How do fireworks work?

Note: This is an automatic transcript, likely 95% accurate, but should not be relied on or quoted from. Please check the original audio for details.

Jorge: [00:00:00] Hey, Daniel. I have an explosive question for

Daniel: you. Uh, oh. Are you gonna ask me about how to blow things up? isn't that what you

Jorge: do every day anyways, at the particle Collider, I mean, like on a more everyday basis, how do you feel about summer

Daniel: fireworks? Hmm. I used to love fireworks as a kid.

Jorge: You used to love him.

You don't

Daniel: like him anymore. I guess I just used to have a more sparkling personality.

Jorge: Uh, well, you can be a real firecracker. Trust me.

Daniel: well, I'm hoping one day that all blows over. You're very

Jorge: bright and, uh, popping personality. Also, you seem to make a lot of noise

Daniel: so far I've never been fired from work for setting off fireworks.

Jorge: Hi, I'm [00:01:00] Jorge, a cartoonist and the creator of PHP comics. Hi, I'm

Daniel: Daniel. I'm a particle physicist and a professor at UC Irvine, and I really do love blowing things up. Oh yeah.

Jorge: Do you do that as a hobby? Not just in your work.

Daniel: yeah, I'm pitching a new reality show called will it explode?

Jorge: Interesting, I guess, uh, if you don't like, uh, your fingers or hands, that sounds like a, a great show to

Daniel: join.

I think everybody would want to tune in and see how much T and T does it take to blow up this or that? A banana, a watermelon, a

Jorge: coconut. You remind me of my cousin when we were little that could love to blow things up with firecrackers.

And

Daniel: how'd that work out for your

Jorge: cousin? uh, alright. He's still alive.

Still has all his fingers. He managed

Daniel: to survive success. And I hope his job lets him blow things up on a regular basis. Like mine

Jorge: actually, he fixes planes now. So I hope, I hope he doesn't blow things up.

Daniel: His job is the opposite now of his childhood passion.

Jorge: Yeah, that's [00:02:00] right. Keep things from blowing up, please. Gus . But anyways, welcome to our podcast, Daniel and Jorge, explain the universe, a production of iHeartRadio. We're

Daniel: the only thing we wanna blow up is your mind. As we delve into the secrets of the universe and try to understand how it all works.

We take apart the very fabric of space and time and reality. Seek to understand it at the smallest level. How does the universe really work? What are its most fundamental bits and how do those weave themselves together to make this incredible, exciting, and explosive universe that we enjoy every summer?

Jorge: Yeah, it is an exploding universe. As we know, dark energy is making the universe accelerate and expand. Faster and faster each day, literally it is sort

of exploding and it's also full of sparkly and amazing and colorful things for us to wonder

Daniel: about that's right. Although thinking about the big bang and the expansion of the universe as an explosion does tend to lead people to thinking about things the wrong way.

A lot of people think about the big bang as like this tiny dot of matter, which [00:03:00] then blew up into space, which already existed though. These days, our vision of the early universe isn't as much like a firecracker as it is like a big rubber. Getting stretched everywhere. Mm.

Jorge: That maybe you shouldn't have called it the big bag.

I mean, it's in the name, Daniel, the big bang sounds like an

Daniel: explosion. It does indeed sound like an explosion. And so we'll add it to the list of horribly named astronomical concepts.

Jorge: I mean, you just misnamed the entire universe. I mean, Just a small error there.

Daniel: We should have called it the big stretch

Jorge: but it is interesting.

Do you see your job as blowing things up? You said earlier, you like blowing things up and you're a particle physicist, which means you collide things. But does that, is that also the same thing as blowing things up?

Daniel: Yeah. Well, the reason we collide things is to blow them up. Like you wanna know what's inside a proton.

We can't like put it on the table and tease it apart with PLIs. What you gotta do is smash two of them together. Blow them up and see what comes out from that explosion. So every collision inside the large ha and Collider is like a [00:04:00] mini explosion and we do millions of them per second.

Jorge: Mm. Although it's more like a smashing, I don't know if it's exploding really

Daniel: well, what happens if you smash two watermelons together?

They explode don't they?

Jorge: No, they just smash . If you put a grenade inside of a watermelon, that's an explosion.

Daniel: Well, if I could put a grenade inside a proton, I would totally do it.

Jorge: but what would the grenade be made out of Daniel

Daniel: grenade ons, obviously the delicious dessert explosions, but I am also a big fan of aerial explosions though.

Maybe more so as a kid. Yeah.

Jorge: You mentioned that before, so you don't like fireworks. Like you go to a display and what do you do? You, you close your ears or you close

Daniel: your eyes. I used to be really amazed by them. I thought they were fantastic when I was a kid. And now I don't know if I've just gotten old and grumpy, but they're just sort of less impressive.

Jorge: Mm they're beautiful now. And they're, they're getting more complicated now. Right? Like now they can, you know, like sync them up with music and do all kinds of things. Uh, like multiple explosions that make. Different formations up there in the

Daniel: [00:05:00] sky. Mm-hmm and as we come up on July 4th, it reminds me that the best fireworks display I ever saw for July 4th for American independence day was actually in Switzerland.

Oh yeah.

Jorge: They make everything better out there. More precise.

Daniel: There's a huge American population in Switzerland. And so in Geneva they have an incredible July 4th fireworks, display. In Geneva it's like outside the us, but they go all out and have a live orchestra, which plays music and coordination with the fireworks.

It really was pretty impressive. Well, so

Jorge: you do like fireworks

Daniel: then? Yeah. Occasionally I've been known to enjoy them. Yeah.

Jorge: occasionally. I mean, who doesn't like fireworks Daniel , maybe dogs, dogs, and, and physicists

Daniel: dogs and jaded physicists. Yeah. Well, when you blow things up for a living, you know, you expect a higher standard, I

Jorge: guess.

Right, right. When you smash things for a living, you mean , I mean, uh, you said you got the bit name for the, the origin of the universe wrong. Maybe you should be a little more careful. Yep. Point taken, but anyways, [00:06:00] fireworks are pretty amazing and incredible. And part of our tradition and part of how the world celebrates big events like independence and new year's.

But it's kind of interesting to think about how that actually works. Yeah. It's an

Daniel: example of how we have put our knowledge of how the universe works. To work for us. We manipulate these things and take advantage of them to create these incredible bright displays, but to do so you have to know some physics and some chemistry.

