Entropy: The Clue of the Universe

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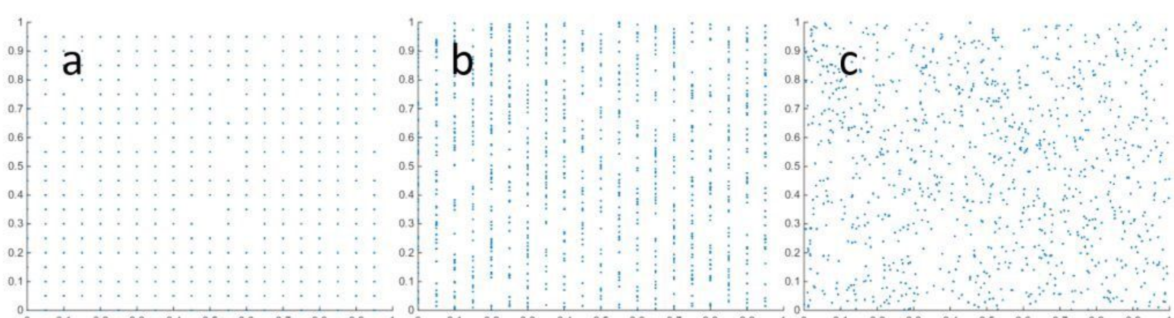
Introduction

When you are staring blankly at the professor in the classroom, dazing with those abstract and complex physical equations that have filled all the blackboard, have you ever pondered those equations thoroughly, that why the physical process behind those equations only go one way and not the other? Why the scent of perfume diffuses through the air, why cream spreads in the coffee, and why hydrogen leaks out of a punctured air balloon[1]? The answer is the entropy, a notoriously perplexing concept for people to comprehend. Generally, the entropy is regarded as the evaluation of disorder for one object. However, this statement is unfortunately misleading and somewhat fallacious. Therefore, in this paper, we will figure out what actually the entropy is, and how it has acted as an indispensable role in the universe.

What is entropy

Before we start to work on the definition of the entropy, let's first figure out what is "disorder". Below are three different point diagrams randomly generated by the program, with 1000 points in each diagram. See what is the most disordered one.



[1] All of these phenomena can only happen on one way

Apparently, on the level of disorder, C > B > A. Points on diagram C are all randomly chosen, so C is the most disordered one. Though diagram B is vertically disordered, the points have regularly made up in lines. Diagram A is the most ordered one, that not only do the points forms line vertically, but also align horizontally. In other words, points in C can be chosen randomly within the (1,0) two-dimensional panel, while the points on B can be chosen randomly on those 20 lines, and the points on A can be only chosen on points where x and y both divided exactly by 0.05. By comparing these three diagrams, we can see that, the more disordered the diagram is, the more the possibilities the points can choose. **Therefore, we can conclude that "the disorder" is actually the measurement of the number of possible states within a system.**

On the basis of that, scientists then introduced a word "microstate" to describe the possible states in the system, and the letter "W" to describe the total number of microstates. Generally speaking, "W" represents the number of all the possible states in a system that could happen. **Therefore, it turns out that the higher the number W in a system is, the more disordered the system is.** For example, suppose there are two ways to throw dice; one is to randomly throw two dice, and the other is to keep throwing until two dice come out with the same number.

If you just throw two dice randomly, W will be 6 * 6 = 36 microstates, which means you will have the outcomes like 1-6, 2-4, 3-2, and 33 other possible states. However, if you throw dice in the second way, since it has banned 30 possible states that have the different number of two dice, W = 6 microstates. As the example shows, the first way, with the higher W and more possible-states, is more disordered than the second way.

