I have a certain fondness for saying everything is chemicals, mostly this is because I'm tired of all the people complaining about all the "chemicals" that they are exposed to when literally everything you have ever been exposed to, including the most organically grown lettuce is composed entirely of chemicals. But when I say everything is chemicals, I am in fact wrong. There are quite a lot of things that aren't chemicals: sound, heat, laser beams , the existential concept of selfness… rainbows. All of those things are things. And all of the things and also all other things are, in fact-- oh god this is weird but it's true-- they're all the same thing: energy. Everything is energy.

(intro music)

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=====Trebuchets (00:48)=====

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Let's talk about trebuchets. The trebuchet was a weapon of war, but it is also a feat of ancient engineering so I remember it for that instead of for all the people it killed. Well, I happen to have a very small one that I built from a kit, because I'm a nerd.

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=====Forms of Energy (01:07)=====

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This tiny trebuchet contains quite a lot of energy. In fact, more than you might suspect. And because we are humans and we like to understand stuff, we shall put the energy it contains into a bunch of different boxes. Let's start with the least obvious one: its mass, since, as Einstein told us, energy and mass are the same thing. Now we're not gonna go into detail there, instead we'll just say that the energy is well and locked up and extremely difficult to access because the nuclear energy of the wood is not easy to release. Which is excellent, because the nuclear energy of this trebuchet, if released, could destroy the entire building that I'm sitting in.

This little war machine also has thermal energy; anything warmer than absolute zero has thermal energy, even very very cold things. This basically means that all of the individual atoms and molecules are jiggling imperceptibly. Only at absolute zero would they stop jiggling. If I were to touch it then my hand would instantly freeze and then fall off of me. Absolute zero is very cold. It also has chemical energy, which is stored in the bonds between the atoms. All of the bonds in the molecules of cellulose and lignin that make up the wood contain energy, and some of them could be broken, releasing that energy, which is what would happen if I lit my trebuchet on fire, which I will not do because it took like four hours to put together.

==========Potential Energy (02:11)
Now none of those forms of energy are the forms of energy that the ancient generals were interested in, of course, but I wanted to illustrate how much energy really is in there. What the ancient generals were interested in was the system's gravitational potential energy, because this heavy thing here which is full of pennies-- oh God, that's dangerous-- this thing is heavy, it's full of pennies, and it has been lifted up, and the force of gravity is trying to pull it back down. This stored gravitational energy is a form of potential energy; that is, energy contained within a system because of its position. This does not mean that it has the potential to become energy. It *is* energy. It's just stored. If it wasn't there, and then it was, then you would be creating energy.

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=====Law of Thermodynamics (02:49)=====

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And as we all know, you cannot create energy. Like, we all do know that, right? It's the first law of thermodynamics, also known as the law of conservation of energy, which is a real, hard and fast, not just unbreakable but unbendable law of physics. Energy cannot be created and it cannot be destroyed. The amount of energy in the universe is constant, and since everything is energy, the amount of everything in the universe is constant, which is a little bit trippy. Deep

thoughts like that one are what formalized the study of energy into what we call thermodynamics, the branch of science studying heat, energy, and the ability of that energy to do work.

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=====Work (03:25)=====

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Okay, now I just said three words that you think you know the definition of but you probably don't. That's okay, you're gonna be wrong many times in your life, this is just one of them. So, what were those words?

Energy. I know that you don't know what energy is, because, like, I don't either. Nobel Prize-winning physicist Richard Feynman said "it is important to realize that in physics today we have no knowledge of what energy is." But let's just give the same cop-out answer that my textbook gives, which is "the capacity to do work or produce heat."

Work. In the common vernacular, that's anything that you have to do but you don't want to. But in physics and chemistry, work is when a force acts on something, causing it to move. If nothing moves, then no work is done. There are a few different symbols that represent work, we're going to use the lowercase "w."

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=====Heat(04:05)=====

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Heat. Which is maybe the most misunderstood word in chemistry after the word chemicals. Heat is not something that objects contain. Just like something can't have work, something can't have heat. Instead, heat, just like work, is an energy transfer. But instead of transferring energy by mechanical movement, heat is a transfer of energy by thermal interactions, such as radiation or thermal conduction.

Now crazy as this might seem, those are the only two things that energy can do. It can either be work applying force and moving things or it can be exchanged as heat. Both process result in an energy transfer between systems. And just in case you weren't confused enough, the most common symbol for heat is lowercase "q." Yup. Lowercase "q," deal with it.

