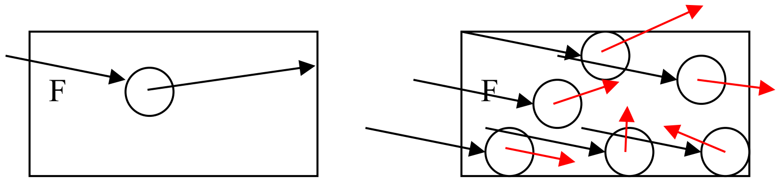
Lecture 18 Temperature



So far we know how to explain the motion of a particle by the Newton's law. If too many particles are moving in a box, we can not calculate motion of the system of particles. That means we need a new technique of statistics. **Thermodynamics explains the bulk properties of matter and the correlation between these properties and the mechanics of atoms and molecules.**

18.1 Temperature and the Zeroth Law of Thermodynamics

Objects that can exchange energy with each other in several ways (heat or electromagnetic radiation) are said to be in thermal contact.
Eventually, the temperatures of the two object will become the same???.
Thermometer is a device calibrated to measure the temperature of an object.

Zeroth law of thermodynamics: if objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

The same temperature -> the same energy ?? What is the temperature?

Thermal conductivity: W m^{-1} K^{-1}

Fe	Cu	Ag	Al	Steel	Wood	Water	Air
80	401	429	210	46	0.13	0.58	0.026

Specific heat: Joule kg^{-1} K^{-1}

Fe	Cu	Ag	Al	Steel	Wood	Water	Air
470	390	230	900	500	1800	4186	1000

Heat of vaporization: He (84.5 J / mole), N_2 (2792.8 J / mole)

18.2 Thermometers and the Celsius

Temperature scale

Some physical properties that change with temperature are:

1. The volumn of a liquid (Hg - mecury)
2. The length of a solid
3. The pressure of a gas held at constant volume
4. The volume of a gas held at constant pressure
5. The electric resistance of a conductor – Pt100 (4 points probe)
6. The color of a hot object (light (blue – red in color) or light in infrared (IR) range)
7. Thermo-voltage – thermocouple (K – type, a positive leg of 90% nickel, 10 chromium and a negative leg of 95% nickel, 2% aluminum, 2% manganese and 1% silicon)

A common thermometer consists of a mass of liquid – usually mercury or alcohol – that expands into a glass capillary tube when heated.

Celsius Temperature Scale:

zero degree – ice point or freezing point

100 degree – steam point or boiling point of water

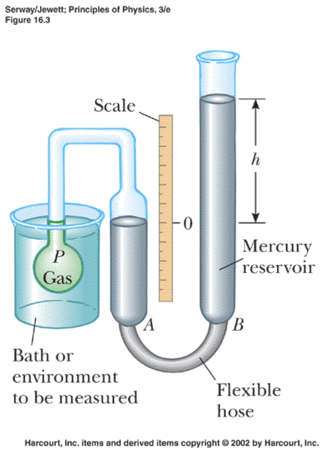
Once the liquid levels in the thermometer have been established at these two points, the length of the liquid column between the two points is divided into 100 equal segments.

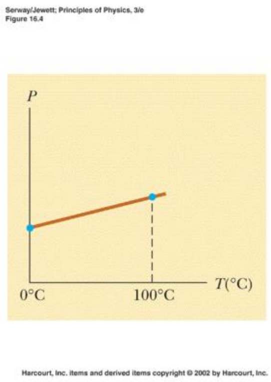
Thermometers calibrated in this way present problems:

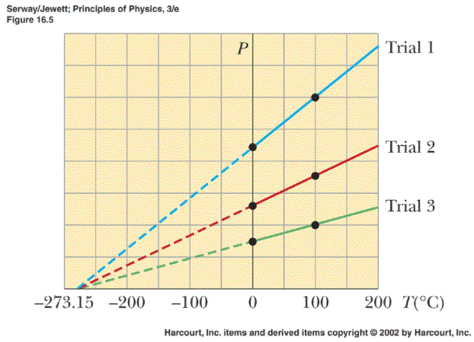
1. Nonlinear: when one thermometer reads a temperature, the other may indicate a slightly different value
2. Limited range: the freezing point of mercury is -39ºC; the boiling temperature of alcohol is 85ºC

