multipole radiation

(automated transcription)

So in this video we will discuss the concept of multipole radiation. And we will do that for two different situations. We will discuss multipole radiation for classical systems, and once we understood that we will discuss it for quantum systems. And we will also examine what are the reasons why quantum systems need a different treatment. For classical systems, let's take the most standard antenna setup, this dipole antenna. If such an antenna is working, it emits dipole radiation. This is the characteristic spatial distribution of dipole radiation. You have an oscillating electric multipole. The plus and minus charges are continuously changing sides in that antenna. And therefore the electromagnetic fields around the antenna are time dependent, and you get this time dependent, spatially dependent pattern. The typical pattern for dipole radiation. I have another animation of this, which shows exactly the same. The oscillating dipole and the characteristic wave pattern. Now a charge distribution, or an antenna in general, need not to be a dipole. It can be a more complex distribution. For instance, a quadrupole, a pure quadrupole in this case, two dipoles that cancel each other. If that quadrupole would be oscillating, in the way as is shown on the screen, then you get a characteristic electromagnetic wave pattern around it that is different from dipole radiation. This is quadrupole radiation. In general, quadrupole radiation has smaller amplitudes than dipole radiation. So you could already imagine a kind of series expansion for general electromagnetic radiation. You could separate it in a dipole contribution, a quadrupole contribution, and so on. That might give you the impression that you could also have monopole radiation for electromagnetic waves. Now what would that correspond to? That would require a time-dependent monopole moment. So the total charge of your object should be time-dependent. It should oscillate between positive and negative charges. That's very hard to realize. If you strictly require that there is no dipole moment, no quadrupole moment, a purely changing value of the charge, how do you realize that in a real system? Where does that charge come from? You cannot do that. So monopole radiation for electromagnetic waves does not exist. It does exist in other situations that are not electromagnetic. If you would consider only the size of the object, say an object that changes in volume, that continuously oscillates in volume, that could produce sound waves, vibrating air molecules, sound waves that have this monopole pattern. So monopole radiation for sound waves is very common. That is the point microphone. But for electromagnetic radiation it does not exist. So our summary is this multipole expansion of electromagnetic radiation that starts from the dipole term. So much about classical systems. Let's translate that to quantum systems. And let's examine why the classical system is not a good way to represent the quantum system. I immediately think about a nucleus, a nucleus that decays and emits photons, emits electromagnetic radiation. Why can we not consider that decaying nucleus as a classical oscillating multipole? Two reasons for that. When a dipole, even if a nucleus does not have a dipole moment, I consider for simplicity the simple example of an oscillating dipole. If a classical dipole is oscillating, it emits energy through this electromagnetic radiation. And that energy disappears from the dipole. So in order to keep the dipole oscillating, you need power. The antenna needs to be connected to the electricity grid. With a nucleus that will not happen. It's in a highly excited state. It decays to a lower lying level, emits a photon, decays again, emits a photon and so on until it reaches the ground state. But once it's there, it stays there. There is no external power to bring the nucleus again to a higher level. So that's one reason why the classical picture is not applicable to quantum systems. You don't have this continuous supply of energy. The second reason is that all these different states of the nucleus, they correspond to a nucleus with a particular set of multipole moments. In this highest level, my nucleus has a strong oblate quadrupole deformation. In the second level over there, the nucleus is completely spherical. Then it has a quadrupole deformation again. And in the ground state it has even a completely different quadrupole deformation. So whenever you go from level to level, the multipole moments of the nuclei change. But there is never the situation of a nucleus that is in a single level and has a vibrating multipole moment in that level. So the picture of a stable object that is oscillating does not happen in the quantum context. There you always have a transition from one level with a given multipole moment to another level with possibly a different multipole moment. So how do we describe that? I will label my upper level state i for initial, the lower level state f for final. And I first wonder, how do I find in quantum physics the shape of the nucleus in these levels? What are the multipole moments and think about the quadrupole moments in these levels. Conceptually, this is, you take the Hamiltonian that describes the interaction between the neutrons and protons, and you take the expectation value of that Hamiltonian in, say, level i. And what comes out of that will be all the multipole moments of that nucleus in level i. Same for level f. If the nucleus decays, if there is a transition from one level to another, then the Hamiltonian changes. This is not only the Hamiltonian with the interaction between the nucleons, there is now also the interaction with the electromagnetic field. So I add an extra term, w, to the Hamiltonian that represents this interaction with the electromagnetic field. If you do the math, then it turns out that the probability to have this decay from i to f is a matrix element that starts in i, on which the electromagnetic field operator works, and then you project it on the final state f. You need this transition matrix element. If you know quantum physics, then you have an idea about the mathematics that is behind. If you don't know quantum physics, then just take this as a piece of information. This transition matrix element describes the probability of that decay. And this transition matrix element, that itself can be multipole expanded. You can have contributions that have the symmetry of an oscillating electric dipole field, plus an oscillating electric quadrupole field, and so on, plus an oscillating magnetic dipole field, and so on. So in the multipole expansion of that transition matrix element, all these different symmetries can appear, with the lower ones being the most dominant ones, although the nucleus itself cannot have a dipole moment. The nucleus does not have a dipole moment, but in the transition matrix element there is a dipole contribution. So the nucleus can emit a radiation pattern that has the symmetries of an oscillating dipole, although the nucleus itself never will be an oscillating dipole.