Thermodynamics: Crash Course History of Science #26

Crash Course: History of Science
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===== (00:00) to (02:00) =====

(Complexly intro)

We've talked about an industrial revolution that wasn't really about epistemic or what's really going on questions, but about how to make stuff work in the real world. Now it's time to come back to all that cool technology from the early 1800s. How does steam work? How can we quanitfy hot air or mathematically describe the motion of a piston or the heat from the barrel of a cannon?

(Crash Course History of Science intro)

Thermodynamics, or the physics of heat and temperature, energy and work, doesn't really have a Darwin and Wallace. It's a lot messier. Scientists were confused about the basic concepts of heat transfer or how stuff heats up or cools down and temperature, and for most of human history, they didn't even have a good way to measure temperature. Galileo and Newton made attempts but it wasn't until the early 1700s that Gabriel Fahrenheit finally nailed it, but that still doesn't explain how and why things heat up. A lot of people tried to crack the physics behind these phenomenons.

Like chemist Antoine (?~1:10), remember him from episode 18? He used the caloric theory, which explained heat transfer as an ether or colorless fluid that migrated from a body at a higher temperature to one at a lower temperature. This made sense to (?~1:25) when he was upending chemistry, but it was wrong. In fact, ether was the explanation for many unknown phenomenon in the 18th century and there were a lot of conflicting ether theories.

Throughout the entire 1800s, a large number of chemists, physicists, engineers, and mathematicians across the world worked out the not-wrong physics of heat and motion. One of the first was American physicist Benjamin Thompson, better known as Count Rumford. We've actually met Rumford before. He married (?~1:56)'s scientifically inclined widow, Marie, so yes, Marie (?~2:00) helped to develop the modern sciences of both chemistry and the physics of heat and energy.

===== (02:00) to (04:00) =====

Rumford conducted a lot of experiments in the barrels of cannons, like how to measure and insulate against heat. He noticed that certain materials insulated better than others and that air seemed to be involved in the transfer of heat and concluded that air is a great insulator. He then moved on to liquids and concluded that they are also great insulators, all of them, which, you know, water boils so kinda problematic science. But he kept going.

In his experiments, Rumford noticed that something other than the caloric ether was heating up various substances. So, he devised an experiment which showed that the boring of a cannon, like the hollowing out of the barrel, released heat. Basically, he just created a cannon barrel by drilling a hole in a long piece of metal for over two hours, but this was the twist, Rummy did this underwater, which eventually caused the water to boil. Heat wasn't the invisible fluidi part of a chemical reaction, but simple mechanical motion.

In some ways, this result should have been obvious to anyone who had observed friction, but Rumford brought it back to scientific attention. How is heat created and transferred? (?~3:17) needed to catch up with (?~3:20) and ether needed to be replaced by a new science. This science picked up steam with the invention of the steam enginge after engineers like James Watt designed ways of producing steam and directing it to move machines, scientists tried to improve the efficiency of these systems.

Steam engines were not an example of basic research applied to the real world. The cool new tech came first, later propelling a lot of useful research into how heat and energy function. French physicist and engineer Nicolas Sadi Carnot grew up during the Napoleonic Wars. He believed that steam engine efficiency was the key to helping France become a glorious empire. Carnot's work with steam engines led him to think a lot about thermodynamics.

===== (04:00) to (06:00) =====

In an engine cycle, parts of the system move through different states of energy and finally return to the inital state. Inventors were thinking up all sorts of great applications for engines like locomotives, but no one could mathematically explain what was going on. Carnot figured out what became known as the Carnot Cycle, or the science of what happens inside heat producing engines.

The Carnot cycle describes the upper limit of the efficiency of a model thermodynamic system or a system where heat moves around within set boundaries. In 1824, Carnot published the paper "Reflections on the Mode of Power of Fire and on Machines Fitted to Develop that Power". This contained, although not in the same words we would use today, the second law of thermodynamics, which states that the total entropy of a closed system can never decrease, only stay steady or increase. Heat can't randomly flow from a colder point to a hotter one. This is just one way to express the universal principle of entropy, or the state of disorder in a system.

But don't get too philosophical about chaos, entropy is ust a variable that you can calculate with the right math. Carnot didn't quite know what he had going. He presented his findings in terms of the reigning caloric theory and then he died of cholera at the tragically young age of 36. Many other physicists around Carnot's time realized that heat, light, chemical reactions, and motion aren't merely very complex phenomena on their own, they're all part of a larger, more complex system and they interact with each other.

In the 1840s, several scientists independently discovered what we now confusingly call the first law of thermodynamics, or the conservation of energy. Energy can change from one form to another, but energy is not lost. It has to go somewhere. Energy in coal, for example, is released into heat and light as fire, and the first law is not just a metaphysical idea, it can be quantified. The whole point of thermodynamics is to put numbers to all of the complex motions and reactions that move energy from one form to another, to find the fixed exchange rates between states of energy.

