

MITOCW | L12.3 Light and atoms with two levels, qualitative analysis

PROFESSOR: Let's turn to our next subject then. So this is still time dependent perturbation theory. We will be doing time dependent perturbation theory a little longer, all of today's lecture and a little of next time's lecture.

So we're going to be talking now about light and atoms. So this is a classic application of what time dependent perturbation theory does, the problem of radiation interacting with atoms is more and more detailed applications and their ionization. So light and atoms, and we think one of the situations we will be considering is a collection of atoms and they're interacting with light.

But the way they interact with light is maybe not as controlled as we had in hydrogen ionization, in which you send in a wave. But rather, it's interacting with light in thermal equilibrium. So there's black body radiation. There's all these photons, unpolarized, in all directions, coming at the atoms in all ways. And they can produce transitions in the atoms.

And for that purpose, we will consider a collection of atoms. And we will assume that relevant to our situation, we have two energy levels. This state will be called b . Still we'll call a , E_a and E_b . So this is interacting with light or with photons at a temperature T .

So a little bit of statistical mechanics today. In order to discover what Einstein did, basically, we're going to go through Einstein's argument of balance of radiation rates and emission rates and things like that. And we need to use some statistical physics for that.

Einstein was very good at using statistical physics. And the frequency associated with this transition is $E_b - E_a$ over \hbar . And we'll take it to be greater than 0. The state b will be considered to be higher than the state a .

So the question we ask is, what happens to these atoms when light shines? And in particular, suppose the light contains photons with a frequency ω_{b-a} . That's the frequency associated with the transition.

So what will happen? And basically, a couple of things can happen. These are things we already know from time dependent perturbation theory. And surprisingly, as we will see, Einstein, when he went through his argument that we're going to go through soon, came with a different angle and saw things a little differently.

But let's follow up the direction that is based on the evidence we've presented so far. So there will be two possibilities, two cases. In the first case, the atom is initially with its electron on level a , electron in a . So what happens?

Well, we've coupled, a system with two levels, two harmonic perturbations. And we saw that sometimes the particle or the system goes up and sometimes goes down. And now we're going to see the source a little bit more realistically. Before it was a perturbation. Now we're going to identify the perturbation.

The electron is in state a. And here comes photons. And what's going to happen is a process of absorption of the photon. And the electron goes to state b. So we'll draw it here.

So this is before. And here is after. So before, you had this thing and the electron was on state a. There was a photon coming here with energy $h\omega_{b-a}$. And then after, the electron has been pushed up. And there's no photon anymore. The photon was absorbed. That's physically what we would expect.

The other possibility is associated to the process of stimulated emission. This is absorption. And here we have electron in b initially. And we have stimulated emission. And in this case of the electron goes to a. And another photon is released.

It's a very surprising thing if you think about it. And here, this is the absorption process. Now this stimulated emission process, you have the electron originally in b. And here comes the photon. And the end result is an electron in a and two photons.

We notice that, when we're doing perturbation theory between the two energy levels and we have the harmonic perturbation, we even notice the probability to go from the bottom to the top or going from the top to the bottom was the same in perturbation theory.

And you would have said, look, I understand that when you have an electron in the bottom level, you need some energy from the source to kick it up. But why do you need this source to make it go down? It's just there. It should go down by itself.

Well, you still need to couple the system to something. Because if you are in an energy eigenstate, you stay there forever. The reason it goes down is because it couples to something. And somehow, the coupling through the electromagnetic field helps this go down.

That's why it's called stimulated emission, because it's stimulated by the radiation itself. And so this doesn't seem to play too much of a role, but actually does, in which just by the presence of a photon at the right energy difference, it stimulates this to go down. And now you have two photons.

So this is, of course, something that is used in technology a lot. This is the principle of lasers. And therefore, this discussion of stimulated emission, which was a lot due to Einstein, is the idea of a laser. So laser is Light Amplification by Stimulated Emission of Radiation.

So what do you need for a laser? You need something that is kind of a little strange to begin with. Because from the viewpoint of statistical physics, if you have a two-level system, particles will tend to be in the lower level. So why would they go here?

Well, they won't go there by themselves. That's the term called population inversion. You need to get the electrons that are in the bottom to go up to the next level and put them there. That's a technical difficulty, of course.

And it's usually solved by optical pumping. We are not going to be doing engineering here today. But there is a third level here in a typical laser. And you can send the electrons, that are sitting originally here, with light again into the third level.

And then it turns out that that third level, if you have the right atom, has a transition to this level that is rather quick. So the electrons fall here, fall very quickly. And the lifetime of this state here is very long. So they pretty much stay there.

So this is the principle. This extra level is sometimes called the pump level. And so this is done by optical pumping, so optical pumping to create population inversion. That you get more states in the upper state than you would get in thermodynamic equilibrium.

And then, you now have, say, the levels here-- I'm going to draw them this way. It makes it a little easier. I think of one electron here, maybe two here, maybe four here. And then comes a photon and stimulates this electron to go down.

And now you have two photons. And they stimulate these two electrons to go down. And now they have four photons. They can stimulate these four electrons to go down. Have now eight photons. And that's the amplification process of stimulation. Each time you stimulate one down, you achieve this.

In fact, technically speaking, apparently in good lasers, this transition doesn't produce light. You would say, oh, it produces more photons. But there's some energy levels that radiate by communicating vibrational energies to the atoms. So apparently these transitions are not electromagnetic. And you don't mix more light.

So basically, stimulated emission of radiation is the thing that gets this process going. And that's what we're going to try to understand now. The whole discussion that follows and what we have to understand about light and atoms will make all this quantitative and allow us to produce numbers and calculate rates.