According to the people's previous understanding of the microstates and the "disorder", scientists set up a word "entropy" to express them, that:

$$S = k * \ln(W)$$

Among them:

S: S is the value of the entropy

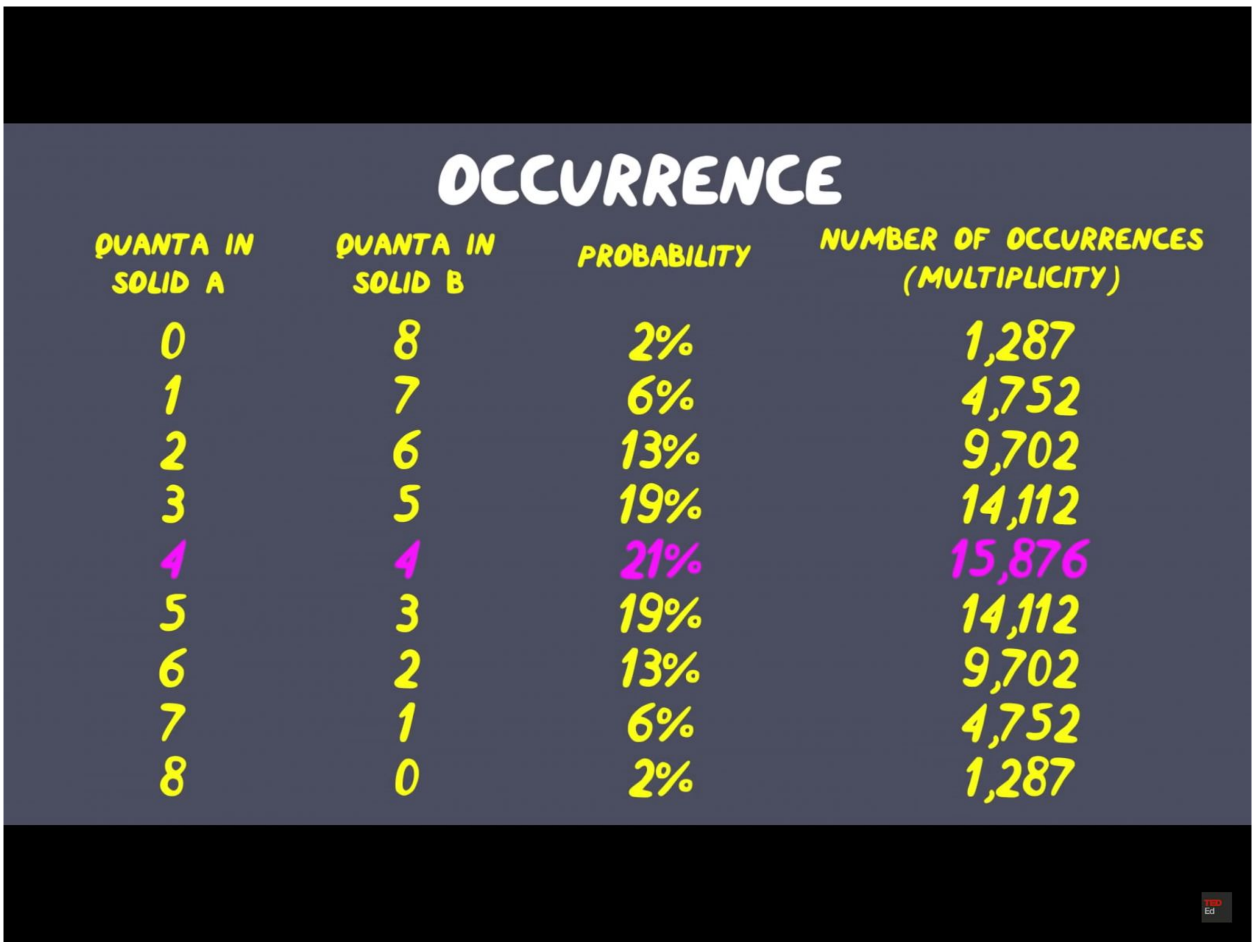
K: K is a constant called boltzmann constant used to represent the relations between temperature and energy

W: is the number of microstates

According to this equation, entropy, as the S, is actually the ln function that increases as the number of microstates increases.

Why entropy is always increasing

Generally, there are two reasons to explain this phenomenon. The first reason is the probability. As I mentioned before, entropy is the proportional function of the number of microstates. In another word, a system with high entropy also has a bigger number of microstates. According to the probability, if all the microstates have equal chances to occur, the system with more microstates is more likely to happen. Therefore, entropy is always increasing, since higher entropy means more microstates, and then is more likely to happen. For example, suppose there are two solids, with each having six bonds. If there are eight quanta randomly distributed to two solids, and we assume each state is equally likely, the possibility of outcomes will be like the graph below.



