Class 37

Vapor Pressure and Humidity

Kinetic theory applied not only to gases but also to liquids. That means that the temperature is proportional to the average kinematic energy of the molecules.

So the molecules of the liquid, just as with a gas, are moving with velocities distributed according to Maxwell's distribution.

In a liquid, as opposed to a gas, there is an *attractive* force between the molecules.

The molecules are held in the liquid by the cumulative attractive forces coming from the molecules at the surface.

These forces create a force at the surface which is analogous to the force of gravity on Earth.

Surface tension which results in water droplets staying together, is a result of this cumulative intermolecular attractive force.

Molecules which move toward the surface will go above the surface like an artillery shell goes above the ground.

As long as the speed of the molecule is low, it will be drawn back to the surface by the collective attractive forces of the molecules still on the surface.

However, just as with gravity, there is an *escape* velocity, above which the object will escape the gravity of the Earth, there is velocity above which a liquid molecule will escape the attractive force from the liquid surface.

Because of the exponential tail of the Maxwell distribution, there will always be molecules whose velocities are above the escape velocity.

If the temperature of the liquid is increased, the number of molecules above the escape velocity increases, and the rate of escaping liquid molecules will increase.

The process of the escape of liquid molecules forms a *vapor* phase of the liquid, and is known as ***evaporation.***

Evaporative Cooling

Since only the fastest moving molecules escape from the liquid, the average speed of the remaining molecules *decreases*. Just like if you move the best performing students from a class the class average declines.

Since the temperature is proportional to the energy of the molecules evaporation leaves the temperature of the remaining liquid *lower*.

Evaporative cooling is an important way that we have of controlling out body temperature. Our sweat evaporates on our skin leaving the liquid remaining behind cooler.

The pressure resulting from the vapor of the liquid molecules leaving the surface is called ***vapor pressure.***

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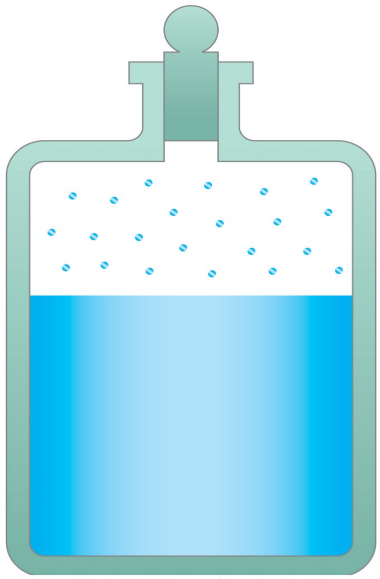
Saturation



If we have a liquid in a closed container, the molecules leaving the surface will accumulate in the space above the liquid surface.

Some of these molecules which are moving around as molecules in a gas do. will randomly crash back into the surface.

The greater the number of molecules above the surface is, the larger the rate of molecules returning to the surface will become.

Eventually the number of molecules above the surface will become large enough so that the rate of molecules returning to the surface becomes equal to the rate of molecules leaving. Thus the liquid is in equilibrium with its vapor. This condition is called *saturation.*

If the liquid is *not* in a closed container, the evaporating molecules will not accumulate, and so the evaporation process continues.

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Boiling

From the Maxwell distribution, we know that the number of molecules whose velocity is above the surface escaped velocity increases with temperature, thus the vapor pressure increases with temperature.

When the vapor pressure equals the pressure of the atmosphere, **boiling** occurs.

When the temperature of a liquid gets close to the boiling point tiny bubbles of the vapor phase form in the liquid. However due to the fact that the vapor pressure in the bubbles is less than the atmospheric pressure the bubbles are crushed by the pressure.

When the vapor pressure becomes greater than the atmospheric pressure the bubble can grow, and this is the boiling process.

Partial Pressure and Humidity

Typical air is made up of several gases.

Each of the component gases of air has a ***partial pressure***. Partial pressure if the pressure which the component gas would have if that gas were present alone.

If the partial pressure of water vapor in the air reaches the saturation pressure, which is the pressure at which the rate of molecules leaving the surface equals the rate of molecules returning, then no evaporation of water will occur.

Thus the partial pressure of water in the air, determines the rate at which water will evaporate.

Relative Humidity

Relative humidity is the ratio of the partial pressure of the water vapor in the air, to the saturation pressure, expressed as a percent.

$$RH = \frac{P_{water}}{P_{water}^{sat}} * 100$$

Since relative humidity determines the rate at which sweat will evaporate from our skin, at high relative humidity it is harder for our body to control its temperature. Thus high temperature when accompanied by high humidity is more uncomfortable than low humidity.

TABLE 13–3 Saturated Vapor Pressure of Water

Temperature (°C)	Saturated Vapor Pressure torr (= mm-Hg)	Saturated Vapor Pressure Pa (= N/m^2)
−50	0.030	4.0
−10	1.95	2.60×10^2
0	4.58	6.11×10^2
5	6.54	8.72×10^2
10	9.21	1.23×10^3
15	12.8	1.71×10^3
20	17.5	2.33×10^3
25	23.8	3.17×10^3
30	31.8	4.24×10^3
40	55.3	7.37×10^3
50	92.5	1.23×10^4
60	149	1.99×10^4
70†	234	3.12×10^4
80	355	4.73×10^4
90	526	7.01×10^4
100‡	760	1.01×10^5
120	1489	1.99×10^5
150	3570	4.76×10^5

† Boiling point on summit of Mt. Everest.
‡ Boiling point at sea level.