===== (06:00) to (08:00) =====

In the 1840s, English physicist James Joule and German doctor Julius von Mayer indpendently figured out that heat transfer and mechanical work were different forms of the same thing, which we now call energy transfer. Thought Bubble, give us an introduction.

This was such a big deal. Heat is just motion and vice versa, just like Rummy's cannon experiment showed. In fact, today, the Joule is the unit of energy, but alas, neither of their mechanical theories of heat was accepted at the time. Joule experimented with batteries and electromagnets, trying to determine the relationship between heat and motion. He concluded that the heat needed to increase the temperature of a pound of water by one degree of Fahrenheit scale was equal to a mechanical force capable of raising 838 pounds to the perpendicular height of one foot. Today, we would say that's about 4 Joules per calorie of work.

Joule told this to the other members of the British Association for the Advancement of Science in 1843 who were like, congrats, bro, you've just invented warm water, I guess. Undaunted, Joule set out

to prove his theory, conducting experiments on his honeymoon, Joule put a dynamo in water and measured it, experimentally confirming his mechanical theory. He forced water through a perforated cylinder measuring the very slight degree to which the water heated up and found that his mechanical heating up energy was the same as his electrical heating up, about four Joules, or as he said, wherever mechancial force is expended, an exact equivalent of heat is always obtained. Bam.

And then, in 1845, Joule dropped *On the Mechanical Equivalent of Heat*, in which he detailed his experiments using a falling weight, that is, gravity, to move a paddle wheel inside an insulated barrel of water in order to heat it up.

===== (08:00) to (10:00) =====

Again, he measured the energy involved and found around four Joules. Joule finally began to get his peers' attention, but caloric theory still reigned. Thanks, Thought Bubble.

Julius von Mayer, on the other hand, tried to publish his ideas but he was rejected so he attempted suicide, but only broke his legs. He was declared insane and locked up in an asylum. For a long time, Mayer was overlooked as the independent co-discoverer of the mechanical equivalence of heat energy. Joule got all the credit, although Joule did give Mayer a shout out in a paper in 1850. Mayer also hypothesized that plants convert light into chemical energy, or photosynthesize, way ahead of his time.

Meanwhile, Scottish physicist William Thompson, better known as Lord Kelvin, heard Joule talk at the British Association in 1847 and wanted more evidence. Lord Kelvin was also a big fan of Carnot's but he wanted to push his theories farther so he tried to reconcile Carnot's work as explained by caloric ether with Joules. Lord Kelvin is usually credited with coining the term 'thermodynamics' in 1854. Here's his definition: "Thermodynamics is the subject of the relation of heat to forces acting between contiguous parts of bodies and the relation of heat to electrical agency." Ultimately, Lord Kelvin rejected caloric theory and he teamed up with Joule.

Kelvin worked on many aspects of physics and also other sciences. Today, he is probably best known as the dude who worked out the science of absolute temperatures, which are now measured in the unit called 'Kelvin'.

In the 1850s and 60s, German physicist Rudolf Clausius figured out that there were actually two distinct laws at work in Carnot's most famous paper and they contradict each other. Clausius restated the first and second laws of thermodynamics, removing the contradiction. His version of the second law: Heat can never pass from a colder to a warmer body without some other change connected therewith occurring at the same time.

===== (10:00) to (12:00) =====

In 1865, Clausius also gave the first mathematical description of entropy and named it and this paper ended with the brilliantly simple summary of the first and second laws of thermodynamics: the energy of the universe is constant. The entropy of the universe tends to a maximum.

Thermodynamics deeply united chemistry and physics, in the way that Newton's (?~10:29) had united mathematics and astronomy. Suddenly, experiments and theories that looked very different on the surface were joined at a basic level. Thermodynamic concepts from the studies of heat engines were all applied to chemical reactions. Entropy proved a very useful idea in many disciplines, including statistics.

So at the end of the 19th century, if you were a fan of thermodynamics, you might say that the question of 'What is stuff?' was close to being solved. But you'd be wrong, because of Einstein, wait for him, but also because the history of thermodynamics was a hot mess, pun definitely intended.

This history is often presented as an orderly progression of ideas, each building on the foundation of laws created by earlier investigators, but that's not quite true. After all, what we now call the second law of thermodynamics preceded the first by more than 25 years. Not super orderly! And then there were long periods where invalid ideas were tenaciously held in the face of decisive evidence of their falsity. In other cases, as with genetics, lots of scientists simultaneously adopted a whole new bloc of theory and built upon it.

Next time, sparks will fly as we meet another gang of 19th century physicists and engineers: the pioneers of electricity. Crash Course History of Science is filmed in the Dr. Cheryl C. Kinney Studio in Missoula, Montana and it's made with the help of all of these nice people and our animation team is Thought Cafe. Crash Course is a Complexly production. If you wanna keep imagining the world complexly with us, you can check out some of our other channels like SciShow, Nature League, and The Financial Diet, and if you'd like to help keep Crash Course free for everybody, forever, you can support the series at Patreon, a crowdfunding platform that allows you to support the content you love.

===== (12:00) to (12:29) =====

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