OCCURRENCE

QUANTA IN SOLID A	QUANTA IN SOLID B	PROBABILITY	NUMBER OF OCCURRENCES (MULTIPLICITY)
0	8	2%	1,287
1	7	6%	4,752
2	6	13%	9,702
3	5	19%	14,112
4	4	21%	15,876
5	3	19%	14,112
6	2	13%	9,702
7	1	6%	4,752
8	0	2%	1,287

We can see that the state with the highest entropy(most possible states) is also most likely to happen. In the microworld, the possibility of increasing entropy is not extremely high. As the example shows, it is only high as 21%. But in a case with larger scale, like our real world, the probability of increasing entropy is exceedingly high that we can overlook the chance of decreasing entropy.

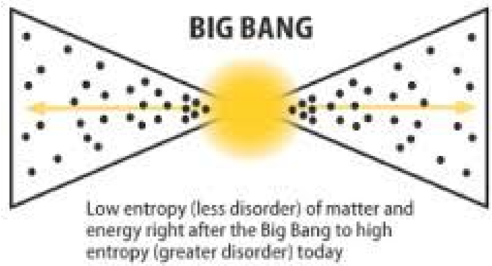
Another reason is even simpler than the former one. **Because the random process inside a system has broken the original limitations of the system, the possible states of that system became more and more.** For example, in the past, your room was settled in a perfect order; the clock ought to be put on the night table, slippers should be placed beside the door, and the laptop needs to be turned off after leaving. You can see that there are many limitations. But once you mess up your room, breaking the original limitations, the possibilities where the clock and the slippers are put, and whether the laptop is turned off after leaving, both increase. Therefore, the entropy is growing.

Time and Entropy

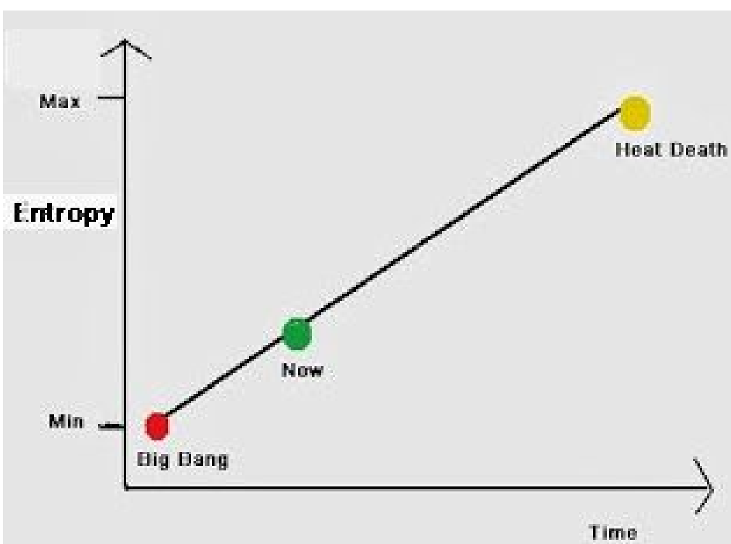
We have figured out what the entropy actually is, and now let’s move to the next page that how entropy behaves as a crucial role in the Universe. We have learned multiple physical equations before, but none of them directly points out the direction of the time. Admittedly, given the current state, we can find out what’s going on next and what has happened before by applying those physical equations. However, according to those equations, there is no distinction between the future and the past. In the microscopic world, time forward or backward are on an identical basis. In the macroscopic world, however, physical processes like ice melts to water, sugar dissolves in coffee, are all irreversible, and only valid for a certain time direction. Why time has a direction in the macroworld but the microworld? The answer again is the entropy. As I mentioned before, because in the macroworld probability of increasing entropy is extremely high, any isolated systems on a macroscopic scale will tend to increase entropy or disorder over time. In the microworld, however, it is not really high that there exists some possibility like hot particle gets hotter. Therefore, in the macroworld we can feel the direction of time, because the entropy is always increasing, while in the microworld we cannot, because the entropy is not always increasing.

