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3.091SC Introduction to Solid State Chemistry, Fall 2010
Transcript – Exam 1 Problem 6

Hi I'm Sal. Today we're going to solve problem number 6 of exam 1 of fall 2009. Now before you attempt a problem, there are a lot of things that you should know, that is background material that's going to help you solve the problem. Especially during an exam, given that this was the hardest on this exam. So you should be able to finish this within 15 minutes or so.

So before you start the problem you should know what the energy is of a charged particle in an electric field, which is given by this equation. The conversion from an electron volt to a joule, which is just a conversion of energy and this should be given to you on your table of constants. Also the energy associated with an emission spectrum, which is given by this equation where k is actually the ionization energy of hydrogen, which is 13.6 electron volts and the z squared is the atomic number of your atom of interest. And then the n f and the n sub i are your transition states. The DeBroglie wavelength, which is given by lambda, is equal to a Planck's Constant divided by the momentum. And always remember that you need to conserve energy. This is what's going to get you the full points on the problem.

So the problem, it's best to solve if you draw a little image as you read the problem. So the problem reads, atoms of ionized helium gas, He plus, are struck by electrons in a gas discharge tube operating with the potential difference between the electrodes set at 8.8 volts. So I'm going to go ahead and start drawing an image.

So let's say I have two plates where the voltage between these two is set at 8.88 volts. And what's happening here is that you're accelerating electrons through here. So you can imagine that-- say this is positively charges and this is negatively charged-- that an electron starts from your negative plate and then it accelerates toward your positive plate and you can imagine your plate having hole or something small where your electron can then exit and then be in free space under the influence of no potential. So then these electrons are actually being aimed towards your helium plus ions. So that's your target.

Now if I continue reading the problem, it says that the emmision spectrum includes the line associated with the transition from n equals 3 to n equals 2. Calculate the minimum value of the DeBroglie wavelength of scattered electrons that have collided with helium plus and generated this line in the emission spectrum. So it's an energy conservation problem. And all this tells you is that, you have an electron that is being accelerated through your potential. The electron is going to strike a helium plus atom and upon that you detect an emission spectrum. Well what does that tell you? That tells you that that electron actually excited an electron in the atom. The electron had to transition to a higher state to absorb energy and then decay and in the process of decaying it emits a photon, which is what you detect.

So this information is given to you. But the problem asks to find the value of the DeBroglie wavelength. So since this an energy conservation problem, and this is the very first step that happens and I know that my energy equation for a charged particle is simply q times the voltage. So I know that q, which is a certain value of charge, the product of these two when I'm multiplying by 8.8 volts, this yields 8.88 electron volts. So it's a new unit of energy where we just saw the conversion. And the reason why this takes this shape is because one electron has the charge of 1.6 times 10 to the negative 19 coulombs and that's where the conversion from electrical volts to joules come from.

So I'm going to go ahead and call this e sub i initial. Because this is our initial energy that we're given. So we just start with this energy, nothing else. Nothing else was given from the problem. So we want to go ahead and conserve this. So our final state, the combination of whatever we are solving, should not have a higher energy than what initially we started with. So because the problem says that we have an emission spectrum, I'm going to go ahead and draw another image. I'll label this one, initial and I'll label this one, final. So my final image, you can imagine a helium plus atom. And the electron strikes the helium plus atom and we detect a photon and you're getting a scattered electron. That's what the problem says. Scattered electron.

So what this tells me is that this energy now is going into creating a photon and scattering an electron from your atom. So if I was to equate those two or what not I can already say that, well in my final state I detect an emission or an emission spectrum. And I know what the transition says. It goes from n equals 3 to n equals 2. That's what the problem tells us.

So if I take my equation, my delta e of my emission spectrum, is simply going to be negative k, which is 13.6 electron volts. And I'm going to multiply by the atomic number, squared now. This is where people also make mistakes during the exam. The atomic number is not 1. It's actually 2 because we're talking about helium. And the atomic number is not the number of electrons or values in terms of an ion, but it's actually the number of protons that you have. So helium has 2 protons. So I can multiply this by 2. And I'm going to square it. And I know that I'm going from n and equals 3 to n equals 2. So if I plug this into my equation I have 1 over 3 squared minus 1 over 2 squared, which is 9 and 4.

And if you plug this in, and assuming that your calculator works and is correct, you get a value of 7.56 electron volts because that was the unit that I was using. Everything else is unitless, so my energy is now 7.56 electron volts for my transition. Which covers this part for my photon.

