MITOCW | Investigation 3, Part 6

MARK HARTMAN: Light production models, right? And before, we said in general, bouncing charged particles produce-- oops, I can't spell produce. And I'm going to do this so you can all see me. Produce photons. Hi, Juan. OK. So this is our general model. Bouncing charged particles produce photons.

This idea, one particular model of thermal light production is this idea of bouncing charged particles. But there's a particular model that we're going to look at, and it's called the black body model. Black body model of light production. OK? And this black body model, it's actually a pretty complicated idea. It's got lots of different parts. It has to do with quantum mechanics.

It's called a black body because it talks about that this object absorbs all radiation or absorbs all light and doesn't give any other light back. There's a lot of different parts to this, but we're going to simplify it so that we can think about it in terms of our objects. So we are going to say the black model applies-- oops, a-p-p-l-i-e-s to an opaque object.

Has anybody heard this word, opaque? Bianca, what does opaque mean? Nice and loud.

AUDIENCE: It's, like, semi-transparent.

MARK HARTMAN: OK. Semi-transparent. What do you think, Steve?

AUDIENCE: Doesn't allow light to pass through.

MARK HARTMAN: OK. It doesn't allow light to pass through. So we've got transparent, which means light can go all the way through. Translucent is this idea that some light can go through, and I think that might be what you're thinking about, Bianca. But opaque means that you can't see light from an object on the other side. Like, a shirt is opaque. A person is opaque.

A window is transparent. You can have light pass through that. So we're going to say applies to an opaque object. Opaque means you can't see-- well, let's just say light does not pass through. OK. So let's think about it. Is the sun an opaque object? What do you think? Why is the sun an opaque object?

AUDIENCE: Because light can't go through it.

MARK HARTMAN: Light can't go through. We can't see stuff on the other side of the sun. The sun does produce its own light, so it produces the light from the surface. So the sun is an opaque object. We can't see through it. Light doesn't pass through it. Light is produced at its surface.

What about a supernova remnant? How about a supernova remnant group? Have you guys seen pictures of supernova remnants? Can you see stuff on the other side of the supernova remnant? Say it again?

AUDIENCE: Some of them you can.

MARK HARTMAN: Some of them you can. What do you think? Do you agree, Lauren? Yeah. So if you take a look at a picture of a supernova remnant, sometimes you can see stars on the other side. So supernova remnant is not an opaque object. What about a galaxy cluster? Clusters group?

AUDIENCE: Well, the space in between you would be able to see from more distant objects.

MARK HARTMAN: OK. OK. So you can kind of see there's light coming from the other side. So this is an important idea, this opaque object, which means it has a surface that produces light. OK? So we're going to say it applies to an opaque object. It has a surface that produces light. The sun's surface produces light, and it produces light because it has this thermal motion.

This is the simplification here. We're going to say charged particles bounce around inside the object and when-- let's say and by the time the photons reach the surface that bouncing has created a distribution of light.

Now, we're going to say has created a distribution of light. We had a special word for that last Friday. What did we call the distribution of light or the composition of light?

AUDIENCE: Spectrum.

MARK HARTMAN: A spectrum. Right? We said a spectrum was how many of each different energy of photon are we receiving? So that bouncing has created a spectrum that depends only on temperature, not what the material is made of. Not what the object is made of. It's not the world's greatest sentence, but I think it gets across the point. It's a very long sentence.

So let's look at each part in turn. OK? Charged particles bounce around inside the object. So if we look at our model of sodium chloride, we are seeing these bounces happen. Photons are produced from each one of those bounces. A hard bounce produces a high energy photon, a not so hard bounce produces a low energy photon.

Those photons then bounce around inside too. And by the time that those photons have bounced around to reach the surface, the bouncing creates a spectrum that depends only on temperature. So if we were to take an iron, say, a piece of iron and say, a piece of aluminum and we heated them up to a really high temperature.

The spectrum that we would get from the iron and the aluminum would be the same. It wouldn't matter that it was iron versus aluminum, at least not for this kind of spectrum. Now, we'll see later on that some spectra have to do with what objects or what elements are making up that object.

But here, we're just saying anything that's really hot, it doesn't matter. It gives off the same amount of light if it behaves like a black body. Now, let's think for a minute, though, because here we've got a solid object. But is the sun a solid? Is the sun a solid, a liquid, or a gas?

AUDIENCE: It's a gas.

MARK HARTMAN: It's a gas? It's actually not a gas. It's a plasma, which is a gas of ions. So even though here we're talking about a solid thing, we can have a black body that is made of gas. But the gases is dense enough that the light still doesn't pass all the way through. It still has a surface. OK? So when I think about this black body model of light. That's one way or one of our models that we're gonna think about.

Shakib, can you bring up our other, our non-thermal model? Let's take a look, so scroll down a little bit. And let's play this animation again. So click to animate. So we were saying before that if we had charged particles that were spiraling around a magnetic field, that they would produce photons as they bounce, right? And just as a quick little review, I want to show us again.

