Lecture 15-2 Fundamental Laws of thermodynamics

We will use ideal gas and heat engines to understand "heat".

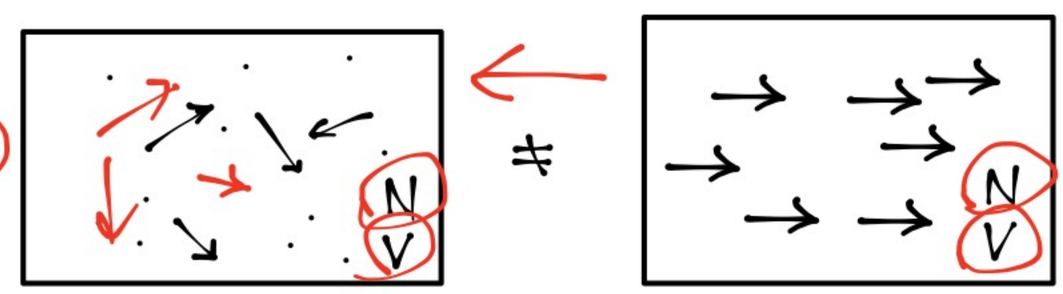
Thermodynamics: Physics of heat: Conversion to other form of energies.

Transform and transport of heat

So what is heat and how is it different from other kinds of energy?

Heat is some form of energy (E_K for an ideal gas) that is random in nature

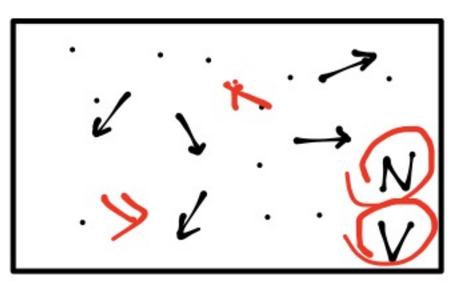
$\langle E_K \rangle = \frac{3}{2} kT$



$\neq$

$\parallel ?$

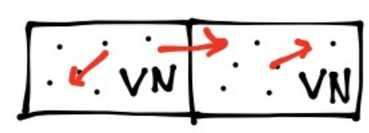
$E_K \overset{?}{=} \frac{3}{2} kT$



Are these systems identical?

Are they thermodynamically identical?

Compare them thermodynamically:



if energy flows to the right $\rightarrow$ $T_L > T_R$ until equilibrium is reached $T_L = T_R$

0th law of Thermodynamics: A & B in equilibrium, B & C in equilibrium $\Rightarrow$ A & C are in equilibrium.

$\Rightarrow$ equilibrium are defined between 2 systems

$\Rightarrow$ equilibrium exists, can be compared by T

$\Rightarrow$ What's temperature, why does it exist?

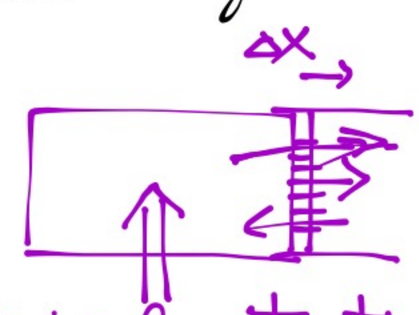
$\Rightarrow$ 2 Systems are identical when they are in "equilibrium" and share the same thermodynamic variable $T, V, N \ldots$

1st law of thermodynamics: conservation of energy and heat.

Heat is a new form of energy that moves between 2 systems.

$$\boxed{\Delta U} = \Delta Q + \Delta W + \Delta C + \cdots$$

heat; mechanical $-P\Delta V$; chemical energy $+\mu\Delta N$



μ: chemical potential

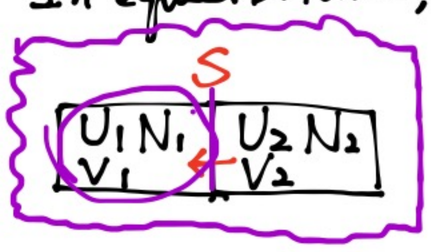
Heat is a new way of energy flow. If the system has N (family) thermodynamic variables $\Rightarrow$ $N+1$ ways to exchange energy. $P \equiv -\partial U/\partial V$, $\mu \equiv \partial U/\partial N$, $T \equiv \partial U/\partial S$ (entropy)

$$\Rightarrow \Delta U = T\Delta S - P\Delta V + \mu\Delta N \qquad \Delta Q = T\Delta S$$