So now we're left with what the energy of this is. So what is the energy of the scattered electron? Well if I equate the initial to the final I know that the final is a composition of the transition in my scatter state. So I know that e initial, which is 8.88 electron volts, this equals to the energy for the emission spectrum, which is 7.56 electron volts. So I'll put the units in square brackets so you don't get confused. And then plus the energy of the scattered electron.

So if I subtract the two, I get the energy of my scattered electron. And that pretty much gives me a value of-- after I subtract that-- e of scattered electron is equal to-- well the distance between these two is actually 1.32 electron volts.

But don't stop here because the problem didn't ask you to figure out the energy of the scattered electron. It actually told us to figure out what the DeBroglie wavelength is of this scattered electron. Now the fact that the electron is scattered, to me that means that the only energy that this particle has is kinetic energy. So it's a classical form of energy. So I can go ahead and I can equate this to just 1/2 mass of the electrons times my velocity squared-- whatever velocity it has. Now I'd don't need to figure out what the velocity is. This is just important to figure out what the DeBroglie wavelength is. So this is good.

Now if we look at what our DeBroglie wavelength is, we know that lambda is equal to Planck's Constant divided by p. And Planck's Constant has a value of 6.6 times 10 to the minus 34 with units of joules seconds. So this is important too. Always keep track of your units because dimensional analysis will help you a lot when solving these problems. A lot of the times you're given energy values in electron volts but your solution will have a constant that doesn't have an electron volt, that will have a joule, so you're forced to make that conversion or else your problem is going to be wrong.

OK so with that in mind, we know what h is. But what about p? Well p is momentum. And classical momentum is just mass times your velocity. So this is just mass times velocity, but this is the mass times our velocity. We know what the mass of the election is. That's given on our table of constants. But the velocity, we don't know what it is but we can grab it from our classical energy. So if I look at my energy-- from the side so I'm going to look at my energy-- I know that my energy-- I'm going to call this scat, for scattered-- the energy of my scattered electron is simply 1/2 the mass of the electron times our velocity squared. Now if I multiply both sides by 2m, I'm going to go ahead and get us to the point where I can get an equation that is just my mass times v. So I'm going to multiply both sides by 2m, So I get 2 mass of the electron, e scat of the electron, equals-- if I multiply this by 2m, the two cancel, so I get an m squared. m squared times v squared is essentially just m times v squared. And this becomes just mass of your electron v squared. Now if I take the square root of both sides, I end up getting a nice relation for just m times v. So I know that m times v now is just simply equal to this-- canceled, the square root cancels the square. The square root of 2 mass of the electron times the energy of the scattered electron.

So if I go back to my DeBroglie wavelength, I have m v. So I can take that value as a function of energy and just substitute it into my equation. And that'll help us get the answer because we know what the energy of the scattered electron is. We calculated that on the first part. So with that in mind we'll come over here. Again this is 6.6 times 10 to the minus 34. And the units are joules seconds. And down here I have the square root of 2 times my mass of the electron, which is on your table of constants. And it's just 9.11 times 10 to the minus 31. And this has units of kilograms. And the energy of my scattered electron, which is 1.3 times 1.32 and this units of electron volts.

Now this has units of electron volts. This has units of joules. This problem's a little bit-- now you're not going to get a good answer with that unless you make the conversion. I pointed it out, the bullet point in the beginning was that 1 electron volt is equal to 1.6 times 10 to minus 19 joules, so if I simply multiply this by that conversion, just 1.6 times 10 to the minus 19, this has units now of joules per electron volt. So this has units of joules per electron volt. The equation turned out to be pretty long. But this cancels the electron volt and now has units of joules. Which if you go through the math, you're going to go ahead and at the end get a unit of just meters. Because joule is just kilogram, meters squared per second squared. So all that factors out and you end up getting that. If you go through the math and you get your math right, then this should yield a value of 1.06 times 10 to the minus 9 meters.

So this is the value that will get you the right answer on the exam. Again this is lambda for your DeBroglie wavelength because that's what the problem is. So the problem asked for the DeBroglie wavelength but it give you all this information to get to the point where you needed to solve. And by conserving energy and knowing the right conversion factors between energies you're able to get an answer, which is good. It's really easy to complicate things and get a wrong problem now.

I remember from grading the exams, the most common error that people faced was actually letting the energy of the electron be the energy of a photon. Now that can't be because the energy of a photon is just your Planck's Constant times a frequency. And that's the energy for massless particles, your electron has mass so if it's moving it's not going to be h nu. The energy is going to be kinetic energy. 1/2 mb squared. If it's not in an electric field, that is. So with that in mind just be confident when you solve these problems and make sure that you know exactly what energy equations to use to get the right answer.