Universe and Entropy

Once a system gets its fully disorder state, its equilibrium, there is no more entropy increase to determine the direction of time. Therefore, our actual feeling of the direction of time implies that the Universe we live in today is in a state of relatively low entropy that there is still entropy increasing for us to experience the flow of time. In addition, since entropy is always increasing in the macroscopic world, there must exist a point that the entropy of the universe is 0, represented as the origin of time. That it is the so-called big bang. In 13.7 billion years ago, Universe was intensely hot, opaque, flat, and speedily expanding. When the gravitational force among particles became tremendously enormous, although the particles are hot and dense, seemed like disordered and high entropy, particles actually make a very delicately fair low-entropy state.



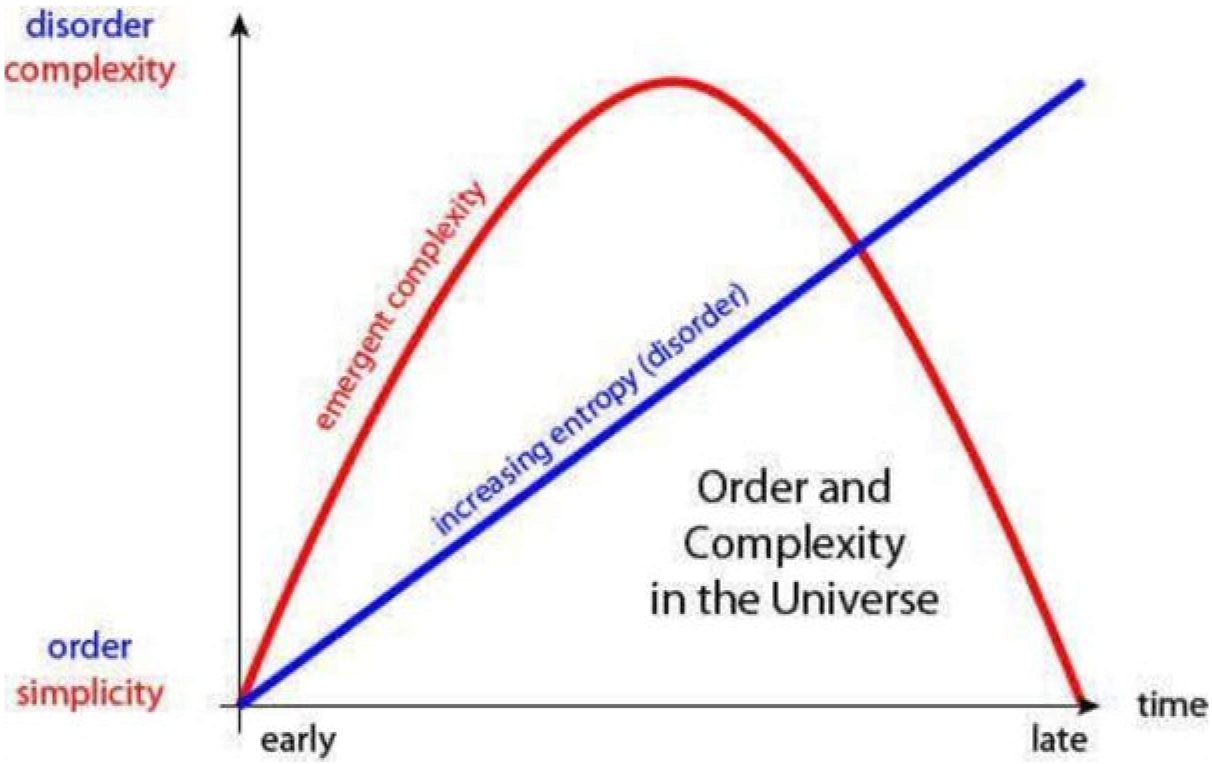
In the future, as the entropy increases, the Universe will finally move to its state of equilibrium. In that case, all the stars will burn out and all the black holes will vanish, left with a place filled with nothing but emptiness. At that time, things like direction of time, all any physical processes in real life will no longer have their meaning. Thanks to the state of low entropy in today and the non-equilibrium starting point of the Universe, we can feel the flow of time and find out our meaning.