Little-known fact: the word "heat" used to start with a silent q, but it was dropped in the seventeenth century when-- I'm just making stuff up.

So we're just gonna have to move on, leave that behind us, and think about what happens when the amount of energy in a system changes.

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=====Energy Transfer(04:47)=====

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If you're currently freaking out, thinking, like, "but Hank, you just said that the amount of energy never changes!" I will remind you that I said "in the universe."

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=====System And Surroundings (05:03)=====

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See, when we're doing thermo, we get to divide the universe into two parts, which is actually a pretty cool thing to get to do. One part is the system, the thing that we're studying, and everything else is the surroundings. The surroundings allow the amount of energy in the system to change. That change just has to come from or go to the surroundings. And we get to decide where that line is. We could say that the system is the rock that the trebuchet propels, or the sling, or the trebuchet itself, or the face of the poor guy that the rock runs into. Whether it's the Earth-trebuchet system or the rock-face system or the entire observable universe system, we get to decide based on what we're interested in studying.

Every system has an internal energy, the sum of all that system's kinetic and potential energy. The internal energy of the system is represented by a capital "E", and usually we're interested in changes in that system. And the way we represent change in chemistry and physics is with the Greek letter delta(?), so we stick the delta in front of the "E" for "?E", the change in the energy of the system. The change in the energy of the system is equal to the heat plus the work. The simplest equation you're ever gonna see on CrashCourse Chemistry.

There are two basic outcomes when you're looking at this internal energy equation. The first is that ?E is positive. It's gaining energy from the surroundings. That's the case if work is done on the system or heat is transferred to the system. Like if I were to do some work to get the trebuchet ready to fire, ?E is positive. The system is gaining energy from its surroundings, which includes my arms and muscles. If work is done by the system or heat is transferred from the system to the surroundings those w and q get negative signs resulting in a decrease in ?E or a loss of energy from the system to the surroundings. Like when the trebuchet fires, the trebuchet's ?E is negative from the transfer of energy to the ping pong ball. So what in the name of Willard Gibbs does any of this have to do with chemistry?

Well, the energy stored in molecular bonds, chemical energy, is a kind of potential energy. It exists because of the position of the particles in the molecule. Just like with the trebuchet, in chemistry we can put energy into molecules and take it out and even use it to do work, creating war machines millions of times more powerful than the biggest siege engine ever constructed but also creating tools to feed and clothe the world.

Some reactions release energy, like if I lit my trebuchet on fire-- which again I will not do! Why do I keep bringing that up!?-- Burning is the rapid oxidation of chemical compounds, and as it results in a heat flow out of the system we call that an exothermic reaction. But other reactions suck energy out of the environment and into the system. These endothermic reactions occur when heat flows into the system. Like in your car engine, at the high temperatures of combusting fuel, Nitrogen and Oxygen will suck some of that energy into chemical bonds forming nitric oxide, a poisonous gas that I once inhaled a dangerous amount of, but I'll save that story for our lab safety episode. Chemistry, it turns out, is largely a study of energy. The energy stored in bonds, transferred between atoms and molecules to find stable forms and released to the environment to do work. It's just like the trebuchet-- put energy in, store it, and then take it back out to do something interesting, fun and useful. That's basically everything that ever happens summed up in one little siege engine. Not bad.

Thanks for watching this episode of Crash Course Chemistry. If you were paying attention, you learned that everything is energy; that there are lots of different forms of energy including potential energy, which is energy contained within a system because of the position or arrangement of its components. And you learned that chemical energy is a kind of potential energy, energy stored up in bonds between atoms. Also you hopefully already knew that energy can neither be created nor destroyed, and that the amount of energy in the universe is constant; but when studying thermodynamics we divide the universe into the system and its surroundings, and a system could give energy to or take energy out of those surroundings. You learned that energy can be transferred in two ways: work, which is force applied over a distance, and heat, which is the transfer of energy by thermal interaction. And finally, you learned that all of this is just as applicable to chemistry as it is to trebuchets.

This episode was written by Kim Krieger and myself, edited by Blake de Pastino, and our chemistry consultants were Dr. Heiko Langner and Edi Gonzalez. This episode was filmed, edited and directed by Nicholas Jenkins, our script supervisor was Caitlin Hofmeister , Michael Aranda did the sound design and our graphics team is Thought Café.