Jorge: Yeah. So today on the program, we'll be tackling the question.

How do fireworks work? Or I guess more technically how to fireworks, fire

Daniel: and work. And can you set off fireworks at work without getting fired?

Jorge: it is a bit of an oxymoron. Isn't it? In one word. You have firing, you can fire someone and they can also works. Exactly.

Daniel: fireworks. It's like WeWorks, but we don't works.

Jorge: yeah. Fire crashed. yeah. It's pretty interesting to think about how [00:07:00] fireworks work, but, uh, I think you sort of said earlier that it's a result of, of our knowledge of the universe, but really sort of fireworks weren't,

you know, didn't come from us understanding anything about the universe. Right. I think it, it was mostly just people playing around with, and maybe figuring out that, so.

Daniel: Blow up. You're absolutely right. That fireworks have been with us for a lot longer than like our understanding of the chemistry and the physics of them. That's for sure. In fact, I think they're invented in China, like more than a thousand years ago. So fireworks been a part of a human existence for a very, very long time, longer than we've had modern chemistry.

That's for sure what, how

Jorge: they were invented. Do you think someone was just, uh, fooling around with things and then they blew up on. And then the person next to them was like, oh, that's interesting. I

Daniel: love thinking about how people stumbled into understanding of how things work, you know, think about like, think about like the metallurgy of swords.

People have really refined techniques for exactly how to make very hard steel. Well, before we had any understanding of the chemistry of it, and I think that must have just been accidentally [00:08:00] discover. People making mistakes and then discovering, oh, wow. Look, this is pretty awesome. So yeah, I think gunpowder probably discovered accidentally.

Mm,

Jorge: interesting. Well, we'll get into what, how it works and how it was discovered. But as you said, the history of it is that it was invented in China about a thousand years ago. People are not sure, I guess there are no

Daniel: records of it. There are some records of it, and you can look at like Chinese historical drawings and visitors who went to China of course, to see evidence of.

For more than a thousand years. It's pretty cool. Mm.

Jorge: Do you think they were, were they invented as a, like a celebration display or more for

Daniel: warfare? They were initially invented for celebration, they think, and then later applied for war, like

Jorge: everything no, it's usually the other way around these days, right?

The internet. It was started for the military. Mm DARPANET. Yeah, it was originally DARPA. And then it became, you know, CAD videos and podcasts.

Daniel: I see. So you're saying fireworks eventually would just turn into cat videos. That would

Jorge: be super impressive. if they can do a CAD video with [00:09:00] explosives,

Daniel: engineers could get to it.

That is the goal. The way every life form eventually evolves into a crab. Every form of weapon eventually involves into a cat video. Well, and

Jorge: then eventually it came to Europe, but not till much later that's

Daniel: right in the 14th century is when Europe started to use fireworks and develop the same sort of technology and

Jorge: then somehow made it to American and became part of July 4th, uh, or celebrations.

Daniel: Yeah. But blowing things up have been part of how people celebrate things for a long, long time. Watermelons, firework. Hopefully not cats beginning

Jorge: of the universe with a big bang. well, it's interesting because it's something that's in our everyday lives almost, or at least once or twice a year, but I bet not a lot of people know how it works.

And so as usually we were wondering what would happen if you ask people on the street or on the internet. How fireworks work.

Daniel: So thanks very much to everybody out there who answers random questions about the big bang, the origin of the universe and how fireworks work without any chance to prepare. We really love you participating.

And if you're out there and you've never joined in, [00:10:00] please don't be shy right to us to questions@danielandjorge.com. We want to hear from you.

Jorge: So think about it for a second. How do you think fireworks work? Here's what people had to say. There's some small amount of gun powder and a tube, uh, that tube explodes creating.

Big old pressure wave in a tiny little enclosed area. So that exerts a force on something that's gonna get shot into the air or, or I guess, uh, whichever way you point it at a

Daniel: friend or, uh, uh, a

Jorge: building or a car. And if it's one of those big fireworks, it probably has a second charge in it. You can put a bunch of different metals in there that are gonna, uh, burn at different colors.

And that would be. What

Daniel: makes all the pretty colors in the sky after that second charge goes off? It's my understanding that you have a shell that is made up of black powder or gun powder or something explosive surrounded by, uh, little things, uh, little balls of something that is dipped in a salt like Aran or, [00:11:00] um, you know, some sort of metal that when it heats up, it glows in a specific color fireworks show differently.

Because I think there are chemicals within each display that one's exploded will reflect light differently. and that's what produces all of

Nobody: the beautiful colors.

Daniel: Fireworks are like an amazing confluence of chemistry and physics. There's all of this energy that you have stored in the, in the propellant and the explosive that you are using.

And then once you get it up there, you're using different chemicals to create all the wild colors and effects. It's early rockets. Payloads of

Jorge: joy. Oh, I am

Daniel: so

Jorge: excited. If y'all are talking

Daniel: about fireworks, I love them. And yet I am not sure how they work. There's something explosive and different elements create different colors.

I think though I have no idea how they make those really cool ones with the different sparkles and sounds that [00:12:00] sound like they're crackling. I love those. I think

Nobody: fireworks

Daniel: work by firing stuff out in the back of them. Um, due to one of Newton's laws, which I can't remember, that means that due to the opposite reaction,

Nobody: the fire will go up

Jorge: and then I guess

Daniel: some dynamite explodes and makes a.

Nobody: Color

Daniel: and shape. Well, I always imagine fireworks as like a tiny little colorful controlled bomb that exploded only once you reached the sky, but maybe it works differently. Fireworks work by oxidizing flamables with a specific chemical that emits light at a certain frequency, creating

Jorge: the different colors.

We see. All right. Some pretty technical sounding answers. I like this one that said the, the confluence of chemistry and physics. That sounds almost poetic. little. Do they know chemists and physicists? Never confluence.

Daniel: Exactly. I was like, that's so naive, man. They're like all the way to other, they influence together.

they're on the other side of campus, man. Like they do a totally [00:13:00] different physics from us. Chemistry might as well be sociology from our perspective. Mm.

Jorge: Is there a stereotype? Of like of chemist and physicists. like one of them wear, wear sandals. The other ones wear wear socks and slippers.

Daniel: I don't know.