So can we change-- let's do group A to video. So again, let's take a look at this demonstration where we have charged particles that are being produced. Actually, let's turn the lights down a little bit more. And we saw that if we change-- see if we can get it here. Right. There we can see that if-- what I'm doing right now is I'm changing the strength of the magnetic field.

If I turn the magnetic field so that it's very strong, I'm causing these charged particles to move in a smaller and smaller circle. If I make the magnetic field less strong, I can make those charged particles move in a larger circle. But they're moving in a circle, and if we look from up above-- let's open up iris a little bit more. Here, we see-- let's turn it to the side.

There, we can kind of see this helix shape. Can we all see that it's making kind of a two-- a spiral shape? Because if our magnetic field isn't perfectly in line with that circle, it's not just going to make things do a circle. It's going to make things do this spiral shape. There, the spiral shape is on one side, and then if I-- I'm tilting my bulb here, and now, you can see the spiral shape on the other side.

So now, the spiral shape is back on the first side. So if you have a strong magnetic field, you're not causing objects to bounce because they have a certain temperature. But you've got some outside force that's causing them to bounce in another way. Hey, Shakib, could you turn the lights back up? And we saw that these charged particles are being moved or being caused to spiral by that magnetic field.

Now, we're going to introduce another model for a spectrum. So this is going to be a model that's called model two, that was model one. Model two, we're going to introduce a power law spectrum model. Now, this is really, really important. The power loss spectrum-- thank you, Shakib. It's just a mathematical model.

It actually is related to a bunch of different physical ideas, like this idea of a particle spiraling around a magnetic field. But this is just a mathematical model, and the mathematical model is actually it's the intensity. Remember, we said intensity is equal to the energy to some power, to the power of x, OK? In a very simple way.

So what that means is if I had intensity as a function of energy, if I wanted my power law to be intensity equals energy to the power of two, I could just say, OK. Well, that's just a quadratic graph. So my intensity is a function energy would go up like that. If I wanted to say that my intensity was maybe just equal to energy to the power of one, what kind of a graph would that be? Bianca? I saw you draw it in the air.

AUDIENCE: Where x equals y.

MARK HARTMAN: OK. This is just y equals x. Anything raised to the one power is still that same number. So in this case, it would just be a line, right? Has anybody ever seen intensity equals energy or y equals x to the power of minus one? It-- would it be negative? So let's think about this. Intensity equals energy to the minus one. That's the same as saying one over the energy, right?

Let's say-- oops I didn't want to do that. I wanted a different color. Let me make it a little bit clearer. The intensity equals energy to the minus one, which is equal to one over the energy. Say that we had an energy of one electron volt, two electron volts, and then out here would be four. And there's three, right?

If our intensity is equal to one over the energy, if the energy is one, what would be the intensity? 1/1, so one. Right. What about if the energy is two electron volts? What happens to the intensity? It's one half. 1/2. So here, we've got one half. What about three? If the energy is three, what happens to the intensity? Does it get bigger or smaller? Smaller. You get 1/3. What happens if it's four? 1/4. It gets smaller.

Will the intensity ever go to zero? It would just get smaller, and smaller, and smaller. As this number energy gets bigger, the shape of the graph, what happens if we went to an intensity where-- I'm sorry, if we go into an energy of 1/2, we'd have one over 1/2, which is the same as one times the reciprocal of 1/2. So one times 2/1, which equals 2.

So at an energy of 1/2, I've actually gone up. So if anybody's has ever seen an inverse graph, it looks like this. OK? So if we have intensity is equal to energy to the minus 1 power, we get a graph that looks like that. Now, you guys are going to have a chance to play around with this in just a little bit and actually try to fit this model, but I wanted to point out one or two other things.

When we have this model intensity equals energy to some power, to the power of x, that's why it's called a power law. Remember, a law, we said, was just something that said this is what always happens. So in this case, we're not explaining why it looks like this. We're just saying the mathematical form looks like that. So we're also going to say that this number, x, we're going to say x is the power law index.

What does an index, like, if you just hear that word in normal everyday language. What do you, Chris, what's an index? OK. Like a little index card. If you've ever gone to the library and actually used the card catalog, they have lots of index cards there.

AUDIENCE: It's just like a listing. It's like a listing. Not meanings, but, like, information. So, like, topics or something.

MARK HARTMAN: Yeah. Like that in the back of a book. An index is where are all the topics in the book. It tells you what's important in the book and where is it. Well, the power law index here tells us what's important about this equation. We know the general form, intensity equals energy to some power, but this is what's telling us well, does it look like that? Does it look like a straight line? Does it go up? You know, something like that.

So x is the power law index. And even though I said this is a mathematical model, we're going to say one interpretation-- because there's a bunch of different processes in astronomy that could lead to a power law model. And sometimes, you know, perhaps they can be very different. You know, this one right here, this line looks very different from this line over here.

So there's different processes. One possible interpretation of a power law is, and this is a model of light production. We're going to say synchrotron radiation. Has anybody heard of this? A couple of people may have heard about that in their expert projects. Maybe not. So synchrotron radiation is a light production model.

