PROFESSOR: Our guiding question through this investigation is going to be why is light produced? What can we tell about the source? Right? If we're looking at these bulbs over here. If we looked at a bulb, and we saw that it was just glowing red, we can tell that it was probably a low temperature without actually having to go up there and touch it. So we're going to think about how is light produced, and how does that help us figure out something about the source, because we want to know about what's going on out in space.

You're going to be able to observe light made in an accretion disk around a black hole and be able to tell what temperature is it at, what kind of gas is it? Let's see if we learn a little bit more, because we only get light from objects in outer space. We can't go to the black hole and pick something up and bring it back. So we only get light.

So we're going to do a review here of atomic structure, because the way that light is produced, we're going to find out, has to do with atoms. So I'm going to draw a couple of diagrams here, and, again, keep in mind some of those points that you guys wrote down about how your notes were different from here and [INAUDIBLE] yesterday. And try to keep those good note-taking habits in mind.

OK. So I'm going to draw two pictures here. We're going to draw a helium atom, and we're going to draw another picture over here. So make sure to leave enough room for side-by-side. We all learned, hopefully, that atoms are made of a nucleus-- which is positively charged. And in a helium atom we have two protons. So the black circles here are protons. And we write the assigned symbol for proton as P with a little plus next to it. Why do I write a proton with a P with a little plus next to it? It's positively charged, right.

And, remember, we're going to be a little bit confusing because we're going to talk about protons-- P-R-O-T-O-N-S-- versus photons. So proton and photon sound similar. A proton is a particle of matter that's positively charged. A photon is a particle of light-- it has no charge.

So we also have in the nucleus we have a neutron, which we write as N with a little 0 next to it.

Why do I write a little 0 next to it? Because neutrons are neutral, and they have no electric charge, right? And so there are two-- there are two protons, there are two neutrons.

Also, around the outside of the atom-- sometimes people-- there are several different models of atoms. You can talk about-- you know, if we had an electron-- which I'm going to draw it as a little tiny dot. Actually, let's draw it as-- just a little tiny dot. We write that as e with a minus next to it. Why do I write it with a minus sign? It's negatively charged. That is an electron.

You guys have probably heard about electrons being in shells around the nucleus. There are a bunch of different models that people use to describe atoms. In reality, none of those models is actually truly correct. The closest thing that we've come to is a quantum mechanical interpretation of the atom, which has to do with this idea of electronic clouds. And it's not the atom that's orbiting like a planet-- we're going to find out why. But it's also that you can't, like, pick up an electron-- it's so small. They're spread out.

What I'm just going to say is there are two electrons that are close, or bound to this nucleus. Something else you can think about them as being on an orbit around-- and you have them being on an orbit around the nucleus, OK?

So this atom is-- it's neutral, which means it has no net charge. The neutral equals net charge of 0, because I have two protons, I have two neutrons that have no charge, and then I have two electrons, so the net charge is 0.

We are going to find out that it is also important in astronomy to think about ions. Over here I'm going to draw a helium ion. An ion is like this-- again, you still have two protons, you have two neutrons. But instead we only have, let's say, one electron. This is proton, proton, neutron. And you can think about this as having an electron go in orbit.

In this case, this is charged, which means it has a net charge of what? What is the net charge here? Right. We have two positive charges, one negative charge. We have a net charge of plus 1. All right. So this should be review. We have an uneven number of protons and neutrons-- or, I'm sorry-- protons and electrons, because here we only have one. How do we go from an atom to an ion? We go from here to here-- the process that Frank talked to us a little bit yesterday-- ionization. Ionization means the creation of ions.

We're going to define ionization this way. How would we-- you know, apparently [INAUDIBLE] we lost an electron. We lost an electron somehow. Ionization is when an atom loses one or more electrons. And it loses it if-- if [INAUDIBLE] and we're going to put [INAUDIBLE] in parenthesis or a type of quotation marks-- if bumped hard enough by another atom or a photon.

So if one atom comes in and bumps into another one, you can kind of bump away one of those electrons. Right? And so if you've ever seen somebody playing football-- two football players come together, sometimes one loses their helmet, or loses like a pad out of their shoulder pads or side pads? Kind of the same thing-- when you bump two things together, sometimes this can fly out. Same thing happens if you take a photon, and you have the photon bump against the atom, it can cause ionization. OK.