Complexity and Entropy

We have talked a lot about the entropy, but if the overall tendency of the Universe is growing disorder, why do the delicately complicated structures, like the human beings, appear in the universe? The key is, disorder and the complexity are different ideas. Disorder, as I mentioned before, increases as the number of the possible microstates increases. Complexity, on the other hand, is a measurement of how hard it is to describe a system. For the complex system, you need a bunch of information to express it, while for the simple system, it just requires a little information. For example, take a cup filled with milk, ice, coffee, and syrup. It begins with a state of relatively low entropy: and all of these four are relatively stationary, you also just need a few words to describe them. But when you to start to mix them up, entropy goes up. While you are stirring, the whole system becomes more complicated as well. It is really hard to clearly describe the swirling among the milk, coffee, and syrup, and how the ice melts into the water and how this water again mixes with the other three. Until these four are completely mixed together, and the ice successfully all melts to water, the whole system comes to the equilibrium, and the entropy also achieves its pinnacle.

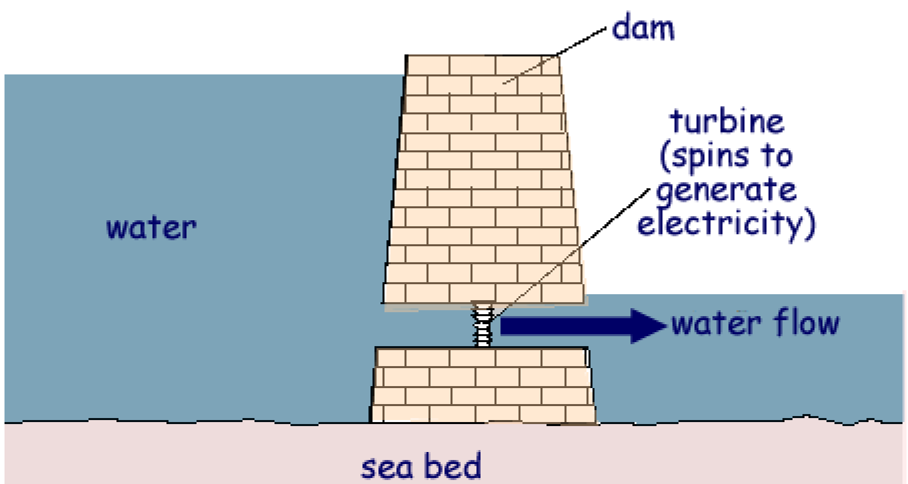
However, this complicated combination among four different things once again becomes simple. It just requires a few words to describe: a uniform mixture of water, milk, coffee, and syrup. According to this example, we can find that when entropy continues to increase, the complexity increases at the beginning and decays, right as this picture shows.



