

Entropy

A simple explanation by John Gordon

Entropy is usually described as the *amount of chaos in a system*. But what does that mean? The term is used in both physics and in thermodynamics.

Here's how it works.

Example

It's easiest if I give an example. We'll pick a very simple system. (*System* just means a defined bunch of objects we're going to investigate, plus the ground rules we're going to use.)

Our system will consist of 5 objects called A1, A2, A3, B1 and B2. In other words they are distinguishable from each other (they have unique names) and there are two kinds, the A and the B kind.

We'll look at different four ways of arranging them.

Arrangement No	Ordering
(1)	A1 A2 A3 B1 B2
(2)	A3 A2 A1 B2 B1
(3)	A3 A1 A2 B2 B1
(4)	B1 A2 B2 A1 A3

If you look carefully you'll see that arrangements (1) to (3) have something in common – the As come before the Bs. They have a kind of pattern or “order” to them. We could say the first three are in some sense “well-ordered”.

Arrangement (4) has them in a more random order. The As and Bs are all mixed up – i.e. “not-well-ordered”.

Altogether there are 120 ways to arrange five objects, and only 12 of them (10%) have the property that the As come before the Bs. All the other 108 ways are “not-well-ordered”.

Any randomly chosen pattern of the 5 objects would have a 10% probability of being well-ordered and a 90% probability of being not-well-ordered. So “not-well-ordered” patterns are more likely. Entropy simply measures the likelihood of a pattern occurring by chance and clearly, well-ordered ones have lower entropy while not-well-ordered ones have higher entropy.

Obviously we could have chosen lots of other ways to define what we meant by “well-ordered”, but however we define it, there are usually many fewer orderings that are well-ordered than jumbled up ones. Entropy is always larger for random or chaotic arrangements, and small for those with a neat pattern.

Because there are more jumbled arrangements than well-ordered ones, jumbled ones arise more often by chance (i.e. are more “typical”).

So high entropy means more chaotic, more random, more jumbled, more untidy and more typical.

Low entropy means well ordered, less likely to arise by chance, more unusual, more neat, less typical.

Moreover if we start with a well-ordered arrangement and shuffle it, we usually end up with a more jumbled arrangement. So shuffling tends to increase entropy because it leads to a more jumbled arrangement.

A cup of tea with all the milk at the top is well-ordered and has a low entropy. There are many fewer arrangements of the molecules with all the milk at the top, compared with the number of arrangements where the milk is mixed with the tea. So stirring tea increases its entropy.

And what goes for a cup of tea goes for the whole universe. Because the whole universe is a closed system and because everything we do is a kind of shuffling, the entropy of the universe is always increasing, and that's the famous *Second Law of Thermodynamics*.

Sometimes people argue “But surely I can take a shuffled pack of cards and put them into a logical order. Doesn't that reduce its entropy?” The answer is Yes, the cards now have lower entropy, but you and the cards taken together have higher entropy because you re-arranged your own molecules to burn off energy to sort the cards into order. You can't cheat on the Second Law.

The thermodynamic connection

It turns out that heat energy isn't enough to produce mechanical work. Victorian engineers quickly discovered they needed both heat and cold.

Steam engines work by boiling water into high pressure steam vapour that drives a piston which has only low pressure on the other side. If everything were at the same pressure, steam engines wouldn't work.

To produce mechanical work from steam we need a region of high pressure vapour and a region of low pressure vapour.

If all the universe were at the same temperature - even a very high one – steam wouldn't condense, so we couldn't have regions of high and low pressure and steam engines wouldn't work. Such a mixed-up and well-stirred universe would be more typical, more chaotic than one in where there were neat piles of hot and cold material, not mixed together. In short, it would have a higher entropy.

Moreover after a steam engine has done its stuff, the high pressure steam has mixed with the low pressure outside the cylinder, and so entropy has again increased. So turning heat energy into mechanical work is a mixing process that increases entropy, another example of the Second Law.

Although we've used steam engines as the example, it turns out that the same applies to any method of turning heat into mechanical or other useful form of energy, be it an internal combustion engine, a solar panel, a fuel cell or plant photosynthesis.