Supersaturation and the Dew Point

If the temperature of a liquid is decreased the rate of evaporation decreases to a point where the number of molecules returning to the surface *exceeds* the rate of molecules leaving the surface. This means that vapor molecules will not only condense on water surface but on any surface. The point at which the temperature of water and the air above it decreases so that the partial pressure of the water vapor is *greater* than the saturation pressure is called the *dew point.* This process often happens as the air cools at night and results in condensation of water called *dew*.

Ch. 14 Heat

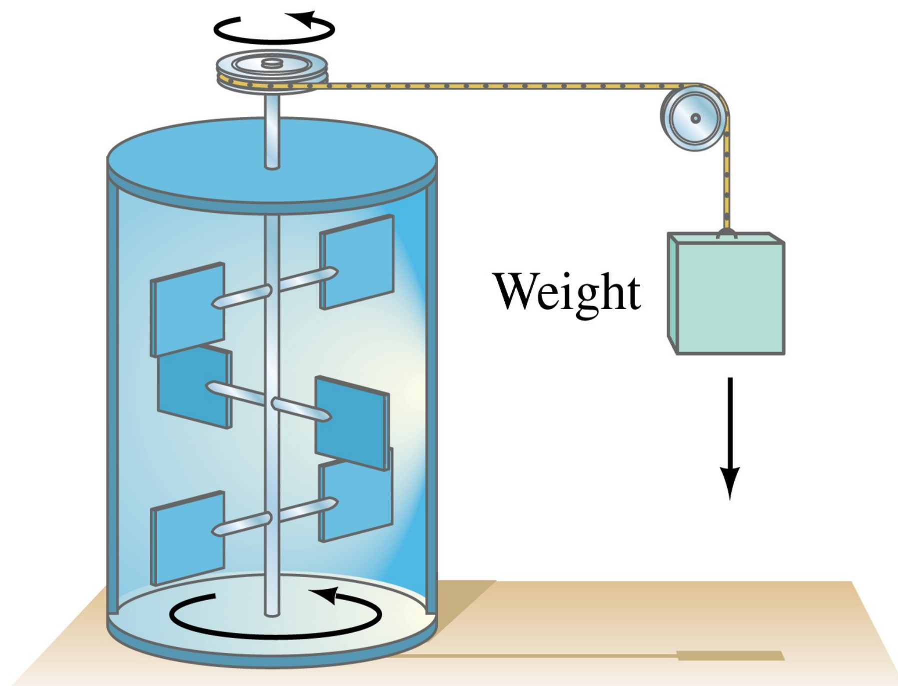
When 2 object of different temperatures are placed in contact the will reach the same temperature after some time. The is what we have referred to as *thermal equilibration.*

In this equilibration process energy flows from the hot object to the colder object.

Heat is the energy which flows from one oject to another because of a difference in temperature.

Units of heat --- the basic unit of heat it the amount of energy required to raise the temperature of 1 gm of water 1 degree C. This unit is called a ***calorie.***

The relationship between temperature, heat, and mechanical energy was established by Joule in the experiment shown below.



By calculating the total mechanical energy of the falling weight we will find some energy has gone into the liquid.

4.186 J = 1 cal.

4.186 kJ = 1 kcal.

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Review Clicker Problem

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37. Choose upward to be the positive direction, and take $y_0 = 0$ to be the height from which the ball was thrown. The acceleration is $a = -9.80\ \text{m/s}^2$. The displacement upon catching the ball is 0, assuming it was caught at the same height from which it was thrown. The starting speed can be found from Eq. 2-11b, with x replaced by y.

$$y = y_0 + v_0 t + \tfrac{1}{2}at^2 = 0 \quad \rightarrow$$

$$v_0 = \frac{y - y_0 - \frac{1}{2}at^2}{t} = -\tfrac{1}{2}at = -\tfrac{1}{2}\left(-9.80\ \text{m/s}^2\right)(3.0\ \text{s}) = 14.7\ \text{m/s} \approx \boxed{15\ \text{m/s}}$$

The height can be calculated from Eq. 2-11c, with a final velocity of $v = 0$ at the top of the path.

$$v^2 = v_0^2 + 2a(y - y_0) \quad \rightarrow \quad y = y_0 + \frac{v^2 - v_0^2}{2a} = 0 + \frac{0 - (14.7\ \text{m/s})^2}{2\left(-9.8\ \text{m/s}^2\right)} = \boxed{11\ \text{m}}$$

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21. Choose downward to be the positive y direction. The origin will be at the point where the ball is thrown from the roof of the building. In the vertical direction, $v_{y0} = 0$, $a_y = 9.80\ \text{m/s}^2$, $y_0 = 0$, and the displacement is 45.0 m. The time of flight is found from applying Eq. 2-11b to the vertical motion.

$$y = y_0 + v_{y0}t + \tfrac{1}{2}a_y t^2 \quad \rightarrow \quad 45.0\ \text{m} = \tfrac{1}{2}\left(9.80\ \text{m/s}^2\right)t^2 \quad \rightarrow \quad t = \sqrt{\frac{2(45.0\ \text{m})}{9.80\ \text{m/s}^2}} = 3.03\ \text{sec}$$

The horizontal speed (which is the initial speed) is found from the horizontal motion at constant velocity:

$$\Delta x = v_x t \quad \rightarrow \quad v_x = \Delta x / t = 24.0\ \text{m}/3.03\ \text{s} = \boxed{7.92\ \text{m/s}}.$$