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 (Ek for an ideal gas) that is random in nature.

\[ \langle E_k \rangle = \frac{3}{2} kT \]

Are these systems identical? Are they thermodynamically identical?

Compare them thermodynamically:

if energy flows to the right, \( T_c > T_r \) until equilibrium is reached, \( T_c = T_r \)
0th law of thermodynamics: \( \text{AD} \text{B in equilibrium, B} \text{DAC in equilibrium} \Rightarrow \text{A} \text{DAC are in equilibrium.} \)

\[ \Rightarrow \text{equilibrium are defined between 2 systems} \]

\[ \Rightarrow \text{equilibrium exists, can be compared by } T \]

\[ \Rightarrow \text{What's temperature, why does it exist?} \]

\[ \Rightarrow 2 \text{ Systems are identical when they are in "equilibrium"} \]

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.

\[ \Delta U = \Delta Q + \Delta W + \Delta C + \cdots \]

heat, mechanical energy, chemical energy

\[ \frac{\partial U}{\partial V} = \Delta V \frac{\partial P}{\partial T} \]

m: chemical potential

Heat is a new way of energy flow. If the system

has \( N \) thermodynamic variables \( \Rightarrow N+1 \) ways to exchange

energy. \( P = -\frac{\partial U}{\partial V}, M = \frac{\partial U}{\partial N} \)

\[ T = \frac{\partial U}{\partial S} \]

entropy

\[ \Delta Q = T \Delta S \]

\[ \Delta U = \Delta (U_1 + U_2) = T_1 \Delta S - T_2 \Delta S = 0 \]

\[ \Delta S_1 > 0 \]

\[ \Delta S_2 = -\Delta S \]

\[ \Delta V_1 = -\Delta V_2 \]

\[ \Delta N_1 = -\Delta N_2 \]

\[ \Delta U = \frac{\partial N_1}{\partial N_1} + M_2 \Delta N_2 = (M_1 - M_2) \Delta N_1 \Rightarrow M_1 = M_2 \]
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: \[ S(B) - S(A) = \int_B^A \frac{dQ}{T} \quad \text{for a reversible path} \]

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

\[
\begin{align*}
\Delta S_1 &= T_1 \Delta S_1 < 0 \\
\Delta S_2 &= T_2 \Delta S_2 > 0
\end{align*}
\]

\[
\Delta (U + \dot{U}) = 0 = T_1 \Delta S_1 + T_2 \Delta S_2
\]

if \( T_1 < T_2 \) and \( \Delta S_1 < 0 \) \( \Rightarrow \Delta S = \frac{T_1}{T_2} \Delta S_1 > 0 \)

\[ \Rightarrow \Delta S = \Delta S_1 + \Delta S_2 < 0 \]

Forbidden. Why?

if \( T_1 > T_2 \) \( \Delta S_1 < 0 \) \( \Rightarrow \Delta S = \Delta S_1 + \Delta S_2 > 0 \]

Allowed. Why?

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

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

\[ S = k_B \ln(\text{# of way to prepare a thermal equilibrium state}) \]

\( k_B \)主办方 wealth.