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Electromagnetic Radiation and the Idea of Quantum

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2When I connect this light bulb, what do you see? You will see white light. Where did white light show up on our electromagnetic spectrum? It wasn't anywhere. So, what is white light? We can see it. Certainly it is visible light.

White light is simply a mixture of all the visible light, all of the visible frequencies of light, everything from red up to purple. That mixture gives us white light. White light from the sun is just the full electromagnetic spectrum of visible light and beyond, certainly.

Now I have a flask here that contains, we'll call this our sample, but it actually is just water in this case. I put that right in front of the light bulb so you can see it here. And now, what do you see? You should still see white light. The white light is being transmitted through the sample. In this case, you are the detector; you are seeing the full white light spectrum come through.

Now, finally, I'm going to take some green food coloring and I'm going to simply add it to our sample. And, no great shock to you, mix it up, it turns green. So, once again I will ask you, what do you see now? If you could look at the wavelengths of light coming to you, what are you seeing? Clearly, the chemical in the green food coloring is doing something. It is changing. It is interacting in some way with the light that is transmitting through the sample so that you are no longer seeing white light. You are not seeing the full visible spectrum then.

Well, what are you seeing? Isn't it in fact that the food coloring is blocking green light? Well, if it was blocking green light, it wouldn't look green to you. Right, that would be missing and so that would be the one wavelength that you wouldn't be seeing. So, what it must be doing is blocking all the other colors or, at least, most of the other wavelengths of light, so that the dominant thing that you see is green light.

In fact, what it could be doing, and is likely to be doing in some cases, is if it blocks out the complement to this color, the complement to green is red, your brain will actually perceive the opposite. So, in other words, when your brain sees the absence of red light, it thinks it is seeing green light.

You can actually do this at home if you draw a big red spot on a white piece of paper and you stare at that rd spot without moving your eyes for about a minute. Then quickly look away and let your eyes refocus on the white paper. You will see the opposite color. You will see a green dot. Your brain will perceive the absence of red because you will have saturated your red receptors. And so you will actually be seeing a green light then. And that is what is going on here essentially. We are absorbing other frequencies, in particular, the complement of green light and so you see the green light come through at you.

What I am describing for you is an absorption experiment. The light bulb would be what we can consider the source. Usually a full spectrum, either an invisible spectrum or sometimes in the ultraviolet or in the infrared spectrum. A sample, in this case just our water and food coloring, and in particular the molecule that we are trying to probe. So, this is a great way of probing what is happening in a molecule. We are putting the molecule in, passing white through the molecule, you are the detector in this case, looking at what wavelengths come through on the other side.

So, let's talk about this a little bit more. But, absorption experiments are one of the most fundamentally Important ways a chemist can probe atomic and molecular structure. Let's review a little bit what we just did. Once again, the idea of absorption is we pass white light through a sample. The white light initially contains the full range of colors. The sample then absorbs some of those frequencies, leaving only specific frequencies coming out the other end to be detected. That is the transmitted light. Again, in my cartoon here you saw a green light managing to make it through the sample. But, a lot of the other frequencies didn't make it through the sample.

I should mention while I'm at it, since I'm wearing this stunning green shirt that the same thing happens with reflectance. My shirt contains dyes, where they got these dyes I will never know. These dyes are capable of knocking out a lot of the other colors of the spectrum. So, white light, from the sun for instance, bounces off the shirt and then the green light comes off of the shirt. So you're seeing the green light, you are seeing the absence of some of these other colors in just seeing that green light there. It's a very similar idea. This is what would be called a reflectance experiment. If this was the sample and we had a source here and a detector. But, of course, we don't need to do an experiment to wear this shirt.

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Again, fundamentally how this is going to be done is we'll have a source, and again, we use our light bulb as a source, we'll pass it through a slit to get a very narrow beam of that white light. That is something we didn't do in the experiment that we just did here. We then pass it through our sample. Now, just to make it interesting, I'm going to talk about a red sample, in this case, instead of a green sample, something that appears red to our eyes. We then take that light which is still a mixture of the different wavelengths. And we need to divide it now into the different frequencies, or the different wavelengths of light.