Eye protection. Chemists are always wearing eye protection when I see them around the building. Oh, I see. Interesting. The chemists here at UCI have these huge labs of like 30 grad students pumping out different synthesis of this and that. And the other thing it's really amazing and impress. No, I don't understand most of it.

You sound a little jealous there. Well, the

Jorge: UCI chemistry department don't do you have like 30 grad students yourself?

Daniel: I only have eight grad students right now. Thank you. But the UCI chemistry department is topnotch. Somebody who graduated from here won the Nobel prize in chemistry last year.

Jorge: I think always an opportunity to plug UCI Zaza.

But, yeah, it's pretty interesting. Everyone seemed to have an idea that it's about exploding things, which sort of makes sense and is maybe a little obvious there's some explosion involved and gun powder. Yeah. But

Daniel: fireworks are much more than just an explosion, right? If you've been to a recent [00:14:00] fireworks display, you've seen that they can do incredible stuff.

They're sparkly, they're shimmery. They have different colors. They can make smiley faces. I've seen butterflies, I've seen Palm trees. It's really amazing what they can do up there in the. Yeah,

Jorge: well for today, let's, um, break it down maybe a little bit further, right? Because when we think about fireworks and, you know, celebrations like new year's or July 4th, there's really sort of three things that people think about, right?

There's the firecrackers, the, the kind that just explode and make noise that the, usually the kind that people throw out in the middle of the street, Uh, there are sparkler, which are the, you know, stake that you hold and they peel a lot of

sparkles. And then there's a big fireworks display that go up in the sky and, and gives us all these amazing

Daniel: colors.

Yeah. And those things are actually all connected. So that's a great order to tackle them in. Right.

Jorge: Well, we'll start with, uh, firecrackers Daniel. How, what is, uh, what are the basics of a firecracker?

Daniel: Firecracker is really pretty simple stuff. It's essentially just gun powder in a little tube with a fuse.

So it's [00:15:00] just like a mini bomb. Right. And all it does is rapidly burn the gun powder, the black powder and explode and give you a loud noise and a little bit of smoke.

Jorge: Mm. Now, but I guess the question is what is gun powder?

Daniel: Yeah, I've wondered this for a long time. Actually. Gunpowder is this weird mixture of stuff.

So it's got some charcoal in it, like 15%, 10% of it is sulfur. And then 75% of it is this stuff called salt, Peter, which I always thought was really weird. Like who is Peter? And why is he so salty? but it's basically just like a funny historical name for a chemical potassium nitrate.

Jorge: Oh, interesting. Maybe saw Peter is the cousin of sweet John

Daniel: I think they're both blue singers. sounds like, you know, Mississippi salt, Peter or something. All

Jorge: right. So to make, uh, gun powder, you just need charcoal, sulfur and potassium nitrate. Now what what's potassium nitrate it. P in a K can N something. Yeah. So the

Daniel: chemical formula is K N oh three. So [00:16:00] it's got potassium, it's got nitrogen, it's got oxygen and it occurs in nature as a mineral.

And it's a useful source of nitrogen and it's used in fertilizers and also for like, Obviously rocket propellant and fireworks, and they also put some of it in processed meats.

Jorge: Wait, what? Oh, that's right. Like a, let's a curing agent. Mm-hmm

Daniel: and like the reason that like red hotdogs are red is because the potassium nitrate.

Jorge: Whoa. Does that mean hotdogs are flamable and they'll explode if you light 'em up. is that why they're called hot dogs?

Daniel: I don't know, but the first thing I would do is take two hot dogs and accelerate them together. See if that can generate a nice hot dog smash. Yeah,

Jorge: that sounds like a great use of a billion dollar, uh, facility in Geneva.

Maybe for July your July 4th party, you can smash hot dogs and, and sell 'em to little kids. Okay. So that's gun powder, charcoal, sulfur, and potassium nitrate. Now, why does that light up? Why does that.

Daniel: And so what's happening. Anytime you have an explosion is just a [00:17:00] rapid release of energy and like one shell of exploding material then sets off the next one.

It's sort of just like a fire in the sense that like the way one piece of wood ignites the next piece, but here it happens very, very rapidly. So you have a rapid emission of energy, usually faster than the speed of sound. That's what an explosive is. It's usually super Sonic. So that's the basics of an explosion.

The details depend on exactly what you have in there, how rapidly it oxidizes, how rapidly it releases that energy. Wait,

Jorge: so maybe take us through that process then, like what's what's going on? What does oxidizing mean? Um, what do you need, like a flame to get it started, right. So

Daniel: fundamental process that's happening here.

Chemically is something called combustion, right? Which technically is just like high temperature exothermic, which means it's releasing. So you're doing

some chemical change to what's going on inside. You're changing the molecules and their bonds in a way that releases some stored energy, the same way.

Like when you burn gasoline, right. It releases energy that used to be stored inside the fuel. So here it's [00:18:00] an exothermic reaction and it's called a redox reaction because it reacts with some oxidant, often that's atmospheric oxygen, like fire needs oxygen, right? It's part of the chemical process. To release the energy.

That's bound inside the wood here. You also need some source of oxygen, but there's not enough oxygen in the atmosphere to get this reaction going and to have it happen so fast. Cause you want it to start in the center and then explode outwards. And you know, there can't access enough oxygen to just take that from the air.

So you have to provide a source of. To make this whole explosion happen.

Jorge: Mm. But I, I guess, uh, you know, like what's the actual reaction, like, why do you need potassium, nitrogen, charcoal, carbon, and sulfur, like what's going on? Is something transforming into something else or something breaking apart? Why do you need those three ingredients?

Start

Daniel: with potassium, nitrate, and carbon and sulfur. And then you get out the same bits, but arrange it in different pattern. So you get carbon dioxide. You get atmospheric nitrogen, which is N two, and then you get [00:19:00] potassium sulfide. So you end up with the same bits, but just rearranged in different molecules in a way that takes less energy.

So you've released some of the energy. Whoa,

Jorge: that's a pretty, that sounds like a pretty complicated reaction there. Like you put in three things and then three other things come out, but they're totally different. The fire somehow triggers that. Yeah. It's

Daniel: actually a complicated multi-stage reaction.