So, you're going to say that-- in most cases, if you have a bunch of helium atoms together, we call that a gas. So helium atoms altogether form a gas. If you have a bunch of ions all together, you can make a plasma. And a plasma is something we're just going to define as a gas made of ions.

AUDIENCE: Is that kind of like a plasma TV?

PROFESSOR: Not quite. A plasma TV, I honestly don't know exactly how that works. It might have something to do with that. That's a good question. So if you want to research that and find that out for us, that would be great!

So the plasma is a gas made of ions. We're going to find out that a lot of astrophysical forces are plasma. Now we are going to take a look now-- we're going to make a couple of observations about a simulation, or a model, of what people think-- or what people know pretty well-- it's a pretty standard model-- of what happens on an atomic scale.

So what we're going to do-- we're going to look at a very, very small box that is filled with atoms. These atoms represent air. So, Peter, can we put up the atoms in motion simulation? So-- we already took pictures of these, so I'm going to-- let's take these down. There. Are we there? OK. So this is a simulation, or a model of a box of air. It's a really, really small box, because we can see the individual atoms.

What I want you to do is, I want you to watch one atom-- like pick out one-- they're moving slowly enough so that you can see it. I want you to watch it-- and I want you to watch what happens to it. It might be hard. If you lose it, pick another one. Oh, I lost it. Sometime it's easier to pick the red ones because there's fewer of them.

How would you describe the motion of your one atom? Let's make some observations. So Mandy, what do you want to say?

AUDIENCE: [INAUDIBLE]

PROFESSOR: Atom goes-- one atom can go a little fast and slow. Goes fast and slow. But it changes speed after it-- after it bumps into another atom. Goes fast and slow, let's say, after bumps, which we call collisions. OK, so bumps-- collisions-- with other atoms. OK. How would someone else describe them? I see, and then I heard [? Jalen ?] start to say something. See?

AUDIENCE: They're just random. Just go anywhere.

PROFESSOR: OK, so the direction seems to be kind of random. So the direction of motion is random. OK, what else? [? Jalen, ?] are you going to say something? Are you sure? OK, so the direction gets changed when it's bumped. And it has to do from where it's bumped, and bumped on one side, the direction kind of changes to that direction. OK, so the direction of motion is random, but changed by bumps or by [INAUDIBLE] What else? Anything else?

AUDIENCE: Would you say it travels in a straight direction?

PROFESSOR: Ah! In between bumps, it's always traveling in a straight line. So between bumps, travels in straight line. OK. What else? Are all of these moving at the same speed? All right, we said that in between the bumps it could be going a different speed. So there are some that are always moving sl-- there are some that are moving slow, some that are moving fast. Are the ones that are moving fast always the same atoms? No. So, like, right now I see a red one in the middle that's going really slow, and down there it just took off. That's one slow again, the other one just took off.

So what I'm going to have Peter do now is he is going to-- we're going to turn the temperature of the floor of this box up. Right now we're at 30 Kelvin, which is a very, very cold temperature, which explains some of the things that we're about to see. So let's turn up to 100 Kelvin, which is still very, very cold. That's the temperature of clouds in space. But I want you to watch what happ-- pick an atom. And I want you to watch what happens to that atom. It's easier to watch the red one.

Some of them are red. It's the simulation of what air is like. Red represents oxygen. And blue represents [INAUDIBLE] OK, so keep your eye on one of the red ones. OK, now I want you to describe at a higher temperature-- a higher temperature-- how do you describe the motion now? How was the motion of one that's different from the way it was before. [INAUDIBLE]

OK, now before we said it goes fast and slow. So what? How can we be more specific about that? It became-- it's-- when you say it became more faster, you mean to say it became faster or it was more fast. OK. Let's just say it-- it's faster. So, Ricky, you were saying? You wanted to add on to that? OK. It picks up speed. See?

AUDIENCE: [INAUDIBLE]

PROFESSOR: OK. If the temperature is high-- so let's write this down. Higher temperature means, let's say, faster motion. OK? Let's check it out. So here the temperature is high. But watch that guy-- oh, well. Watch that guy right there, right? Are they all moving faster? Or are there still some them slow?

AUDIENCE: [INAUDIBLE]

PROFESSOR: OK, so where-- at what temperature, look! High temperature, low temperature. Do they move slower or longer? [INAUDIBLE] Right? So right here, this guy is kind of moving slow a little bit. Oh, now he took off. Right? Jason.

