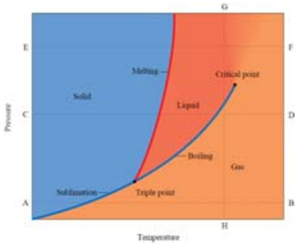
8.2 Temperature and Heat

Phase Transitions

Ideal gas Law

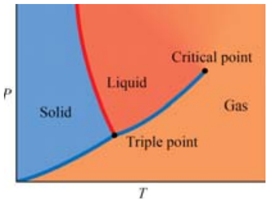
Kinetic Theory of the Ideal gas

Phase transitions



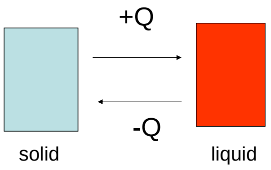
Typical phase diagram.
Boiling temperature and melting temperature depend on pressure.
Triple point is unique.

Phase diagram for ice



Ice is less dense than water
Increasing pressure lowers the freezing point
Pressure causes ice to melt.
Water at the bottom of lakes does not freeze in winter.

Heat of transformation is reversible



+Q

-Q

solid

liquid

Heat is absorbed on melting
Heat is released on solidification

Hand warmer

+Q

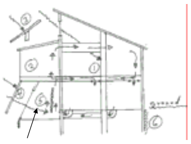
crystaline salt hydrated $\rightleftarrows$ saturated salt solution

-Q

A supersaturated salt solution can be triggered to crystallize by a mechanical pulse.
Heat is released.

Solar Heat Storage

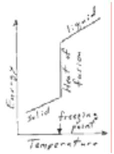
David Allen's Solar Home in Utah
www.allanstime.com/SolarHome/



Salt Chamber

Glauber's Salt . Melting point 90° F. L_f =83 calories/g

Solar heat is used to melt salt during the day
Heat is released during freezing at night to heat the house.



Heat of fusion

RAIN BIRD® *TECH TIP*

Frost Protection By Sprinkling

Utilizing Impact Sprinklers for Frost Protection:

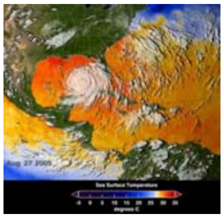
Application of water by sprinklers to protect crops from radiation frost damage is utilized on thousands of acres where adequate water is available. Radiation frosts may occur on clear, calm nights, usually following the passage of a cold front in the previous twenty-four to forty-eight hours. The term "radiation frost" is used to differentiate it from "wind-borne freeze" which describes a below-freezing air mass moving through the area.

Water offers an economical, pollution-free method of frost protection if a grower has a sprinkler system. The heat released for frost protection, when water is applied through sprinklers, depends upon the temperature of the water applied and the amount of water which

Heat released when water freezes can be used to save crops from freezing.

Heat of evaporation

Heat of vaporization provides energy for hurricanes.



Thermal power

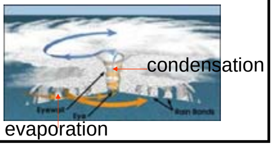
Consider 1 inch of rain falling in an area of $1 km^2$. Calculate the thermal energy released

$$Q = mL_v \quad = \rho A h L_v$$

$$= (1000 kg/m^3)(10^3 m)^2(.025m)(2257x10^3 J)$$

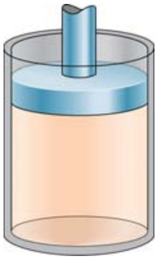
$$= 6x10^{13} J$$

energy equivalent to $4x10^5$ gallons of gasoline.



Ideal Gas Law

The ideal gas law describes be behavior of gases at different temperatures and pressures.



PV= NkT

P = pressure
V= volume
N= no. of molecules
k = Boltzmann's constant
T=Kelvin temperture (K)

$k = 1.38x10^{-23} J/K \quad = 8.62x10^{-5}\ eV/K$

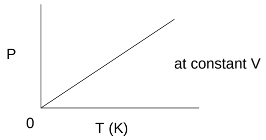
Gas Constant

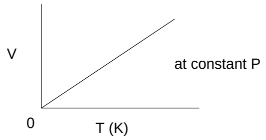
The ideal gas law can also be written in terms of the n the number of moles of gas.

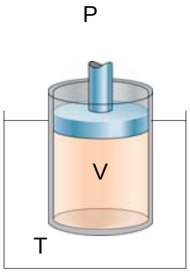
PV= nRT

Where
$R = N_A k_B$ = Universal Gas Constant
N_A = Avogadro's number, the number of molecules in a mole=$6.02x10^{23}$
n = number of moles of gas
T = Temperature (K)

Properties of the idea gas







Question

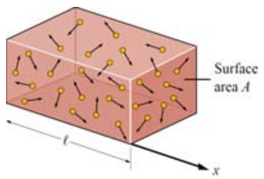
You are taking a road trip for the weekend. Before you start you check the pressure in your tire and the gauge reads $31 lbs/in^2$ (214 kPa) and the temperature is $15^{o\ C}$. After a few hrs of driving you check your tires pressure again and the gauge now reads 35 lb/in^2 (241 kPa). What is the temperature in the tire now?