Doesn't all happen at. And it's something people are still sort of studying and trying to optimize and they've come up recently with more fancy versions of gun powder that like don't release any smoke. So it's a complicated multi-stage reaction. Well, what do

Jorge: you mean? Multi-stage like the first, the potassium nitrate reacts with this and then something else then the charcoal comes in or what

Daniel: exactly?

It's multi-step you don't have all three things happening at the same time. First you have the potassium nitrate, which breaks down and releases the oxygen. And then that oxygen is crucial for the next stages of the reaction. Mm.

Jorge: But I guess you need something to start it, right? Like you need that spark.

And so when you light up a match, you're burning [00:20:00] the stuff in the match, which is creating temperature, I guess, heat, right? High kinetic energy things that are moving really fast. And then when you put it close to the gun powder, That's amount triggers the reaction mm-hmm well,

Daniel: these things are in a stable state as is right.

Gunpowder, just sitting on the table, doesn't give off the energy. That's stored in it the same way, gasoline doesn't or wood doesn't. But if you can trigger this reaction, if you can get it hot enough to trigger this reaction, it will release some of its internal energy. So it's sort of like a ball trapped on a shelf.

You gotta give it a little push. So it'll fall off and release all of that potential energy. And so this is all trapped, stored inside these chemicals. And if you provide some heat to kick it off, then it'll release a lot of that internal stored energy. And that release will then trigger more release from the adjacent molecules.

So it builds on itself. It's a chain reaction that way. Right.

Jorge: And I imagine it's also, you need like a, a certain amount of heat, right? Like, I'm sure if it's sitting there out there in the open, there are air molecules hitting it. And some of them are partly hitting it [00:21:00] pretty fast and it is maybe causing some reactions, but maybe not enough to really get that snowball.

Daniel: Rolling. Exactly. Although you can have that happen naturally from like lightning strikes, fires can start in the woods from lightning strikes, but you're right. Air molecules don't trigger this because they don't deposit enough

energy to get over that hump it's in a stable state, which means like you perturbed a little bit.

It's just gonna go back to hanging out in the molecules. It was in, it needs a big push to get it out of its little local stable equilibrium and over the hump to release a lot of that energy and fall into a different stable equilibrium of these products of the chemical reaction.

Jorge: All right. Well, those are the basics of gunpowder.

Let's get into how they figure into firecrackers, sparkler, and fireworks. But first let's take a quick, all right.

We are lighting up the podcast guy, I guess. In celebrating [00:22:00] July 4th here in the us and or whenever you want, he listened to this episode and we're talking about fireworks and gun powder and how that all works for a, I guess, physical chemist perspective. Are we forcing you to be a chemist in this episode, Daniel

Daniel: as much as I can possibly be.

You know, my natural state is thinking about like one fundamental particle, maybe interacting with another one. And one of the reasons I didn't end up in chemistry is that it's so many particles to keep track of all at once. It seems to be like impossible to really ever understand what's going on. You always have to zoom out and think about things statistically, which makes me less comfortable.

Jorge: Mm you're. Like a one thing at a time kind of guy. Yeah. Like drill

Daniel: down the fundamental nature and look at it, you know?

Jorge: Mm. All right. Well, we talked about gun powder. How, how it's a mixture of charcoal, sulfur and potassium nitrate. And that's somehow when you put a flame to it, it starts a chain reaction that transforms the elements.

And also, I guess, releases energy. Now, um, how is this energy released? Just kinetic energy or photons or what's [00:23:00] going on? Well, the

Daniel: energy is released both as heat, right? Because one shell of exploding gun powder heats up the next one and sets it

Jorge: off. And by heat, you mean just like kinetic energy of the particles, right?

Like a molecule breaks apart and the, the pieces fly off and different directions.

Daniel: And they're flying off with higher speeds. Exactly. That's a good rough idea for what temperature is, what heat is. It's the speedometer of the particles that are inside it. So you release this energy, meaning that instead of being bound into some molecule where you have like Springs that are compressed and tightly wound, now you've released those particles and they're flying out.

Those Springs have released their energy and they're zooming out and hitting other particles. And that creates a shock wave. Because you're hitting other particles, which then hit other particles. And that's what sound is, sound is a traveling compression wave. And so as this explodes, it creates pressure in the air and that pressure hits your ear and you hear it.

So the reason a firecracker sounds like a boom is because it's a little bomb. It's created this [00:24:00] little pressure wave, which travels out

Jorge: and hits your ear. All right. So that's the bang that we hear when you, when a firecracker goes off. And what about the flash? Like where does that

Daniel: light come from? That's again, just from the energy that's released.

Some of it gets converted into sound. Some of it's gets converted into heat and some of it is released as photon. Right. And so just like when you're looking at a fire, it's releasing heat, but it's also releasing visible light. You're gonna see some of that with your eyes. Remember anything that gets hot is gonna release photons.

It's impossible to warm up without glowing everything in physics we think of as a black body radiator, meaning that the temperature you are determines the frequency in which you glow. So things that get hot enough are gonna glow in the visible.

Jorge: I think we covered this in a previous episode, like when things are hot, the molecules are moving really fast.

And somehow that causes the electrons to drop down levels. Right. And then that's what releases thes the universe.

Daniel: Doesn't like to have high energy density likes to spread that energy out. So if a bunch of molecules with energy, either because those [00:25:00] electrons have energy or because the Mo goes themselves a high kinetic energy, or maybe they have vibrational energy in their bonds that like to spread out.

So anything that's excited will release that energy in terms of photons. And that's how things are basically glowing. Mm.

Jorge: I see when things are excited, they, they release photons and in explosion, things are super excited.

Daniel: the way kids get excited in holidays and their faces glow.

Jorge: All right. Well, um, I guess one question I had was how does gunpowder relate to bad poop?

Because I remember thinking or hearing about how, you know, originally, or, or maybe to make fireworks or gun power, you just need like, um, bad poop guano, or maybe Seagul poop. I think I've heard that too. It requires poop.

Daniel: Somehow people used to mine, guano because guano has exceptionally high amounts of nitrogen, phosphate, and potassium.

And so you need that potassium and that nitrogen to make gun powder. So, I mean gun, powder's not like something you find underground. You don't like mine, gun powder, the [00:26:00] way you mine, you know, salt, for example, you have to put it together. It's a chemical mixture of other various elements. You need to find those ingredients to manufacture gun powder, but that's basically have concentrated a lot of these things for you and delivered it to you in the form of poop.

