Author: Tim Baron

2nd Law of Thermodynamics – General Audience

The 2nd Law of Thermodynamics is fascinating! By the end of this paper you'll be convinced of that! The 2nd Law is in effect all around you all the time. Did you know that every time that you "do something" like push a box, or drive a car, or type on your computer, that you are both transferring and using up energy? Did you know that there is a limited amount of this energy in the universe and that it is not renewable? In fact, the universe may very well end because of what the 2nd Law tells us. Someday, one last "box push" could be the last action ever taken in the universe! Pretty powerful stuff huh? Wait, you say, 2nd Law, I'm not ever sure what thermodynamics is! Ok, let's knock that out.

Thermodynamics is kind of a scary word isn't it? It sounds like something fancy scientists work on in some deep underground laboratory. But, in fact, thermodynamics is happening all around you right now. You might think you need to know some fancy math and a bunch of crazy looking formulas to make any sense of thermodynamics. The fact of the matter is that the basic concepts are pretty straightforward. Not only is it an interesting subject, it can help you to understand the world around you. It will give you a whole new perspective on what's happening around you all the time.

Thermodynamics is a study of energy. In particular, it is the science of the movement of heat, which is a type of energy. In thermodynamics we call what we're analyzing **objects**. Objects can be anything that you want to analyze such as: an atom, a hand, a dog, a building, or even a planet. In thermodynamics, we look at **systems**. A system can be an object or a group of objects, but it must have a geometric boundary (some way to tell what is inside the system and what is outside the system). For example, if your garage is a system, then anything inside the garage is in the system, and anything outside the garage is considered something in the **surroundings**. A **thermodynamic process** is when there is a change of energy in a system.

If you are reading this on a computer, your hand (object 1) and your mouse (object 2) were already involved in a thermodynamic process. The moment you touched that mouse heat flowed from one of those two objects to the other (it most likely flowed from your hand to the mouse – unless you are in a very hot environment!). Heat flows from hot to cold and this process is an **energy transfer**. When two objects touch they want to reach **equilibrium** – which means they want to be at the same temperature. Given enough time, the objects will eventually be at the same temperature. This is why your cup of coffee cools to room temperature instead of remaining hot when it's been sitting on your desk for a while – it wants to be at equilibrium with the room.

Author: Tim Baron

So, now that we've got a basic idea of what thermodynamics is all about, let's quickly look at the "rules" for looking at things in thermodynamics and then we can really get into that 2nd Law. I know you must be excited to learn about it by now! These rules are encompassed in the four laws of thermodynamics. Let's go over some very basic descriptions of the laws.

Zeroth Law of Thermodynamics – What is this weird thing you ask? Zeroth? Sometimes things need revising. Since the 1st, 2nd, and 3rd law were already taken and this law was so fundamental, they thought that this one should come first, so they decided on the zeroth law.

It states: If two bodies, say A and B, are each in thermal equilibrium with a third body C, then A and B are in thermal equilibrium with each other. It's like your old algebra buddy, if A = C and B = C then A = B.

1st Law of Thermodynamics – Heat is a form of energy flow and energy changes are subject to the laws of conservation of energy. You've probably heard this one as energy cannot be created or destroyed.

2nd Law of Thermodynamics – In a thermodynamic process the disorder (or entropy) of an **isolated system** tends to increase or stay the same. An isolated system is one that cannot exchange energy with its surroundings. There is no process that can decrease disorder (entropy) in an isolated system.

3rd Law of Thermodynamics – The entropy of a system approaches zero as its temperature approaches absolute zero (–273.15 degrees Celsius or –459.67 degrees Fahrenheit – also known as zero degrees Kelvin). When something is super super cold and crystalline it is perfectly ordered, thus there is no disorder.

So all that's pretty straightforward right? Let's sum it up the 1st, 2nd, and 3rd laws in plain English.

The 1st Law states that you can't get something for nothing. Essentially, if you want to build a fire you have to "use up" wood.

The 2nd Law states the entropy (disorder) of a system, such as the universe, will either increase or stay the same as thermodynamic processes take place. Some processes will make entropy increase and some will allow it to stay the same.

The 3rd Law states that at absolute zero there is perfect order, thus there is no disorder (entropy).

There are many different ways to describe the laws of thermodynamics. For the curious, here are two of the longstanding descriptions of the 2nd Law regularly found in texts:

Author: Tim Baron

A process whose only result is to exchange heat with fewer than two different heat reservoirs and produce work is impossible. (Carnot's version – from Mere Thermodynamics by Don S. Lemons).

A process whose only result is to extract heat from one heat reservoir and reject heat to another hotter reservoir is impossible. (Clausius' version – from Mere Thermodynamics by Don S. Lemons).

Ok, now let's take a look at why the 2nd Law is so fascinating! Do you see it? It's because it tells us that once disorder is introduced in an isolated system, there's no way to get back to less disorder. It can only become more disordered.