You know, this is just a mathematical model, but synchrotron radiation is an actual light production model, just like the black body model was a light production model. The black body model also has a mathematical form, but it's a little bit tough to understand or to interpret in the same way. So it's a light production model, and the synchrotron is this idea of particles bouncing up and down around a magnetic field.

All right. So you would expect this model to fit. I mean, we are going to change this parameter. We're going to change the power law index so that it fits well, but if you had an object like a supernova remnant that did have strong magnetic fields, you would expect well, maybe there was some synchrotron radiation there. OK? So this is the basics of these two models.

We've got a thermal model, which is the black body spectrum. We've also got this idea, this mathematical idea, of a power law spectrum, which is much more generic. And when people do astronomy, sometimes they want to fit things to mathematical models first, and then they'll think about, OK. Well, let's just describe the spectrum first. Then, we'll think about, well, what's actually going on?

Because you could get a power law model but not have synchrotron radiation. In our case though, in some cases here, we're going to see synchrotron radiation. And that's what we're going to use this power law model. All right. I wanna show you guys one instance of how you're going to try and fit data to models. So you are going to, on your screen-- actually, are there any questions first? Go ahead, Lauren.

AUDIENCE: In the equation, intensity equals energy to the x power, can x equal zero?

MARK HARTMAN: OK. If x equaled zero, what is anything raised to the zero power? OK. It can, and you're actually going to play with that in just a minute. So I want you to keep that in mind when you're looking at this. Any other questions? That's a great question. OK. So here's what you're going to do. I'm going to do the first example for you, and then we're going to have our fellows come around and work with you for just a few minutes.

So you're gonna open up Spectrum Explorer. So I need everybody-- well, don't open it up just yet. I want you to just watch what I'm doing. And I am, just like we did last week, going to look at the spectrum of the sun. But first, I'm going to change my x-axis dimension to energy, and then I'm gonna change my range to-- what did we say-- 0.1 to 6.2.

I'm going to pull up, under astronomy data file, and of course, it's going to take a long time. There we go. And I pull up my data about the sun, and I say, OK. So this is what our spectrum of the sun looked like. The sun has a certain way that it produces light. We don't know exactly what it is right now, but let's try our two different models.

We are going to say, all right. You'll see here at the bottom it says add. It gonna say black body, power law, data file, drawing. We did a drawing. Element, we're going to worry about that later. So let's add a black body. So this is a black body model.

And what we see here-- yeah, don't worry about this information down at the bottom just yet. What we see here is a temperature gauge, and it goes from 0 Kelvin all the way up to 15,000 Kelvin. We said that the black body model depended only on the temperature. Doesn't matter what the object's made out of.

So what I want to do is, if I looked at the black body at a very low temperature, why do I get this shape? Why do we get-- why do I get intensity at low energies if I'm looking at a low temperature object? What do you think? Juan?

AUDIENCE: Because red's a low energy.

MARK HARTMAN: OK. Red is a low energy, so I'm getting more red photons. Right. There you can see up at the top. You know, I've got only red, and I don't have a lot of any of the other colors. Where does each one of these photons come from in the black body model?

Let's take a look back at atoms in motion. If we have a low temperature, we say go down 10, what did we say about the number of collisions and how hard the collisions are? Go ahead, Nikki.

AUDIENCE: Less collision and less [INAUDIBLE]

MARK HARTMAN: So what happens in the number of collisions and how hard the collisions are?

AUDIENCE: Like, they don't collide as much, and they don't bounce that far.

MARK HARTMAN: Yes. So if you have low temperature, the bouncing isn't as hard. And if the bounces aren't as hard, then each photon that you produce is not going to be very high energy. So if we look just generically here, we look at a low temperature object. We're getting a lot of low energy photons down here at one electron volt, but not a whole lot out here at four electron volts.

We're still getting a range because the bounces that happen inside the object, not all of them are the same, you know, strength. You're not bouncing as hard with every atom. So-- but if I turn the temperature way up, what happens, you know? If I'm all the way out here, why do I have so much purple, but not so much red? What do you think, Chris?

AUDIENCE: Because all the bounces you can get the really hard mass, so it's going to get higher energy than soft bounces.

MARK HARTMAN: All right. So if we have a higher temperature, obviously there's going to be more bounces. There's going to be harder bounces, so you're going to get higher energy photons. So what we mean by fitting a data or fitting a model to data is this process. Here we have our data from the sun. Now, this model is applicable. You know, the model is shown in red.

We can-- I mean, it's still a black body over here. It's still a black body over there, but the black body has a different temperature. Let's adjust the temperature until it fits or goes near most of those data points. Right? Because right here, I'm pretty close, you know, my model is pretty close to the data. And over here, yeah. Maybe it's not so good.

So maybe I could, you know, maybe that fits a little bit better. So that's at a temperature 5,000 or turn it up. You know, if I fit the one on the left there, we're at a temperature of 6,000. 6,400. Excuse me. So if I'm right here, somewhere in the middle, that is a pretty good fit to my data. My model is pretty close to most of my data points. So this model fits pretty well. Now, let me take a look at a power law model.