Kinetic theory of the ideal gas

The kinetic theory of the ideal gas is a statistical mechanical theory to explain the thermodynamic properties of the gas based on the microscopic properties.

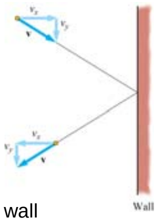
We use classical Newtonian mechanics for a large number of particles in a box, to calculate the pressure.

Model for the ideal gas



1. All collisions are elastic, conserving energy and momentum.
2. Movement of molecules is random. No preferred direction.
3. Large # of identical molecules of mass m, no structure, no size.
4. All energy in the gas exists in form of kinetic energy of its molecules.

Force at the wall



The force exerted at the wall is due to the change in momentum

Change in momentum

$$\Delta p_x = 2mv_x$$

Force

$$F_x = \frac{\Delta p_x}{\Delta t}$$

Time between collisions with the wall

$$\Delta t = \frac{2\ell}{v_x}$$

time to make a round trip from wall to wall

Calculate the pressure

Force due to all molecules

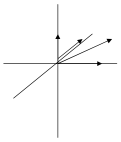
$$F = \sum_N f_i = \sum_N \frac{2mv_x}{2\ell / v_x} = \sum \frac{mv_x^2}{\ell} = N\frac{m}{\ell}\overline{v_x^2}$$

Pressure

$$P = \frac{F}{A} = N\frac{m}{A\ell}\overline{v_x^2} = \frac{Nm}{V}\overline{v_x^2}$$

$$PV = Nm\overline{v_x^2}$$

Average value of v^2



Magnitude of v

$$v^2 = v_x^2 + v_y^2 + v_z^2$$

average value of v

$$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2}$$

but since no direction is special

$$v_x^2 = v_y^2 = v_z^2$$

then

$$\overline{v^2} = 3\overline{v_x^2}$$

or

$$\overline{v_x^2} = \frac{1}{3}\overline{v^2}$$

Connect to the ideal gas law

$$PV = Nm\overline{v_x^2}$$

becomes

$$PV = \frac{1}{3}Nm\overline{v^2}$$

From the ideal gas Law

$$PV = NkT$$

gives a microscopic value for the thermal energy

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

The average kinetic energy of a gas molecule is proportional to the absolute temperature

Thermal speed

The thermal speed is dependent on T and the mass of the molecule.

$$v_{th} = \sqrt{\frac{3kT}{m}}$$

Ideal gas

For 2 gas samples with different molecular masses at the same temperature T

- The kinetic average energy of the gas molecules are equal
- The average velocities of the gas molecules are different. The gas with the larger mass has a slower velocity
- The kinetic energy increases linearly with the absolute T.

Question

Find the kinetic energy of a N_2 molecule at 300 K in eV (1eV= 1.6×10^{-19} J).

It is useful to remember that the value of kT at room temperature is ~25 meV

Question

Compare the thermal velocities of a molecule of N_2 and He (Molecular mass 28 g/mole, 4 g/mole) at 300K

Question

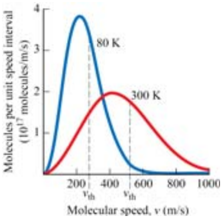
Compare the thermal velocities of a molecule of N_2 and He (Molecular mass 28 g/mole, 4 g/mole)

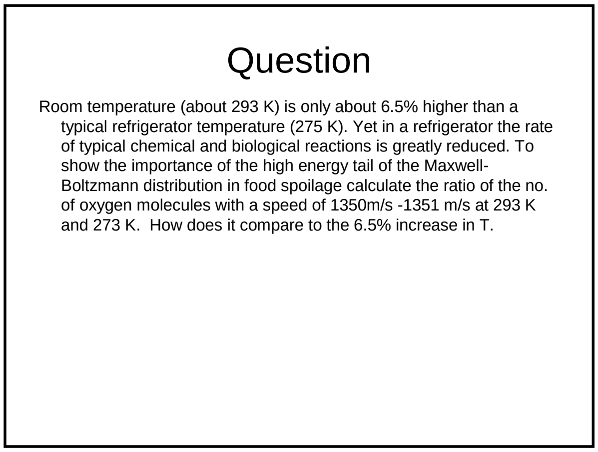
Maxwell-Boltzmann distribution

$$N(v)\Delta v = 4\pi N\left(\frac{m}{2\pi kT}\right)v^2 e^{-mv^2/2kT}\Delta v$$

N(v) no. of molecules with speed v.

Distribution
Goes through a maximum
Depends on Temperature





Question

Room temperature (about 293 K) is only about 6.5% higher than a typical refrigerator temperature (275 K). Yet in a refrigerator the rate of typical chemical and biological reactions is greatly reduced. To show the importance of the high energy tail of the Maxwell-Boltzmann distribution in food spoilage calculate the ratio of the no. of oxygen molecules with a speed of 1350m/s -1351 m/s at 293 K and 273 K. How does it compare to the 6.5% increase in T.