THERMODYNAMICS

Temperature

Definition: Average KE of a substance. (Temperature of an object cannot tell how hot or cold you might feel.)

Total Internal Energy

$$\sum KE_i$$

An iceberg's temperature is colder than a cup of hot coffee, but it has more total internal energy than coffee.

Temperature Scale	^{0}F	^{0}C	K (no degree mark)
Boiling water	212	100	373.15
Body temperate	~ 100	~36.6	~310
Average Earth Temperature			~300
Freezing water	32	0	273.15
Ice + salt	0	- 18	255.37
Dry Ice melting	- 40	- 40	233.15
Absolute Zero		- 273.16	0 (where KE = 0)

Triple Point of Water (= 273.16 K)

Temperature at which water can exist as "gas", "liquid", and "solid".

Heat (Q)

Flow of thermal energy from hot to cold (never the other way). Typical misunderstanding of "heat" is "hotness", but it is incorrect. BE CAREFUL. Even sometimes we say, "heat flow", but that is redundant. For thermal energy, "calorie" is a typical unit used in thermodynamic.

1 calorie: Thermal energy required to raise 1 gram of water by 1 ^{0}C. (= 4.186J)

Specific Heat Capacity

Definition: (Thermal) Energy required to raise 1 gram of substance by 1 ^{0}C.

Unit: cal/g ^{0}C, J/kg K

Heat of Transformation (It should be noted that there is a huge energy gap between states of matter)

L_V (Heat of vaporization)

Energy required to change 1 gram of substance from the highest temperature as liquid to the lowest temperature (same as the highest temperature of liquid) as gas. (cal/g)

Ex. $L_V = 539$ cal/g for 100 ^{0}C water to 100 ^{0}C of steam

L_F (Heat of Fusion)

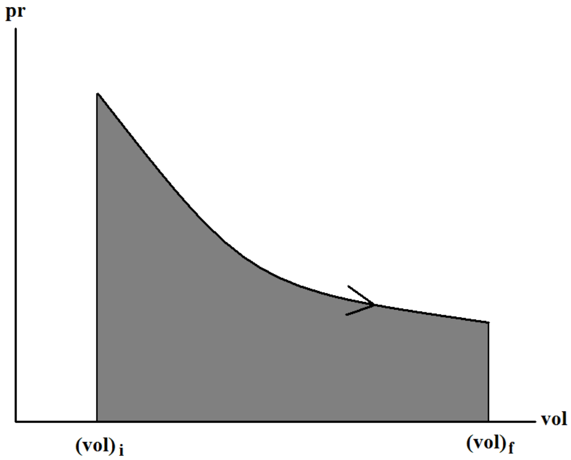
Energy required to change 1 gram of substance from the highest temperature as solid to the lowest temperature (same as the highest temperature of liquid) as liquid. (cal/g)

Ex. $L_F = 79.5$ cal/g for 0 ^{0}C water to 0 ^{0}C of ice.

Heat & Work

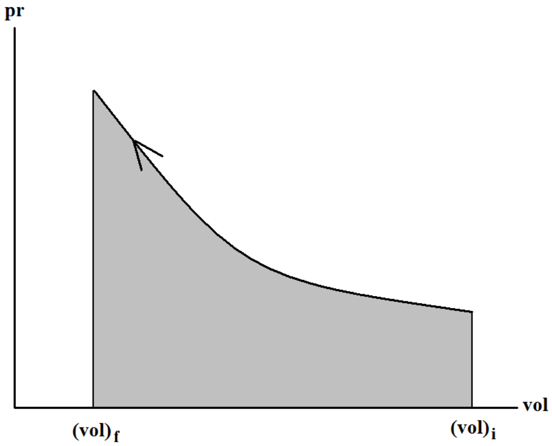
$W = \int \overrightarrow{F \cdot dr}$, but since $pr = \frac{F}{A}$,

$W = \int (pr)\, A \cdot \overrightarrow{dr} = \int_{vol_i}^{vol_f} (pr) \cdot d(vol)$



The diagram shown on the left:

W > 0 (positive work is done by the system)



In this case, W < 0, which means negative work is done by the system = positive work is done to the system by some outside force.

