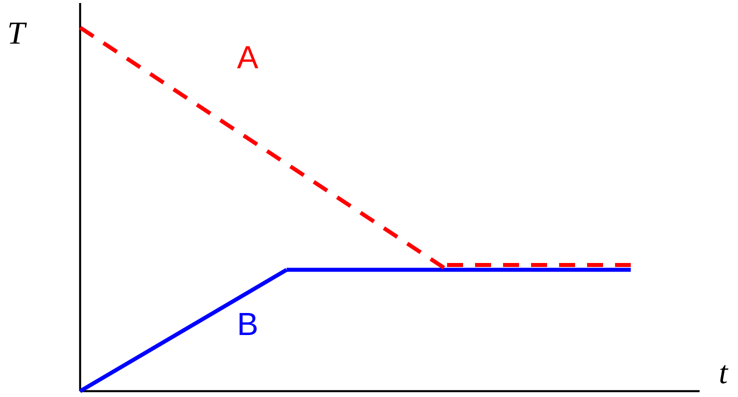
Adding heat in in a given phase changes the temperature.

Specific heat c: $\Delta Q = c*m*\Delta T$

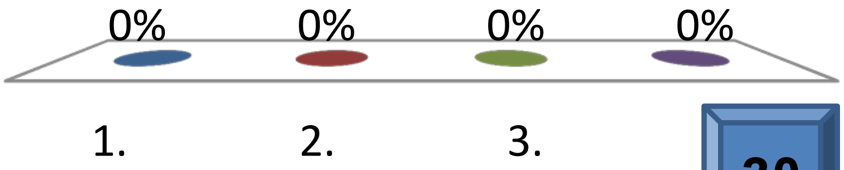
Adding heat during a phase change converts from one phase to another phase without changing the temperature.

Latent heat L: $\Delta Q = m*L$

A sample of liquid water A and a sample of ice B of identical masses, are placed in a thermally isolated container and allowed to come to thermal equilibrium. The diagram below is a sketch of the temperature *T* of the samples verses time *t*. In the time interval shown, what is happening?



1. The ice does partially melt.
2. The previously liquid water partially freezes.
3. The ice stays ice and the water stays water.
4. The ice completely melts and the final temperature is above 0 °C.



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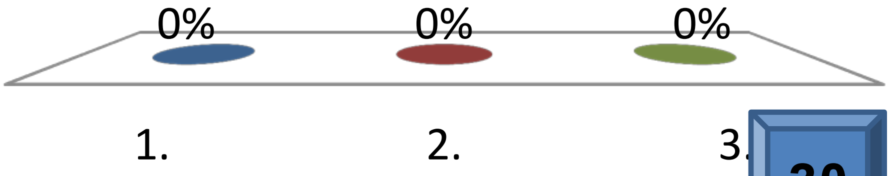
Orange growers in Florida spray their trees with water when they expect a freeze. Why does this work?

1. If a mixed phase of water and ice is present, the temperature does not drop below 0 °C.
2. During an extended freeze ice forms a protective layer around the plant.
3. This only works with hot water. The hot water melts the ice.



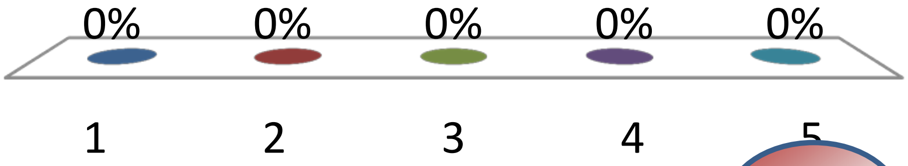
When the water freezes on outside of a plant, latent heat is released. As long as a mixed phase of water and ice is present, the temperature does not drop below 0 ^{o}C. Ice formation on the outside of the plant keeps the liquids inside the plant at a temperature of 0 ^{o}C.

The liquid inside the plant is a solution of various substances dissolved in water. The dissolved materials serve as a kind of natural anti-freeze that lowers the freezing point of the liquid inside below 0 ^{o}C, and ice does not form on the inside of the plant.

If the spraying continues for a long time, the weight of the ice load on the plant becomes great enough to damage it.

Ice initially at –20 °C is to be turned into steam at 130 °C. To figure out how much heat is required, how many separate terms will there be (i.e. $\Delta Q = c*m*\Delta T$, $\Delta Q = m*L_V$, and $\Delta Q = m*L_f$)?

A. 1
B. 2
C. 3
D. 4
E. 5



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Relative humidity

The **relative humidity** is the ratio of the rate of condensation to the rate of evaporation.

If twice as many molecules leave the liquid than are returning to the liquid, then the relative humidity is 0.5 or 50%.

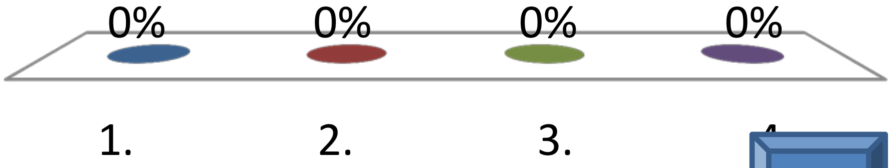
The relative humidity depends on the temperature and on the density of the water vapor in the air.

The higher the temperature, the higher is the average kinetic energy of the molecules and therefore the rate at which they are leaving.

The higher the density of water vapor in the air, the higher is the rate the molecules are returning.

Your dryer is broken, so you have to hang your wet clothes from the washing machine outside to dry. Under which conditions would your clothes dry fastest?

1. When it is 50°F with 50% relative humidity.
2. When it is 75°F with 50% relative humidity.
3. They will dry at the same rate at any temperature with 50% relative humidity.
4. The clothes will not dry with 50% relative humidity.



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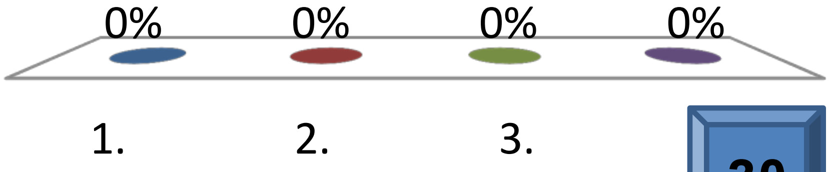
On a humid summer day, perspiration does not cool you off much.   Why?

1. The air density is extremely low and the air pressure is too high to permit water to evaporate.
2. The water vapor in the air is moving too fast to condense on your skin as perspiration.
3. The air density is extremely low and its pressure is too low to permit water to evaporate.
4. The air is almost saturated with water vapor and there is almost no net evaporation.



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