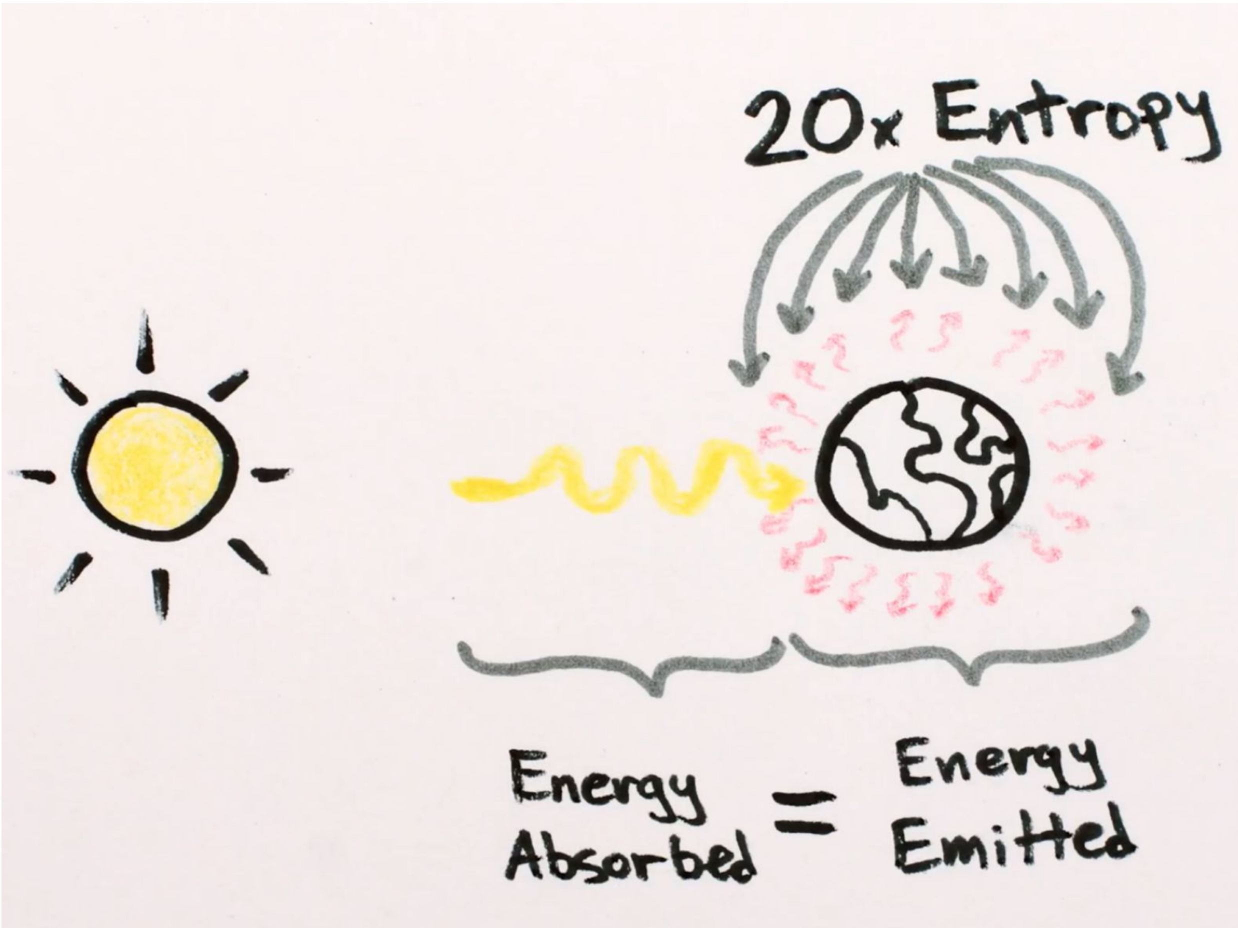
Another example is the Universe itself. At the beginning, the Universe is smooth and dense; at the end, the Universe is still smooth, but dilute. Though the entropy is keeping on increasing, the start point and the end point are both very simple. We are right at the point where the entropy is in the middle, and the complex comes to its apex. In the future, it can be predicted that the complexity of Universe will decrease again, and the complex things like us will be simplified out of existence.

Energy and entropy

Many people have heard the first law of Thermodynamics that the total energy of an isolated system is constant. So if the energy is always constant, how can we possibly ever use any energy to do anything? The thing is, what we consume in our daily life is not the energy, but the useful energy: and the energy is only useful when it is conserved in a low-entropy state. For example, the dam is only useful when the water level is not same, which is in the low-entropy state. When the two sides of water reach the same height, the entropy reaches its equilibrium, and the dam is no longer useful. You never would see a dam with equally high water will suddenly split to two sides with different height, even though the total potential energy keeps constant.



Therefore, the useful energy is always low entropy, still far from the equilibrium that can be put to work. Another example is the sun. The Sun, in every second, emits 90 petajoules of energy to the Earth, while the Earth also radiates almost the same amount of energy in every second. For every photon we see in the Earth, there will be 20 infrared photons radiated by the Earth; though the amount of energy keeps same, the entropy has increased to 20 times bigger.



Similar to the previous example of the dam, if the Earth is equally light as the Sun, though the energy in the Earth will be much bigger than now, it will quickly reach the equilibrium state, and things like driving and living will be impossible. When all the energy has averaged out, reaching the same equilibrium state, we cannot do anything, even though the energy might be really sufficient. So thanks to the difference, thanks to the entropy, it enables us to change things and live in this world.

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