That's

Jorge: super interesting. Right? Isn't it like, it's a biological process that actually kind of makes gun powder, right? Meaning like their poop is kind of explosive.

Daniel: well, they're essential ingredients in gun powder. It's not like they have really, you know, explosive farts or something like this. .

Jorge: Well, you don't know the bats that I know ,

Daniel: but yeah, these are essential ingredients.

And, you know, we rely on biological processes all the time to capture energy, to produce chemicals that we find important. You know, basically everybody on the planet is eating the results of biological processes that have stripped out energy from the sun and taking carbon dioxide and do this essential chemical processing for us.

So, yeah, we, we are all building on top of this huge pyramid. Of photosynthesis and B poop production.

Jorge: Yeah. That's interesting. Yeah. I [00:27:00] guess when you eat a salad, you're kind of ingesting, you know, prepacked, uh, energy packets, right. Prepacked by another biological being. Yeah,

Daniel: exactly. It's this like pyramid of energy processing and chemical conservation to take that energy and stored in a useful way.

And it's much more economically feasible and easier to just gather this from biological process. To synthesize this in the laboratory in a pure way that could be done, but then you'd have to do the bats job for them.

Jorge: Yeah. Uh, no, thanks. I wouldn't wanna be, you know, poop for a living, I

Daniel: guess. I think bats eat a lot of fruit, right?

So that doesn't sound too

Jorge: bad. Oh, there you go. I guess I wouldn't want to, you know, go to that fireworks display featuring, uh, fireworks made only from a cartoonist poop.

Daniel: no bats or cartoonists were hurt in the making of this firework

Jorge: but anyways, one thing that's interesting here that you wrote down is that gun powder and firecrackers and fireworks in general are slow, explosive.

What does [00:28:00] that mean? So the

Daniel: speed at which the explosion happens, determines a lot about how useful it is and what it can be used for T and T and other related chemicals.

Those are actually more explosive. And so the speed at which this thing blows up, determines whether you're getting like a big shock wave or a bang.

And it's interesting that black powder is better for fireworks because it blows up more slowly than dynam. Yeah, by a lot, right? Yeah. Black powder blows up at like a hundred yards per second. That's the detonation velocity and dynamite has a velocity of detonation more than a thousand yards per second.

So 10 times as

Jorge: strong. Yeah. It's super interesting because, you know, I think to us as humans, with our limited kind of capacity to these, to see things and perceive things, you know, to us, they're both just explosions, but I guess if you had like a super duper. Fast camera. You would see the difference between a T and T explosion and a fireworks explosion, right?

Like one of them would be 10 times slower. So does that mean that then firecracker explosions are less [00:29:00] dangerous, but they they'll still blow up your fingers or if you put enough of them, they'll still blow up a tank for

Daniel: example, right? Yeah. They're both explosives and you definitely don't wanna mess around with either of them.

They're both definitely dangerous, but they produce a different sort of character of explosion. So you get like a longer duration of the explosion. And I think you get a different mixture of light and sound because the explosion is slower. So I think it's more time for this stuff to heat

Jorge: up. And I guess if it's faster too, it's also more destructive, right?

Like you're concentrating more energy in a smaller place, which is probably better for, you know, destroying things.

Daniel: yeah. When you wanna like crack open a rock than you wanna convert most of the energy into high pressure waves, whereas with a firework, you don't wanna produce as much pressure cuz you don't wanna like pop people's Eard drum.

So you want more of the energy to produce bright flashes of light, which requires heating this stuff up. So you actually want a lower explosion velocity so that the stuff actually gets hotter. Mm

Jorge: interesting. And so that's what a gun powder is. And that's what a firecracker is. You just take a bunch of gun powder, put it in a little package and I guess have [00:30:00] a attach a fuse to it.

Right. Which is really just a string. And so when you light up the string, the fire. Kind of travels along the string and then eventually it hits the gunpowder.

Daniel: And one nice thing about black powder and gunpowder is that it's sort of insensitive to friction. Like if you have a pile of it and it rubs against itself, it doesn't just set itself off, which is good.

You want it to only blow when you want it to blow. And so what that's, what the fuse does is it delivers that first spark of energy to get the reaction

Jorge: going. Right. Oh, I see. Well, by ING, I think you mean like dropping it, like you don't wanna drop a firecracker and have it explode. Like, I think if you drop a, a stick of T and T it could blow up, right?

Yeah.

Daniel: T and T is much less stable gun powder. If it rubs against itself, won't blow up that you can blow up gunpowder without a spark. Right. You can just use percussion. That's how a gun works. Right. Black powder gunpowder is in the back of the bullet and then the hammer comes back and hits the back of the bullet.

And that actually sets off the gunpowder. So you can set off gunpowder without

Jorge: a. Oh, interesting. Well, I think these days in bullets, they [00:31:00] use a little, like the back of the bullet has something that causes a spark. But I think maybe you're thinking like way before, when they would use, like, they would literally pour gun powder into the gun, then just hitting it.

Hitting gun powder makes it at ignite. Yeah. Sun

Daniel: firing guns. Just have a hammer, right? There's no spark in a lot of those guns. There's a huge range of technologies though. All

Jorge: right. Well, those are firecrackers that kind of go pop up up. Um, but now let's talk about sparkler. I think these are my favorite from when I was a.

I'm still a fan of sparkers sparkers

Daniel: are super fun because you can hold them. Right. It makes them feel much more immediate, like a firecracker. You said it and you run, it goes bang. But as sparkly, you can hold it, you could wave it around and you can like draw on the air with a light because the impression stays in your retina for a while.

And it also lasts for a while. You know, it can burn for like 30 seconds or a minute. So those are definitely one of my favorite childhood memories. Yeah,

Jorge: they're pretty cool. And if you're not familiar, I guess they're like a stick. There's usually like a metal stick and the top half of it is covered in some sort of gray stuff that just makes it sort of look like [00:32:00] a corn dog, I guess.

right. like a gray long corn dog. Although you don't know what a sparker looks like. You probably don't know what a corn dog looks like either.

Daniel: It looks really gross. It does not look like a corn dog. It's like totally gray and metallic. It's completely unappetizing. Oh

Jorge: boy. Did I just insult. Corn dogs. are you a big fan of corn

Daniel: dogs?

It doesn't matter how much mustard you put on that thing. It's not gonna taste good.