AUDIENCE: Last time [INAUDIBLE]

PROFESSOR: OK. Can we still see-- can you watch for some red particles still moving slow, though?

AUDIENCE: A little bit.

PROFESSOR: OK. There's a slow one there. So what we're going to say is, on average, the speed of these particles has increased. There are still some that are going slow. There are stil some that are going fast. But overall, they're all living just a little bit faster, because the slower ones, you know. Peter, let's turn the temperature back down. We got down to, like, 10, maybe. So we're still bouncing. What's happening to the number of collisions?

AUDIENCE: [INAUDIBLE]

PROFESSOR: We can go longer without having a collision. So at high temperature there was a faster average motion. There were still some that were going slow, there still some that were going fast.

But in general, most of them had speeded up just a little bit. There was faster motion, there was also more collisions, more bounces, or I guess you said bumps. More collisions.

And at a lower temperature, we have on average-- there's still some of them that are moving slow and some that are moving faster, but the average speed is a little bit slower. And I can watch one atom for much longer in between bumps.

So lower temperature has slower average motion and it has less collisions, like maybe less collisions per second. But in this case, most of them aren't colliding with each other. Can we turn the lights back up?

We're going to-- put it back over here, put it on this side. Just like we did with the particle model of light, and we made a nice simple model we could use to make some predictions, we're going to do the same things with-- I guess I didn't label this. These are observations of atoms in a gas.

I'm now going to introduce a model of light production. It has to do with all of these observations that we've been taking. What have we seen with these [INAUDIBLE]? What did we see with that simulation?

And I'm just going to say, when a charged particle, and that could mean an ion, it could mean an electron just by itself, but there has to be a charged particle-- and particle is just our word for a very small amount of something-- when a charged particle bounces, or, if some of you are familiar with this word, accelerates, which we mean-- so "ie" means I've gotten to know one of you, for example-- or what we really mean is, if it changes velocity or direction. So if something is accelerating, it's either changing its velocity or changing the direction of its velocity-- velocity is actually a factor in both the speed as well as the direction.

But an easier way to think about it is sometimes is bounce. If something bounces, like [INAUDIBLE] said before, you change the direction of the atom's motion. And in between the bounces, Juan said, all of the atoms go in straight lines. So if they're going in a straight line, no bounce. If they bounce off of another atom then that's the acceleration.

So when a charged particle bounces or accelerates it emits a photon of light. So you remember when we said yesterday that light, a lot of people talk about the electromagnetic spectrum? Well, electromagnetism is the name of the force that holds nucleus and electrons together. It's the electrostatic force. The electromagnetic force that comes into play when the charges are moving.

So if we're bouncing around, we're moving some of these charged particles that have an electromagnetic force that's acting. We can make the connection that a photon of light could come out of that interaction.

So we're going to find out that there's two general ways that you can produce this light. You can either produce it, we're going to say, thermal light production. And if we're talking about thermal, that means it has something to do with temperature.

What do you see over there when we saw the higher temperature? What happens to the particles?

AUDIENCE: They sped up.

PROFESSOR: Sped up. What else?

AUDIENCE: They had more collisions.

PROFESSOR: They had more collisions, they had more bounces. So thermal light production happens when particles bounce because of their thermal motion. So thermal light production happens when particles bounce because of thermal motion.

Now thermal motion, what does that mean? That's just the motion of every particle, like we saw in that simulation. And the bouncing, if you have a higher temperature, you have things moving at a faster speed, and you can have more thermal motion. So these are the particle bounce because of thermal motion. Its bounce [INAUDIBLE]

And again, just to make it clear, let's define temperature. Temperature is going to be a measurement of the average kinetic energy of moving particles. And some of you may have heard about kinetic energy and some of you may not have. But kinetic energy is related to how fast the particles are going.

So we said before, if we had a low temperature you had a low average speed. There was some that were moving faster, there were some that were moving slower. But on average, they were moving slower. At a higher temperature, we saw that the particles moved faster. They have a higher average speed, or higher average kinetic energy.

So temperature is a measurement of how fast they're moving, or how much energy they're moving. We can also have something called nonthermal light production. I'm oversimplifying this for us because it's actually a little bit more complex.

But as I say, nonthermal light production is anything else, anything else that doesn't have to do with the bouncing because of the thermal motion. And I'll give you an example.