{ measure of randomness,

$\Delta Q = T\Delta S$

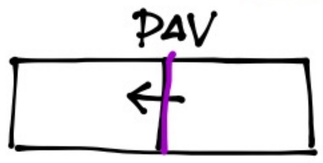
In equilibrium,



$$\Delta U = \Delta(U_1 + U_2) = T_1\Delta S - T_2\Delta S = 0 \qquad \Delta S_1 > 0, \quad \Delta S_2 = -\Delta S_1$$

$$\Rightarrow T_1 = T_2.$$

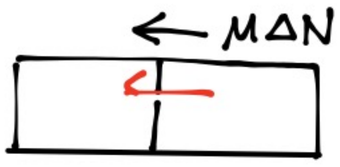
$\Delta V_1 = -\Delta V_2$



$$\Delta U = -P_1\Delta V_1 - P_2\underbrace{\Delta V_2}_{-\Delta V_1} = (P_2 - P_1)\Delta V_1 \Rightarrow \boxed{P_1 = P_2}$$

e.g.

$\Delta N_1 = -\Delta N_2$



$$\Delta U = \mu_1\Delta N_1 + \mu_2\Delta N_2 = (\mu_1 - \mu_2)\Delta N_1 \Rightarrow \mu_1 = \mu_2$$

e.g.

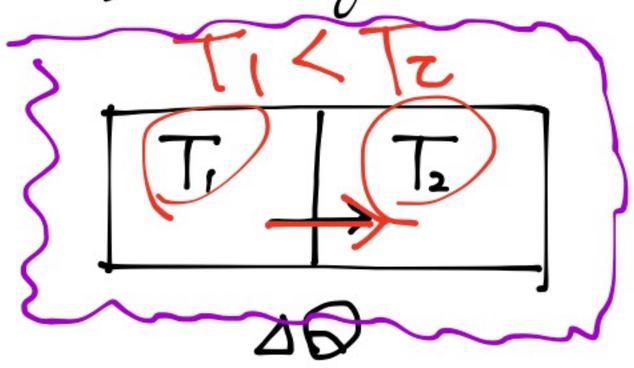
However, the difference is that we cannot control entropy flow. Heat always goes from hot to cold.

2nd law of thermodynamics: A thermodynamical process tends to increase the total entropy of an isolated system.

Fermi: $S(B)-S(A) \geq \int_A^B \frac{dQ}{T}$ $\quad \int \frac{dQ}{T} = \int dS = S$

$S(A) = \int_*^A \frac{dQ}{T}$ for a reversible path

Postulate by Clausius: A transformation whose only final result is to transfer heat from a body at a T to a body at a higher T is impossible.



$\boxed{\Delta Q_1} = T_1 \Delta S_1 < 0$

$\Delta Q_2 = T_2 \Delta S_2 > 0$

$\Delta(U_1+U_2) = \boxed{0 = T_1 \Delta S_1 + T_2 \Delta S_2}$

if $T_1 < T_2$ & $\Delta S_1 < 0 \Rightarrow \Delta S_2 = \frac{T_1}{T_2} \boxed{|\Delta S_1|} > 0$ $\quad < |\Delta S_1|$

$\Rightarrow \boxed{\Delta S = \Delta S_1 + \Delta S_2 < 0}$

Forbidden. Why?

if $T_1 > T_2$ & $\Delta S_1 < 0$. $\Rightarrow \boxed{\Delta S = \Delta S_1 + \Delta S_2 > 0}$

Allowed. Why?

2nd law violates time reveral symmetry, only physics law that does not allow time machine. We don't know why?

Third law of thermodynamics $\boxed{\lim_{T\to 0} S(T) \to 0}$ $\Rightarrow$ S is going to be a positive function for all T.

$S = k \ln(\#$ of ways to prepare a thermal equilibrium state$)$ $\quad >1$

← Stat. Mech.