Thermal Expansion

$\Delta \mathbf{L} = L\alpha\Delta T = L\alpha(T_f - T_i)$, where "L" is Original Length and "α" is Linear Thermal Expansion Rate/Coefficient of linear expansion (Units: $\frac{1}{C^0 or K}$)

$\Delta Vol = (Vol)\beta\Delta T$, where "(Vol")" is Original Volume and "β" is coefficient of volume expansion ($\beta \sim 3\alpha$)

First Law of thermodynamics

ΔE_{int}: Internal energy change

Q: Heat (thermal energy flow from <u>outside</u> to the <u>system</u> – about a half textbooks say this way and other half define opposite way. We will stick with this way.)

W: Work done by the <u>system</u> to <u>outside.</u>

$$\boldsymbol{\Delta E_{int} = Q - W = E_{int,f} - E_{int,i}}$$

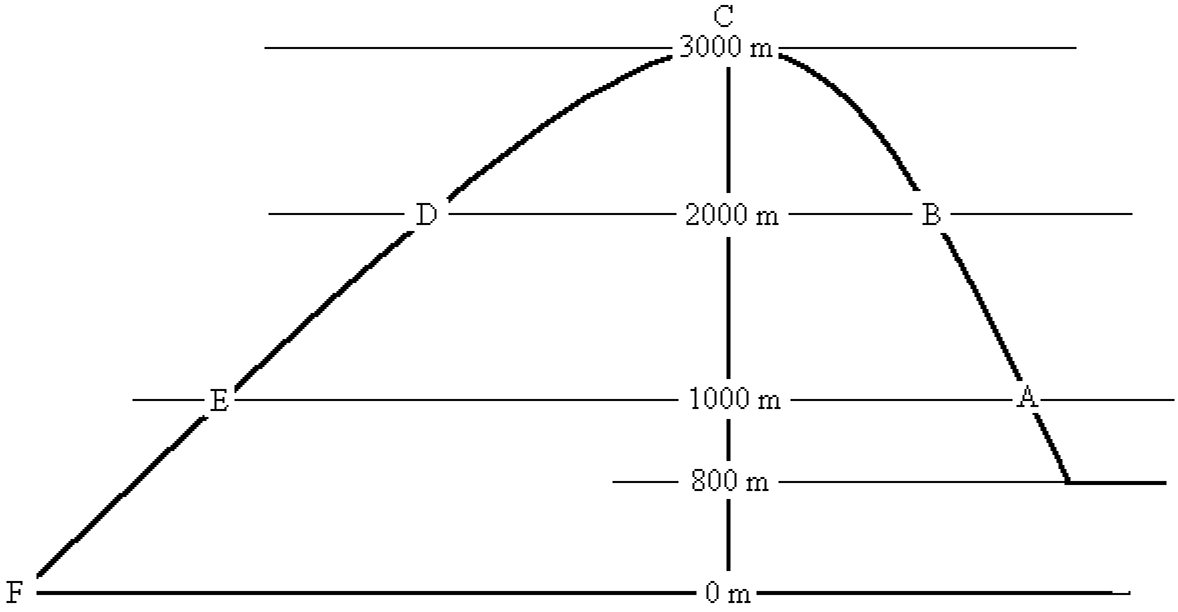
Special cases

1. Adiabatic Process – No thermal exchange

   $Q = 0 \therefore \Delta E_{int} = -W$

   Ex. Santa Ana Dry air (to make it simple, air less than 100 % humid): 10 ^{0}C/km