Jorge: it's gonna, it's gonna sparkle though, in your mouth. So the way these works is that, um, you take a sparkler and then you light up one end, but it takes it. Sometimes it takes a while to light up, right? Like it's not like you put the flame to it and it immediately starts sparkling.

You kind of have to wait a little bit.

Daniel: Mm-hmm it's not like a fuse that immediately goes, you gotta get it like hot. To really start. And a sparkler is sort of like a slow motion, firecracker. Like it's got the same basic material inside of it. Again, it's black powder and doing a lot of the work, releasing energy.

That's like the fuel that powers the sparkler, but then it's got stuff inside of it, which sparkles and [00:33:00] also stuff that slows down the reaction. So it doesn't just like blow your hand

Jorge: off. Mm. Right. I it's sort of diluted in a way. That's the idea to slow it down. You, you mix it with other things that don't explode.

Daniel: Exactly. You modify this mixture of like potassium, nitrate and sulfur and charcoal so that you get a slower explosion. Sometimes adding more sulfur or more charcoal reduces how fast the oxygen is released. And so you can tinker with those mixtures to get a different speed of the reaction, essentially.

Jorge: Mm. And then for the sparkler, you actually mix it with sugar, right? Like there's sugar on that

Daniel: thing. There is sugar in there. That's mostly just to hold it together. To make it like a goop and not just like a powder, but the reason that it sparkles is sort of weird. They have metal powder in there, like you put aluminum or steel or something in there.

And then that steel gets really, really hot. And it glows for the same reason we talked about earlier. You take metal, you heat it up. It's gonna glow. And so here you have metal powder, which gets heated up and that's, what's actually making those little [00:34:00] sparkles that shoot out. Oh,

Jorge: interesting. It's the, it's the metal that heats up.

Well, there's a central flame in the middle, right? And then that's the big, bright thought that you see in a sparkler, but then there's other things shooting off of it. Uh, these sparkles basically, and you're saying the sparkles are metal, that's getting super heat up by this central kind of flame. Mm-hmm , it's

Daniel: basically tiny bullets, right?

A sparkler is shooting super tiny little pellets of hot metal. It sounds like a terrible idea. Right now, give this to kids and let them run around. But these things are so small, they burn up quickly and basically vaporize. But if you do put your hand really close to a sparkler and you will feel these tiny little hot pellets hitting your hand, it's not a

Jorge: great idea.

Well, what's interesting is sometimes it sort of looks like a, almost like a snowflake pattern, right? Like, you'll see a big stream of, uh, sparkle and then that will divide and then those will then divide in itself making sort of like this beautiful tree, like almost snowflake. Pattern

Daniel: mm-hmm , it's sort of like [00:35:00] fractals, right?

They keep breaking down into smaller and smaller pieces and that's those little bits of metal getting heated up. And if they're big enough, they'll split in half before they completely vaporize and then maybe split in half again. And so you get these really cool patterns and they're ephemeral, right?

They don't last very long. They all happens very, very quickly, but long enough for the pattern to remain in your eye. So it's really a beautiful effect. And

Jorge: I guess, why does it need to be metal that, uh, heats up? Like why does metal. Give off light when it gets heed up more than other things like carbon.

Daniel: That's a good question. I think you use metal because it doesn't burn. Right. It just heats up and vaporizes. So it like absorbs the energy and then gives it off as light rather than like contributing to the explosion itself. So it's fairly inert that way. Chemically, it's not getting modified, it's just getting heated up and vaporized.

Jorge: Cool. All right. Well, and, and so you heard it from Daniel sparklers have sugar in. So, um, no, I'm kidding. Don't give, don't give him a try. do not. And don't put your hand. You're too close to one. If your little child [00:36:00] we just give him bad advice here today, Daniel. But they are super fun and they are super cool.

And so the next time you look at one, you know, think about all the processes that are going on in there. Right? Let's get into now how far works, the big ones, the ones that, um, light up this guy and have all these amazing displays and colors, how they work. We'll dive into that. But first let's take another quick break.

All right. We are celebrating, I guess, July 4th, Daniel, this episode will come out around July 4th.

Daniel: Mm-hmm yeah. And all the summer holidays, you know, on France, this best deal day. And it feels like a lot of cultures. Have a reason to set off fireworks in the summer.

Jorge: Right. Right. Who doesn't love a good explosion?

Daniel: the particle physicist in us.

Jorge: well, the, well, all right. I won't get into it anymore. I'm debating you. Go ahead. Smashing and [00:37:00] exploding. Daniel. I'm

Daniel: just trolling. You.

Jorge: May should have call it the big smash instead of the big banks, since it all means the same to you. Anyways, let's be more confusing. Sounds good.

Let's do it. . How about the small, the small smash that needs to be extra, extra confusing.

Daniel: The micro smash that started it all.

Jorge: The small smash they're formerly known as the big bang. ,

Daniel: that's what we need to change the name of something. Everybody already knows the name of now so that some people can say, actually it's now called

Jorge: Are, are you, are you mocking chemist or physicist with that voice

Daniel: physicist? Definitely both. Both. I would never mock chemists because they're better at making poison gas and bombs than I am.

Jorge: I see. Right. You don't wanna lose that chemistry with. All right. So now let's get into now fireworks. Now this is the question we started off at the beginning.

So these are the ones that most people think of, you know, in July 4th or, or Bastille day, they throw these up in the [00:38:00] sky. They light up the sky. There's all kinds of colors nowadays. There's all kinds of shapes too. Yeah, they're

Daniel: very dramatic. And fireworks are basically a combination of everything we've talked about so far.

They're a combination of sparkler and firecrackers, and then all wrapped together in a little mini rocket. One of the essential components in fireworks are these things called stars, which again are not the burning balls of plasma in the sky. There's something totally different. They're like sparkler, like stuff formed into little

Jorge: balls.

Oh, interesting. You're saying a firework. It's like a bunch of sparkler stuffed in with an explosion.

Daniel: Exactly. When you see the firework in the sky, you see it sparkling, it's a sparkler up there. And so the way you make a firework is that you pack a bunch of little balls of sparkler together into a little tube, and then you also fill it with black powder, which sprays all the sparkler out when it explodes.

And that's what makes your pattern in the sky?

