

Heat Death of the Universe

51. Fills the foreshore
with dead men,
reddens reigns abode
with red gore;
black was sunshine
the summer after,
the weather unsafe.
Understand ye yet, or what?

-Völuspá, Poetic Edda, Odin visits a seeress
who narrates the events of Ragnarök

54. "First, there is a winter called the Fimbul-
winter, when snow drives from all quarters,
the frosts are so severe, the winds so keen
and piercing, that there is no joy in the sun.
There are three such winters in succession,
without any intervening summer."

-Gylfaginning, Prose Edda, Hár replies to
Gangleri's questions on preludes to Ragnarök
(extract)

There are some things in the universe which seem to occur in only one direction.

(1) A Cannonball dive in a pool splashes water everywhere. (2) Vapor escapes a glass of hot water as it cools down to room temperature. (3) An egg when left to fall splashes into pieces.

We almost never see these processes occurring naturally in reverse. (1) We never see someone still in a pool and suddenly water from the surroundings concentrate into the pool and push the person out. (2) We never see water in a cup suddenly boiling. (3) We never see a splashed egg reconstituting itself and jumping up!



The processes in both directions obey the law of Conservation of Energy.
But for some reason, nature prefers one direction over the other.

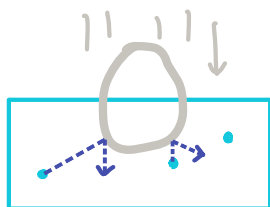
It Surely Can't be that it has chosen one over the other! To know more,
let's study one of the processes in a little more detailed fashion. We shall
see that it is not a physical but more of a Statistical principle!

Egg falling to the ground.



(1) As the egg moves down, friction between air and the egg causes the surrounding air to heat up. (2) As the egg falls down, its kinetic energy is redistributed into 2 parts. First, the impact of the egg causes the ground to heat up slightly and secondly propel the shards in various directions.

We need to look closer into heat exchange. Consider a little parcel of air around the egg for an instance.



As the egg falls through, it encounters air particles. They collide with the egg and bounce back with more energy. The collisions are random. Any 3 molecules has the same chance of hitting the egg. For this parcel, let only one molecule interact. (Simplify)

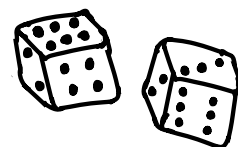
When the egg leaves, we look back at the parcel of air. We know only one of the molecules got the energy but we know not which one. The parcel of air is now in a state where we have less information and more uncertainty. It could be any of the 3 molecules which has captured the energy (Randomly). Same for when the egg hits the ground.



The egg in its scrambled state is preferred over its full constitution. There is only one state called "fully constituted" but there are a lot of ways for the egg to be "scrambled". Piece A can go left, B right or C up or any other other configurations. The Scrambled state has more configurations compared to the full state.

Natural Processes occur in a direction of less configurations to more configurations. WHY?

Consider a game where 2 dice are tossed and we are only TOLD the sum.



SUM CONFIGURATIONS

2		
3		
...		
7		
...		
11		
12		

When we get a 7, it is only one specific config. But there are many other possible ways (Configs.) that yield 7.

This corresponds to the mean!

The no of Configurations for a given state is called the ENTROPY of that state.

As we see, nature makes it such that the state more likely to occur occurs. Every process which occurs spontaneously in the universe tends to the state in which there are more ways to reach that state (# Configs.).

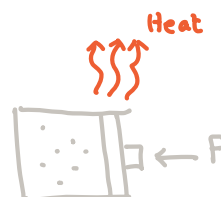
The universe started in one specific configuration. Since 13.77 billion years, it is still tending towards its most probable state which is its state of maximum entropy.

This is the popular Second Law of Thermodynamics: $dS_{univ} \geq 0$. The universe is a closed system which encompasses all the processes within it.

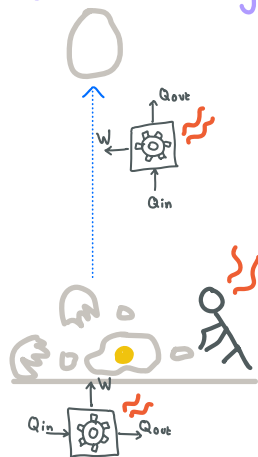
$$dS_{univ} = dS_{sys} + dS_{surr} \Rightarrow dS_{sys} + dS_{surr} \geq 0$$

Local Entropy decrease (by doing Work) can take place but it must be accompanied by a greater entropy increase in the surroundings.

Work is another way of transferring energy. Think of pressing a piston with force F . ALL the molecules have their energy increased similarly, unlike heat which does so randomly. Ideal work is reversible and does not contribute to Entropy. For the reverse, the gas recoils and pushes the piston back out. But like all real cases, friction releases energy as heat which contributes to entropy!



Let's take the egg again as an example,



Someone could expend energy to bring the pieces back together. Work is done as we do not energise the shards randomly but in an order.

The heat engines are there to turn the energy lost to friction into work to push the egg back up.

We now have the egg in its original low entropy state but this came at a cost. The person sweats while doing so (respiration releases heat) and friction in the engines releases more heat. We have decreased entropy locally but the process was a net global increase!

Furthermore, the engine themselves are not 100% efficient in ideal conditions and more work (and thus heat) is involved to return to initial state. Also, remember, there is friction back up.

As the arrow of time continues its march, White dwarves release their heat and turn into black dwarves. Everywhere is dark. The universe expanded and light sources redshifted to invisible spectrum. The remaining black holes slowly vanish by emitting heat (Hawking Radiation).

At the end, all work has been converted into heat. Think of how a battery doing work by pushing electrons round a circuit slowly wears out as heat is dissipated in resistive wires. The energy is spread evenly in the large universe. Everywhere is cold and at the same temperature. Heat engines do no work.

There remains nothing except for random thermal fluctuations. Everywhere is same forever. Past cannot be distinguished from present or future for no observable event happens.

Time loses its sense.