So, we can use a prism, which causes the light to bend to a different degree depending on what the wavelength or frequency is of the light. We can use something called a diffraction grading that accomplishes the same task. But, there are ways to optically separate the different frequencies of light. And then we collect, what is referred to as an absorption spectrum, the full spectrum minus the thing that is being absorbed. In this case, in the demonstration I'm shoeing you, everything is making it through our sample except for green light.

So, once again, if we have something that appears red, it is going to appear red if it is missing green light. So, by knocking out the green light our sample appears red to us. But what is particularly going to be important to us is that in this type of an experiment knowing what frequency is missing is going to give us a very important clue about something happening in those atoms in this sample. And, in fact, this is the most important probe we have, in modern chemistry, of finding out what is happening at a molecular level.

Now, related to the absorption is the emission experiment. Now, again, going back to our light bulb for a moment. That light bulb was a source, but it also was a source of emitted light or an emitter. So, we could take a source of some kind, in this case I am actually going to call it our sample now because it is the thing that we are interested in. And, let's talk a little more detail here. We are talking about the filament; the tungsten filament in that light bulb is the sample that we are probing. That sample is heated up to a very high temperature by passing electric current through it. So, it glows white-hot. It emits white radiation, meaning that it emits the full spectrum of visible frequencies. We would pass that then through a slit to get a nice narrowly defined beam. We pass it through a prism or a diffraction grading. Once again, to separate out the frequencies and we would get the emission spectrum.

In the case of the white light bulb, we see the entire emission spectrum. Maybe not all weighted exactly the same. There might be a little bit more yellow and orange than there would be blue and green and the light bulb may even appear to us a little bit yellow. A fluorescent light may give a slightly different emission spectrum with slightly different balance of these colors. Sunlight, again, would be yet another difference in emission. In fact, one of the ways that we can tell the temperature of a star, for instance, is by looking at the emission spectrum from the star. And that tells us something about the temperature of those stars. So, an emission experiment, again, is a very important probe into what is happening at a molecular level.

In this case, what is going on in this tungsten wire here that gives us this? You will notice that in the case of the light bulb we got the full spectrum. And, in fact, if I had a prism here, which I don't, you would see a full rainbow coming out of that tungsten bulb. Well, let's do another emission experiment. What I am going to do now is a hydrogen emission experiment. In this case, what I have is a tube filled with hydrogen gas. And, I have a very high voltage power supply for this tube. And, I'm going to ask my helpers to turn out the lights here. And, I'll turn this on so you get a better view.

Now, you can see this beautiful purple color. Clearly, this is different than the tungsten light bulb in that we're not seeing white light now. We're seeing what looks like purple light. One important thing to notice is something is going on very different in the hydrogen than in the tungsten filament. In fact, if we analyze the frequencies of the light coming out of this light bulb, it's going to tell us a lot in just a little while about what is actually happening at the atomic level in hydrogen.

We'll leave the lights out for a moment. I'm going to simply change the tubes. I'm going to leave you folks in the dark for a moment. Let me just change this tube. Now, with a tube that is filled with neon, now you will notice that this is a much different color. Now it is more of an orangish color, maybe more towards white, but with a little bit of a tint of orange in it.

The point I'm making here is that although these are both clear, colorless gases, hydrogen helium, seemingly very similar to our eye, and in fact their absorption seemingly seems to be the same, they're both colorless. Their

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emissions spectra are very different in that the colors you are seeing being radiated from them clearly are different. You can perceive that with your eye. There are some fundamental differences between hydrogen and helium. Would you bring up the lights please?

It turns out that if we do analyze the hydrogen emission spectrum, which we just saw, that this is what we will see. So, here is our gas discharge tube. And, the light is being passed through a narrow slit and then a second narrow slit to give us good directionality of this beam here. Then it is passed through a prism. And, the prism, again, breaks that light down in to its components. And we see something absolutely fascinating. We see that in contrast to a tungsten bulb where we've got a full rainbow, the hydrogen emission spectrum doesn't have large ranges of frequencies, but very discreet, very well defined frequencies. Only a very specified number of frequencies with very exactly defined wavelengths. Again, frequencies come out of that emission. The information in what those frequencies are is going to tell us the energies in the hydrogen atom. And that is going to be our fundamental probe into what happens within atoms.