Jorge: Oh, interesting. Really. So I, I guess, I mean, I'm not saying you should do this, but you could do this. Like if you put a bunch of sparkler [00:39:00] in with a firecracker, you could make your own firework kind of that's what a

Daniel: firework is. Exactly. It's just sparkler stuff packed in with black powder, those high precision in order to get it to explode in just the right way and at the right time.

And then you also have to somehow launch it up into the air. So it's a bit of a complicated construction, but those are the essential ingredients, black powder and sparkler stuff. I

Jorge: see. Well, let's break it down. How does the rocket launching part work? Is it like a rocket rocket?

Daniel: No, it's more like a gun.

You have like a steel tube with black powder in the bottom. And then the firework is sitting on top of that. So you light some black powder in the bottom of the tube and that explosion like a firecracker inside of it sets off the firecracker to fly up into the sky. And at the same time lights the fuse at the bottom of.

So that's how you launch the thing up. It's just like a little gun.

Jorge: Oh. But it's not like a gun, like it's not an explosion that propels it upward. Right. It's more like a controlled, you know, like a real rocket, right? Like it's not like a big bang. It's like a sh [00:40:00] right? Like it has to, you know, expel the propelling slowly kind of.

Well, no,

Daniel: the explosion happens at the bottom of the tube. It's like a mortar. Right. And that explosion pushes the firework up. It's not like the firework is burning on its way up and pushing itself. It's more like it's gotten thrown up it's on a projectile motion, just from the initial explosion that pushed it out of the tube.

A rocket has like continuous burning. That's pushing it up, has thrust, but a firework doesn't it's just like thrown up by this tube. More like a

Jorge: mortar. Well, maybe that's some of them, right? I think some of do use sort of a rocket, like a thing don't they? Yeah. You can

Daniel: definitely buy some fireworks that you can light off yourself that are like bottle rocket.

Right. That are propelled by those, the kind I'm thinking about, know the big ones you see at the displays. Those are almost all just projectiles that are fired up by an initial explosion. But yeah, there are some versions that are like more like rockets that have a continuous explosion.

Jorge: Mm. I see. Well, I guess it's, it's gotta be tricky because you, you wanna explode something [00:41:00] or rocket something at the bottom, but you don't want it to somehow.

You know, burn up your gun powder and sparkler that are at the front.

Daniel: Exactly. So they pack it very carefully and they have like multiple stages and they have fuses that have time delays. So they have materials that burn at very well known rates. So you light this fuse and you have like four seconds before it gets to the top of the firework and sets off the rest of it.

So you're right. It's a very delicately balanced system.

Jorge: Yeah. And it's interesting what you said, you gotta time it, right? Cuz you want. The fireworks to explode and give you all the sparkles, like at the very top, not as it's going up or right. As soon as it takes

Daniel: off. Yeah. And some of these things happen like two or three different stages, so they'll blow up once and then they'll blow up again at the top.

And then on the way down, they blow up one more time. So people have gotten really advanced with the technology for how to put these things together, to make the most spectacular displays in the sky. But it's all about how you package this. So the explosions happen at the right time. Right?

Jorge: They can even make things like a smiley face, right.

They can make a firework that blows up into a smiley face. Yeah,

Daniel: [00:42:00] you can, you can make all sorts of crazy shapes and the way they do this is by very carefully arranging those stars, these pieces of sparkler inside that tube and arranging the black powder around them in just the right way. So when it blows up from the center, it ends up shooting those things.

In just that right pattern. Cuz when that black pattern goes off, it then sets off the sparkler, which then glow. But it must take a lot of experimentation exactly how to arrange those stars inside the firework to give you that reaction. I imagine they must fail a lot that, or they've done some like really complicated computer simulations to figure out exactly how to build these things.

Mm. Interesting.

Jorge: What do you think it is?

Daniel: Well, I think these things have been around for a lot longer than fancy computers. So initially it must have just been trial and error. You know, people like had an artistic skill at this, you know, coming up with clever things that you can do with your limited ability to arrange the stars inside the fireworks, and then people being creative and discovering new stuff these days.

I bet they could use computers, but I'm not sure if anybody's doing. [00:43:00] Yeah, I

Jorge: guess you, you know, to get a circle, for example, for a smiley face, you just kind of arrange the sparkers in a circle around your explosion. Right. You're explosive. And then when they blows up, it'll come out in the circle. Mm-hmm

Daniel: and if what you want is a heart, then you move some of those a little bit further away.

And some of those a little closer in, so they burn up sooner and some of these things are not like a circle or a heart. They're like a big flower, like a Conantum. Right. And for that, you just have like stars

Jorge: everywhere. All right. So then how do the, how do the colors work? How do you get different colors of sparkler?

Daniel: So the colors come from the different kinds of metal inside the sparkler. Remember the reason the sparkler sparkle is because you have metal powder. That metal gets really hot and then it glows, but these metals are made of different elements. So they tend to glow at different frequencies. Is these metals have different energy levels that they like to release photons?

So different kinds of metals will glow in different colors. And, you know, for example, if you sprinkle copper powder into a flame, the flame turns green and so different metals give you different [00:44:00] colors. Mm. Where

Jorge: does that come from? I guess, I guess, because when it's it, when the Fullton comes out of the metal.

It comes with a specific frequency, which is related to its

Daniel: energy. Just like if you look at a star, you can tell what it's made out of based on the frequency of light that's coming to you from the star. And that's because different elements, glow with different fingerprints. And that comes from the energy levels of the electrons going around the atom and also in more complicated situations from rotational or vibrational modes of a molecule.

But usually it's just from the energy levels of the atom. And those are all different for different element. So you get different mixtures of colors for different

Jorge: elements. So for example, if I wanted an orange firework, what would I use

Daniel: then? You'd

Jorge: use calcium, calcium. Oh, that's a metal, right?

Daniel: Mm-hmm and these things don't have to be metals, right.

They just have to be elements that can accept heat and not participate in the reaction. Mm.

Jorge: What about like, uh, red, red? You

Daniel: can either use lithium, which is gonna give you like a medium red or [00:45:00] strontium for like a really intense red. Oh, cool.

Jorge: What are some other colors?

Daniel: So you can get like yellow from sodium or green from barium.

Copper actually gives you more of a blue than a green. You can get violet from potassium or rubidium. You can even get gold colors from charcoal or iron things like aluminum or titanium tend to give you white. So you have a whole pallet to play with. If you're the person designing these fireworks.