Let's take a look at this **entropy** stuff. Entropy is a bit of a complicated topic. For us, we're going to define it as: the amount of disorder in an isolated system. But, it also represents a special quantity. This special quantity can be thought of as: how much energy is <u>**not available**</u> for conversion into work. So if we take a close look at what we're saying here, entropy is the amount of disorder in a system. As the system becomes more disordered, has higher entropy, it has less available total energy to do work. Ok, let's bust out an example to get a handle on this.

Let's say you just bought a new house. Let's think of the house as a **non-isolated thermodynamic system**. You pack up all of your stuff from your old house (or apartment, or parent's house, or wherever), put it in a moving truck, and pull into the driveway of the new house. You (and hopefully all of your always helpful friends and family!) take all of the boxes into the house. Plates go in the kitchen cupboards, towels in the linen closet, TV stand in the living room, and eventually each thing is in its place. The house is clean, organized, and it's time for you to relax. We'll start right here and pretend that everything is extremely ordered (we won't go so far as to say we're at absolute zero, that would be a bit on the ridiculously cold side) and entropy is low. So, Monday rolls around and life goes on, you have to get back to work. A few weeks go by and there are now dishes in the sink, there's laundry in the basket, and there's dust on the TV stand. Your new house now has a bit of disorder. Well, now you have some choices. You can never clean it and it will just become dirtier and more disordered over time (hey some people do this!) or you can clean it up. If you don't do anything, disorder will continue to increase thus entropy will continue to increase. Eventually there will be a lot of disorder (you'll never be able to find anything and oh those poor dishes!). The other option is to clean it up when it needs it. So, you scrub those dishes, wash those towels, and dust that TV stand. Alright, all set, right? Disorder removed? Not quite. You had to do some <u>**work**</u> to clean that place up. There's no free lunch here!

So, you've decreased the disorder, hence entropy, in the house. But, wait a second here; didn't we just say that there is no way to decrease entropy once it's there? Yes, we did. So, what gives? Well, let's try to find the isolated system that we're talking about in the description of the 2nd Law. In most cases when doing thermodynamics problems we define a theoretical **isolated system** so that we can solve a problem. But in our case, let's think big. The ultimate isolated system is the universe itself. So, although you've removed the entropy from your house, it still remains somewhere in the universe and it can never be decreased. Oh my, look what you've done! Don't fret we all do it, everyday. We are constantly removing disorder from our surroundings and sending it off to some unseen place in the universe.

Well, so what, you might say. It's gone from my house, and I don't have to worry about it. That's true to an extent. But, let's remember that we also said that the more entropy that there is, the less energy there is available to do work. Uh oh, do you see it now? Every time you clean that house and send that entropy away, there's also a bit less energy able to do work available in the entire universe. You don't have to worry about it anytime soon, but eventually as we all do our work, and plants do their work, and animals do their work, and space aliens do their work, and we do all of this work to decrease entropy in our lives, the entropy in the universe increases. At some point, there will be so much entropy in the universe that there will be no usable energy available to do work to remove it from our houses, or planets, or galaxies, or wherever. So, yes indeed, we are all contributing to an increase in entropy of the isolated system we call the universe.

Ah ha, but what about that part about entropy staying the same that was up there in the definition. It is true that some processes may not increase entropy. There are two types of processes. **Reversible** processes do not increase entropy. **Irreversible** processes do increase entropy. How can you tell the difference? Well, the easy way is to think of taking a video of an event. Let's say you drop a crystal vase on the floor and it shatters into a bunch of pieces. Imagine watching the video in reverse. Would you ever expect the pieces of that vase to spontaneously rise up from the floor and reform the vase like they do on a reversed video? No? Well, then the process is irreversible. Using that example, it's plain to see that a lot of events are not reversible. In fact irreversible processes are idealized situations, not the norm.

In the sciences, the 2nd Law of Thermodynamics can be used to: determine the efficiency of refrigerators and heat engines, determine the degradation in energy quality in a process, understand the heat rejection process in refrigerators and heat engines, understand the heat input process in refrigerators and heat engines, understand energy quality, identify the natural direction of a process, see that disorder in a system and its surroundings always increases – that increasing the order of the system through work increases disorder on the surroundings of the system.

The 2nd Law also debunks the idea of a perpetual motion machine. A perpetual motion machine claims to be able to do unlimited work with no energy source. Perpetual motion machines and the conmen hocking them are interesting topics themselves. I encourage you to check out the history of these devices on your own. You'll learn a bit more about thermodynamics and get a smattering of some of the scientific frauds that dot the history of science.

Author: Tim Baron

The next time you look up into the night sky, consider this. The universe started out as a tiny, dense, highly organized mass. After the Big Bang, the universe expanded and has continued to expand and grow more disordered over time. The study of thermodynamics points to a possible conclusion to the story of our universe (with what we know now anyways). It may become a cold, disordered, entropy-filled space with no usable energy left to do work. Oh no, the sky is falling! Don't fret! Perhaps you should consider studying thermodynamics. Maybe you will go on to be the next great scientist that figures out how to avoid the end of the universe. Maybe you will discover something we missed, or even something more mind-blowing like how to travel to other universes. If nothing else, you will start looking at your everyday activities in a new light.