18.3 The Constant-Volume Gas Thermometer and the Absolute Temperature Scale

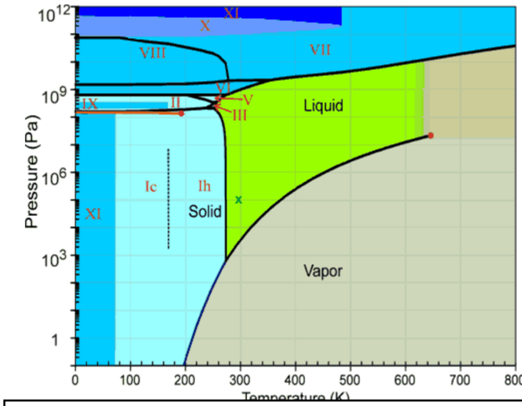
The constant-volume gas thermometer and the Kelvin scale







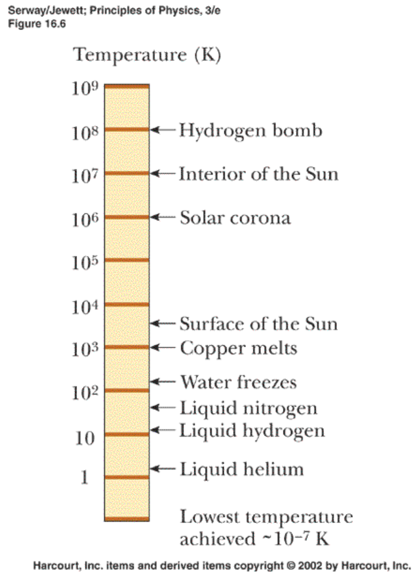
Pressure is linear dependent on the temperature.
In every case, regardless of the type of gas or the value of the low starting pressure, the pressure extrapolates to zero when the temperature is -273.15°C.



Refer: http://www.lsbu.ac.uk/water/phase.html

Early gas thermometers use the ice and steam points. These points are experimentally difficult to duplicate.

The International Committee suggest to adapt the absolute zero and the triple point of water, which corresponds to the single temperature and pressure at which water, water vapor, and ice can coexist in equilibrium. Tc = 273.16 K



The Celsius, Fahrenheit, and Kelvin

Temperature Scales

$$T(C) = \frac{5}{9}(T(F) - 32)$$

T(C)	0	10	20	30	36
T(F)	32	50	68	86	96.8

The Fahrenheit scale:

$$T_F = \frac{9}{5}T_C + 32^O F$$

Sample Example: Human body temperature is normally 98.6°F. What is this on the Celsius scale?

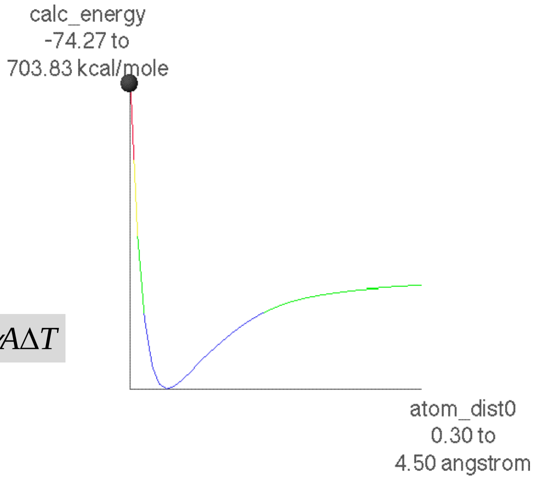
$$T_c = \frac{(T_F - 32) \cdot 5}{9} = 37^O C$$

in USA the use Fahrenheit, feet and inches, pounds ….., but 110 V

$$T_K = T_C + 273.15 \quad \text{(absolute temperature)}$$

18.4 Thermal Expansion of Solids and Liquids

The potential energy curve for atoms in solids is slightly asymmetric. It is this asymmetry that leads to thermal expansion.



Linear expansion:

$$\Delta L = \alpha L \Delta T$$

Area expansion:

$$\Delta A = (L + \Delta L)^2 - L^2 \sim 2L\Delta L = 2\alpha L^2 \Delta T = \gamma A \Delta T$$

$$\gamma = 2\alpha$$

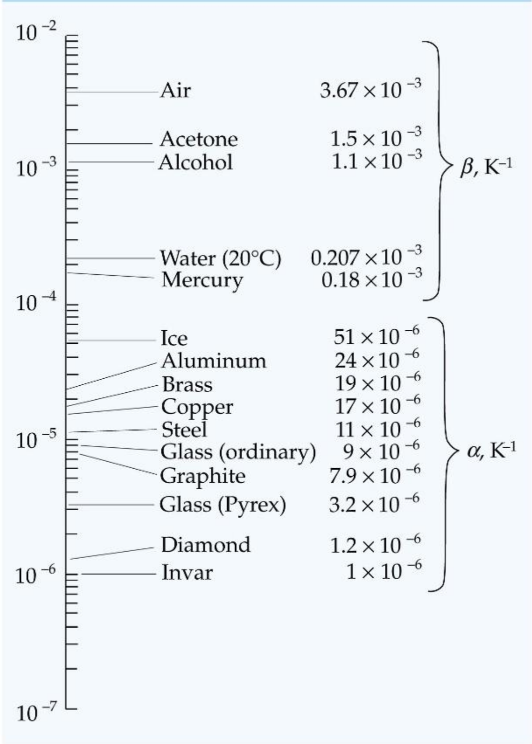
Volume expansion:

$$\Delta V = (L + \Delta L)^3 - L^3 \sim 3L^2 \Delta L = 3\alpha L^3 \Delta T = \beta V \Delta T$$

