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Entropy: The thermodynamical arrow of time

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Abstract:

This article is about how the concept of entropy and thermodynamical arrow of time comes from 2nd law of thermodynamics.

The first law of thermodynamics was nothing but the principal of conservation of energy, but it's drawback was that the law didn't tell about the direction of flow of energy, because in reality not all the processes are allowed. So, a second law was needed to put some restrictions in the direction.

Second law of thermodynamics:

It is impossible to construct a device which, operating in a cycle, will produce no other effect than transfer of heat from colder to a hotter body. In simple words, There exists no cyclic process which has as it's sole effect on the transference of heat from a colder to a hotter body.

Now, what is a cyclic process?. It is a process by which, a system starts at a particular state, goes through different states and returns to the initial state. There can be two types of cyclic processes, reversible and irreversible. For a reversible cyclic process, no mechanical work need to be done to compensate the energy needed while returning back to initial state. Whereas for irreversible process, some work needs to be done to return to the initial state.

Clausius theorem:

Clausius suggested that, if a system is in cyclic process, consisting of different states and interact with different heat sources R1, R2, R3...etc at different temperatures T1, T2, T3....,then

$$\sum_{i=1}^{n} \frac{Q_i}{T_i} \leq 0$$

Equal to zero for reversible and less than zero for irreversible process. The integral form of equation is called Clausius inequality.

$$\oint \frac{\delta Q}{T} \leq 0,$$

It can be shown that the value between initial and final points of the system is same no matter what path is followed.

Taking the reversible process, in mathematical terms, the quantity dQ/T is an exact differential of some function S, which can be represented as dS.

$$\int_1^2 \frac{\bar{d}Q}{T} = \int_1^2 dS = S_2 - S_1$$

The quantity S is called the entropy.
For any cyclic process,

$$S(f) - S(i) \geq \int_i^f \frac{\bar{d}Q}{T}$$

If the system is isolated I.e dQ=0, S(f)>= S(i) , which concludes, ***the entropy of the final state can never be less than that of the initial state.*** This result is of huge importance, because it helps us to determine the direction in which a physical process evolves.

Principle of increase in entropy:

Considering a process in which an amount of heat dQ from surrounding which is at temperature Tsu to the system at Tsy, and a work dW was done by the system.

Then entropy change of surrounding is $dS_{su}= -dQ/Tsu$ and for system $dS_{sy}>= dQ/Tsy$

Net change of entropy of the universe dS is given by

$$dS = dS_{su}+dS_{sy} >= dQ\ [(1/T_{sy}) - (1/T_{su})]$$

Now as Tsu>Tsy, dS is positive or equal to zero. That means entropy of universe will always increase.

But what is entropy qualitatively. Entropy is the measure of randomness of our universe. More disordered the situation, more is the entropy. For example, water is more disordered than ice if you see in molecular level. If you calculate the entropy of water at a certain temperature and ice, water will have greater entropy. But why does things go from ordered to disordered? Like we never see a broken piece of glass assembling itself to a new piece. It is because there greater number of disordered state than ordered ones. As time goes by, there is an extremely high probability that it will be in disordered state with increase in entropy. It was decided at the beginning of the universe by the initial boundary conditions. That is why we see the things the way they work and entropy becomes arrow of time. It can also be shown that during an irreversible process, the energy that becomes unavailable for work is directly proportional to the increase in entropy of the universe.

References:

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