Physics 4C

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§1 Thermodynamics

§1.1 Temperature

Thermodynamics is the branch of physics that deals with temperature, heat, and work.

Definition — Two objects are in **thermal contact** with each other if energy can be exchaqnged between them.

Note that thermal contact does NOT have to be physical contact.

Definition — **Thermal equilibrium** is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact.

Zeroth Law of Thermodynamics — If objects A and B are seperately in thermal equiilibrium wiht a third object C, then A and B are in thermal equilibrium with each other.

Definition — This statement allows us to define the concept of **Temperature** as the property that determines whether an object is in thermal equilibrium with other objects.

With temperature comes the scale to measure this quantity. There are three scales:

1. the **Celsius temperature scale**
2. the **absolute temperature scale**, also called the **Kelvin scale**
3. the **Farenheit temperature scale**

Our SI Unit for temperature is Kelvin, or K. This has two reference points; one at absolute zero, and the other at the **triple point of water** at 273.16K (the temperature where liquid, gaseous, and solid water can coexist).

In contrast, Celsius has its' two reference points, one with the *ice point* of water at 0°C, the other with the *steam point* of water at 100°C. Farenheit's scale has the *ice point* of water at 32°F, and the *steam point* at 212°F.

Conversion Between Temperature Scales —

$$T_{\mathrm{K}} = T_{\mathrm{C}} - 273.15 = \frac{5}{9}\left(T_{\mathrm{F}} - 32\right)$$

§1.2 Thermal Expansion

Solids and Liquids

As the temperature increases, the atoms that constitute a object oscillates at a greater amplitude, and thus the object expands.

Linear Expansion — Suppose an object has initial length L_i, or area A_i, or volume V_i. With α defined as the average coefficient of linear expansion, we ahve

$$\begin{aligned} \Delta L &= \alpha L_i \Delta T] \\ \Delta A &= 2\alpha L_i \Delta T \\ \Delta V &= 3\alpha L_i \Delta T = \beta L_i \Delta T \end{aligned}$$

It has been shown that α is constant for small changes in temperature.

A *bimetallic strip* is used to calculate the difference in coefficients of expansion.

Note. Water is unusual; normally, liquids increase in volume with increasin gtemperature. However, for the specific range of temperatures at 0°C to 4°C, water contracts, and density increases. This explains phenomena, such as why the surface of a pond freezes first.

Ideal Gases The same equations do not hold for gases, as they do not have an initial volume, and don't have an *equilibrium seperation* of the atoms unlike solids and liquids.

> **Definition —** An **ideal gas** is a gas for which the temperature is not too low to condense into a liquid, or too high, and the pressure must be low. This implies the gas molecules do not interact apart from elastic colision, and the molecular volume is negligble.

The *thermodynamic variables*: the volume V, pressure P, and temperature T are all related for a gas of mass m with the *equation of state*, which is complicated for non-ideal gases. However, many gases can be approximated as an ideal gas under normal parameters.

> **Ideal Gas Law —** The equation of state for an ideal gas is given as
>
> $$PV = nRT$$
>
> where n is the number of moles of the gas (one mole of a substance has Avogadro's number $N_\mathrm{A} = 6.022 \times 10^{23}$), and is measured by $n = \frac{m}{M}$, where M is the molar mass. R is called the **universal gas constant**, and has the value
>
> $$R = 8.314 \text{ J}/(\text{mol K})$$

The ideal gas law is sometimes expressed in terms of the number of molecules of gas, N.

$$PV = nRT = \frac{N}{N_\mathrm{A}} RT = N k_\mathrm{B} T$$

where k_B is **Boltzmann's constant**, with the value

$$k_\mathrm{B} = \frac{R}{n_\mathrm{A}} = 1.38 \times 10^{-23} \text{ J/K}$$