$\beta = 3\alpha$

TABLE 20-1

Approximate Values of the Coefficients of Thermal Expansion for Various Substances



Linear Expansion Coefficient $\alpha 10^{-6}$ $(^{o}C)^{-1}$

Al	24	Brass	19
Glass	9	Lead	29
Steel	11	Invar(Ni-Fe Alloy)	0.9
Concrete	12	Air	3670
Mercury	182	Benzene	124

Example: 16.2 Does the Holes Become Bigger or Smaller

A hole of cross-sectional area 100 cm^2 is cut in a piece of steel at 20°C. What is the change in the area of the hole in the steel from 20°C to 100°C?

$\Delta A = 2 \cdot 11 \cdot 10^{-6} \cdot 100 \cdot 80 = 0.18 cm^2$

Example: A steel bridge is 1000 m long. By how much does it expand when the temperature rises from 0 to 30°C?

$\alpha = 11 \times 10^{-6} K^{-1}, \quad \Delta L = \alpha L \Delta T = (11 \times 10^{-6})(1000)(30) = 0.33 \quad \text{m}$

The stress that would result in a steel bridge without expansion joints by using Young's modulus:

$$Y = \frac{F/A}{\Delta L/L} \rightarrow \frac{F}{A} = Y\frac{\Delta L}{L} = \left(2\times10^{11}\right)\frac{0.33}{1000} = 6.6\times10^{7}\ (\mathrm{N/m^2})$$

This stress is about one-third of the breaking stress for steel under compression. This will cause a steel bridge to buckle and become permanently deformed.

Example: A completely filled glass

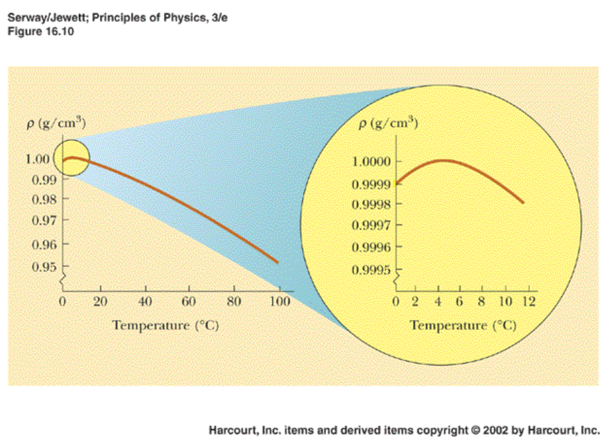
While working in the laboratory, you fill a 1-*L* glass flask to the brim with water at 10°C. You heat the flask, raising the temperature of the water and flask to 30°C. How much water spills out of the flask?

For water: $\beta = 1.1\times10^{-3}\ \mathrm{K^{-1}}$

For glass: $\alpha = 9\times10^{-6} K^{-1}$

$$\Delta V_{spilled} = \Delta V_{water} - \Delta V_{glass} = \beta V\Delta T - 3\alpha V\Delta T$$
$$= \left(1.1\times10^{-3}K^{-1} - 3\times9\times10^{-6}K^{-1}\right)(1L)(20K) = 3.6mL$$

The Unusual Behavior of Water



18.5 Macroscopic Description of an Ideal Gas

An ideal gas is a collection of atoms or molecules that move randomly, exert no long-range forces on one another, and occupy a negligible fraction of the volume of their containers.

$N_A = 6.022 \times 10^{23}$

molar mass M, $n = \dfrac{m_{sample}}{M}$

$m_{O_2} = \dfrac{M}{N_A} = \dfrac{32}{6.02 \times 10^{23}} = 5.32 \times 10^{-26} kg / molecule$

Boyle's law: $P \propto \dfrac{1}{V}$, at const. T

The law of Charles and Gay-Lussac: $V \propto T$, at const. P

Ideal gas law: $PV = NkT = nRT$, $R = 8.315 J / mol \cdot K$

$R = N_A k_B$, $k_B = \dfrac{8.315}{6.02 \times 10^{23}} = 1.38 \times 10^{-23} J / K$