Interesting.

Jorge: It's almost like you're painting with, um, material. Right.

Daniel: And a lot of these things are made sort of by hand, like they are these fireworks masters that pack these things together and very carefully mix the ingredients to get exactly what they want, uh, you know, magnesium or aluminum or whatever.

So they tend to make these things sort of by hand and cut them into these pieces. And that's why some of these things are very expensive because they're like fabricated by artisans. Whoa.

Jorge: It's like organic, you know, artisan fireworks.

Daniel: somebody with like a wax mustache and a long beard is [00:46:00] making this out in a Brooklyn warehouse right now.

You're,

Jorge: you're assuming they're hipsters now. far hipsters , but I wonder if that's a stressful job, you know, dealing with explosives, cuz you're, you're sort of crafting this thing by hand of something that could explode at any moment.

Daniel: I'm sure they have good insurance.

Jorge: well, I don't, I don't know if having good insurance, but makes me wanna, uh, do something dangerous.

It's almost the opposite. If you need good insurance for something, maybe you should, be doing

Daniel: it. Yeah. Maybe not, but you know how it is. Everybody gets inspired by something different. And for some folks, this must be like a deep passion, you know, the mixture of chemistry and artistry together probably really satisfying for a lot of folks.

And then you get to display your works. Everybody goes, Ooh. Right. Almost everybody loves fireworks. So you must be very

Jorge: popular. That's right. Almost everybody except, uh, you, I guess but what about the ones that, you know, sometimes you see these, like they explode and then the little bits explode themselves, you know, like, like a multi-tier explosion, almost like it explodes and it gives us sparkles, but then the [00:47:00] sparkles.

After a little bit explode themselves into other colors. How do they do that? Yeah,

Daniel: that's all in the packaging. You can make like little cardboard packages that have sparkler inside them and they're surrounded by sparkler. And so initially the outside sparkler go and then when those burn, after a while they heat up what's inside, which can then burn.

So it's all about timing, these multi-stage reactions. And you do that based on how you're packaging this fire.

Jorge: Right. Right. And something interesting you just said is that these things are made out cardboard, right? Like you, you kinda have to make him out of materials that burn up, right? Like you can make a firework out, put like a steel

tube or a steel plate on it because that thing's gonna fall back down, maybe hurt somebody.

Everything has to be made outta

Daniel: paper. Mm-hmm and it has to be the right strength to hold the stuff together, but not so strong that it can't explode. Right. And so cardboard and paper is actually just about the

Jorge: perfect strength. Wow. So you need to be like a paper artisan, too. .

Daniel: Yeah. I don't think we're like 3d printing fireworks or anything.

Ooh.

Jorge: But not yet. you just [00:48:00] came up with an interesting idea there. I wonder if you can get more precise sculptures, if you, if you do 3d print

Daniel: them. Yeah. You might be able to guide the sparkler in exactly the right direction. You could have like tubes or sparkler guides or something to get them to do crazy stuff.

I think 3d printing and computer modeling, probably the future of artisanal firework. Wow.

Jorge: Yeah. You could have like a firework that explodes into a photo of your face or something. Yeah.

Daniel: Or the cat video that everybody's been wing and waiting

Jorge: for. Oh my gosh. That would be nice level like animated fireworks.

Can you imagine like fireworks and move? Yeah, that would be pretty incredible. Sounds like something outta Harry Potter. Maybe. Yeah, 4d fireworks. Well, nowadays it kind of seems like the future of these displays are drones. They're using drones more and more, and they're almost kind of as imp and you can do CAD videos, uh, with drones.

Daniel: Yeah, you actually can, and they're not explosive and they don't release toxic chemicals into the air and nobody gets blown up. So drones are pretty nice alternative. They're like the

Jorge: green alternative to artisanal organic [00:49:00] fireworks. It got out out greened and I

Daniel: love a firework display. Like anybody else?

The thing that I wonder sometimes when I watch fireworks displays is all those people taking videos of firework displays. I'm always wondering, like what percentage of those videos is anybody ever watching?

Jorge: well, you can ask about any video ever taking Daniel. If you take a video of your kid eating a, a pizza slice, you know, you're not gonna wait watching that later, but you wanna capture the moment.

I do

Daniel: go back and watch silly videos of everyday moments of my kids back when they were really young. And I think, oh, that's nice to get transported back to that day, you know, remember what they were like, but I don't watch fireworks videos, you know, with nobody in them and go, oh yeah, I remember that explosion.

That was really cool. Mm,

Jorge: well, that's because you're a fireworks. GRMP Daniel , nobody would expect you to where you watch something. It's something you don't like. in fact, more people would probably say, Ooh, to that video than to your kids eating pizza. Honestly, if

Daniel: I invited people over there probably rather see a [00:50:00] fireworks video than an old video of my kids eating pizza.

Jorge: Yeah. Especially your kids. They don't wanna do that stuff. all right. Well, that was an explosive conversation full of, um, sparkling conversation. Yeah, and we

Daniel: hope that illuminated for you, how people have been using physics and chemistry to brighten up their lives and their celebrations, even before they understood how it worked.

Jorge: And I hope that confluence of physics and chemistry, uh, really add a little pop to your day there or night.

Daniel: And I hope my distaste for fireworks. Doesn't blow up your experience.

Jorge: What's not to like Daniel, they're big, they're explosive and they're bright sort of like the universe, right? the big smash.

Exactly.

Daniel: All right. I give up, you win.

Jorge: All right. Well, we hope you enjoyed that. Thanks for joining us. And, uh, we hope that next time you look up at the fireworks display, you kind of think about all of the physics and chemistry that's that's going on and all the artisanal skill that went into making those fireworks

Daniel: and have a happy summer fireworks season everybody and stay

Jorge: safe.

Yep. Take a video and send it to Daniel. for him

Daniel: to enjoy it. I'll [00:51:00] edit them all together and put them on my. For somebody to download and watch 12 hours of fireworks.

Jorge: that does sound pretty good. I think that's called a screensaver. Maybe. I think they invented that already. Anyways. Thanks for joining. See you next time.

Daniel: Thanks for listening. And remember that Daniel and Jorge explain the universe is a production of iHeartRadio for more podcasts from iHeartRadio. Visit the iHeartRadio app, apple podcasts, or wherever you listen to your favorite shows.