   Wet air (100 % humid air): 5 ^{0}C/km



2. Constant volume process - $W = \int (pr)\, A\cdot\overrightarrow{dr} = \int_{vol_i}^{vol_f} (pr)\cdot d(vol) = 0$

$$\therefore \Delta E_{int} = Q$$

3. Cyclical Process

$$\Delta E_{int} = 0$$

$$\therefore Q = W$$

4. Free Expansion

$$Q = 0,\ W = 0,\ \therefore \Delta E_{int} = 0$$

<u>Second Law of Thermodynamics</u>

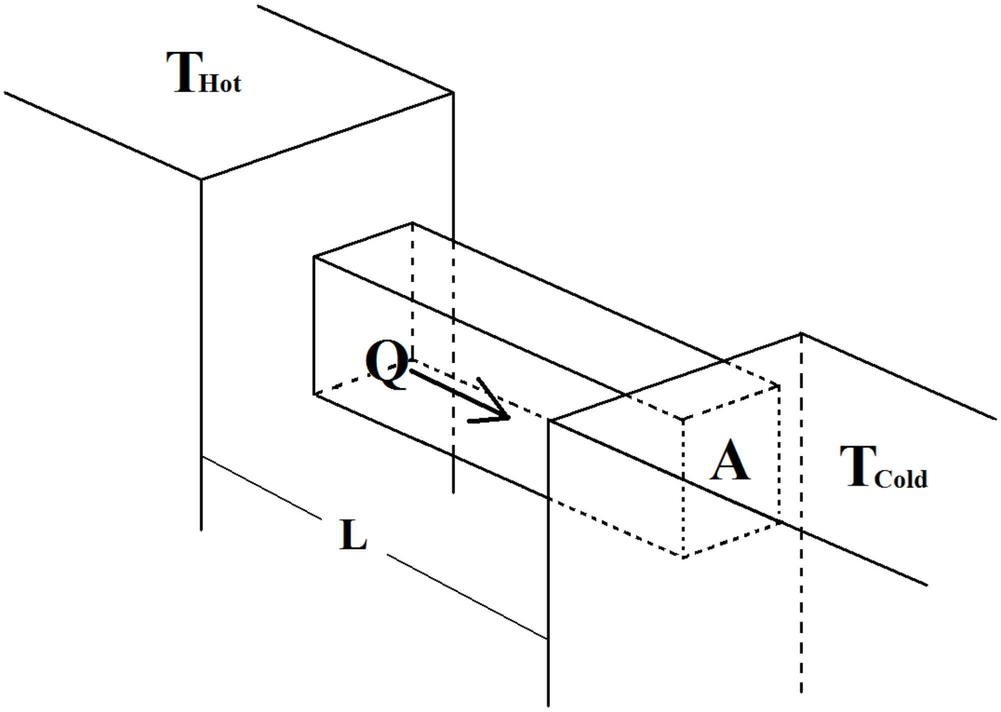
The direction of heat is always “hot” to “cold” and never the other way around.

<u>Heat</u>

There are three ways to transfer thermal energy.

1. Conduction
2. Convection
3. Radiation

1. Conduction



P_{cond}: Conduction rate $= \frac{Q}{t} \propto A\frac{\Delta T}{L}$ (P: power because $\frac{Q}{t} = \frac{J}{sec}$)

$P_{cond} = \frac{Q}{t} = kA\frac{T_H - T_C}{L}$, where *k* is thermal conductivity. Large *k* is a good conductor(poor insulator) and small *k* is a poor conductor(good insulator).

Units: $\frac{J}{sec} = k\ m^2\frac{K}{m}$

$$\therefore k = \frac{W}{mK}$$

Thermal resistivity

$$R = \frac{L}{k} = \frac{m}{\frac{W}{m \cdot K}} = \frac{m^2 \cdot K}{W}$$ (Large R:Good insulator)

2. Convection

Definition of Boiling: $Q_{in} = Q_{out}$, the system will not increase its temperature even (more) thermal energy is added. Boiling is a cooling mechanism.

3. Radiation

Stephan-Boltzmann Law

$P_{rad} \propto T^4$

$= \sigma \varepsilon A T^4$, where

σ: Stephan-Boltzmann Constant (5.6703×10^{-8} W/m^2K^4)

ε: Emissivity (0 ~ 1)

A: Surface area

T: Temperature in Kelvin

Newton's cooling law

The rate of cooling of an object – whether by conduction, convection, or radiation – is proportional to the temperature difference between the object and its surroundings.

$\frac{dT}{dt} \propto \Delta T$, where T is temperature and t is time. Starting with this, derive T as a function of time.

Mixing multiple different temperature and mass objects

Four States of Matter