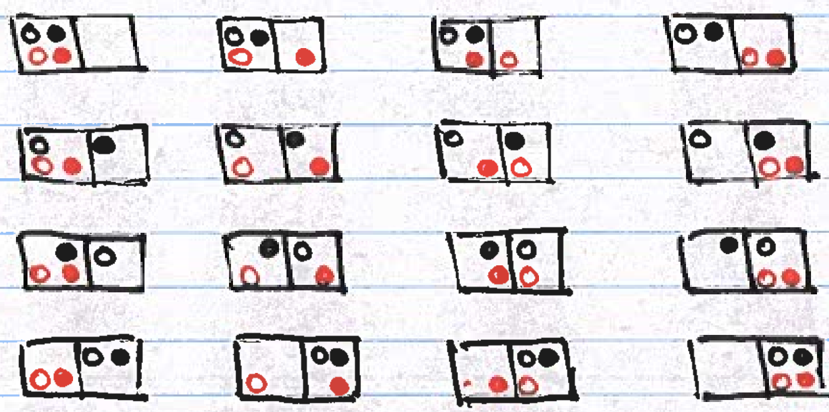
# Microscopic definition of entropy

We already suspect that entropy is related to reversability and degree of disorder

We now look at a statistical properties of our systems.

Each macroscopic state can be realized with a number of microscopic configurations

Example: 4 beads in 2 empty boxes



| # of particles in the first box | # of configuration |
|---|---|
| 4 | 1 |
| 3 | 4 |
| 2 | 6 |
| 1 | 4 |
| 0 | 1 |

It is statistically more likely to have 2-2 split, and very unlikely to have 4-1 or 1-4 split

B. Statistical weight W — # of permutations corresponding to a specific configuration

$W_{4-0} = 1$ | $S_{4-0} = 0$
$W_{3-1} = 4$ | $S_{3-1} = k_B \ln 4$
$W_{2-2} = 6$ | $S_{2-2} = k_B \ln 6$
$W_{1-3} = 4$ | $S_{1-3} = k_B \ln 4$
$W_{4-0} = 1$ | $S_{0-4} = 0$

Entropy $S = k_B \ln W$ Boltzmann definition

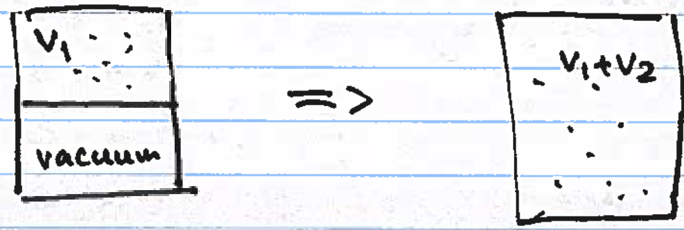
One of my favorite physics quotes:

Boltzmann showed that the laws of physics are <u>mostly</u> accurate

The arrow of time appears not because of any fundamental laws of physics, but because any complex system evolves from more ordered to less ordered (more probable) ⟶ entropy grows

When we can observe the emergence of a more disordered state, we know it is a later deveropment.

Example : gas expansion




Initial volume $V_1$ — final volume $V_1+V_2$

~~Vetos~~

To count the statistical weight, let's break the volume to a number of elementary volumes $\Delta V$, such that it is highly unlikely to have two molecules in the same space

\# of possible positions for a single molecule

$$w_1 = \frac{V}{\Delta V} \leftarrow \text{total volume}$$

If we have N molecules

$$W = (w_1)^N = \left(\frac{V}{\Delta V}\right)^N$$

$$W_{ini} = \left(\frac{V_1}{\Delta V}\right)^N \qquad S_{ini} = k_B \ln W_{ini} = k_B N \ln \frac{V_1}{\Delta V}$$

$$W_{final} = \left(\frac{V_1+V_2}{\Delta V}\right)^N \qquad S_{final} = k_B \ln W_{fin} = k_B N \ln \frac{V_1+V_2}{\Delta V}$$

$$\Delta S = S_{fin} - S_{ini} = k_B N \left( \ln \frac{V_1+V_2}{\Delta V} - \ln \frac{V_1}{\Delta V} \right) =$$

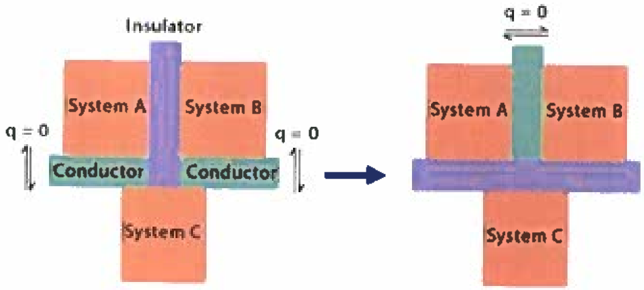
$$= k_B N \ln \frac{(V_1+V_2)}{V_1} = k_B N \ln \frac{V_{fin}}{V_{ini}}$$

same expression we got last time

# Laws of Thermodynamics

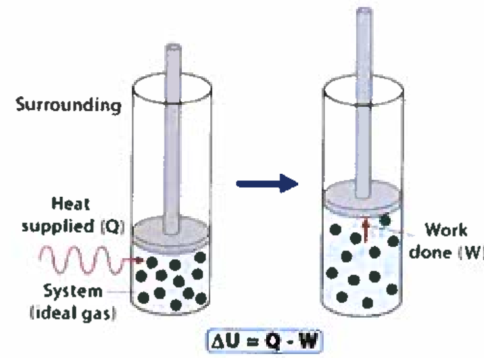
## Zeroth Law

If two thermodynamic systems are in equilibrium (q = 0) with a third, then the two are in equilibrium with each other




## First Law

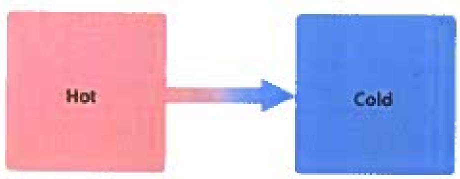
The change in internal energy (ΔU) of a system equals to the heat added to the system minus the work done




## Second Law

The entropy (S) of any natural and spontaneous process either increases or remains constant

Example: Heat flow from a hot body to a cold body

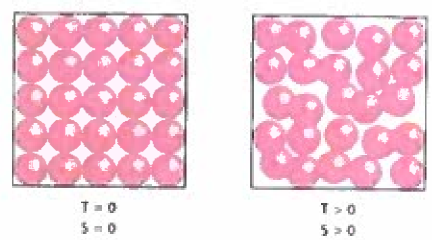



$\Delta S = 0$ For reversible process

$\Delta S > 0$ For irreversible process

## Third Law

Entropy (S) of a pure crystal is zero as the temperature (T) approaches absolute zero

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According to British scientist C. P. Snow, the three laws of thermodynamics can be (*humorously*) summarized as

1. You can't win
2. You can't even break even
3. You can't get out of the game

Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don't understand it, but by that time you are so used to it, it doesn't bother you any more.

— *Arnold Sommerfeld* —