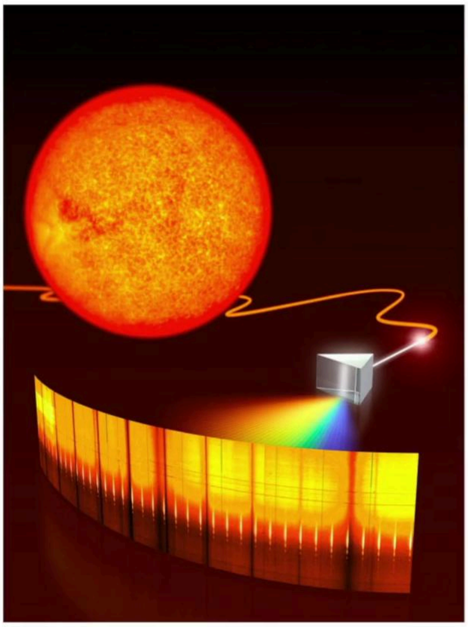
Spectral Lines (part 4)

Kim McAlpine



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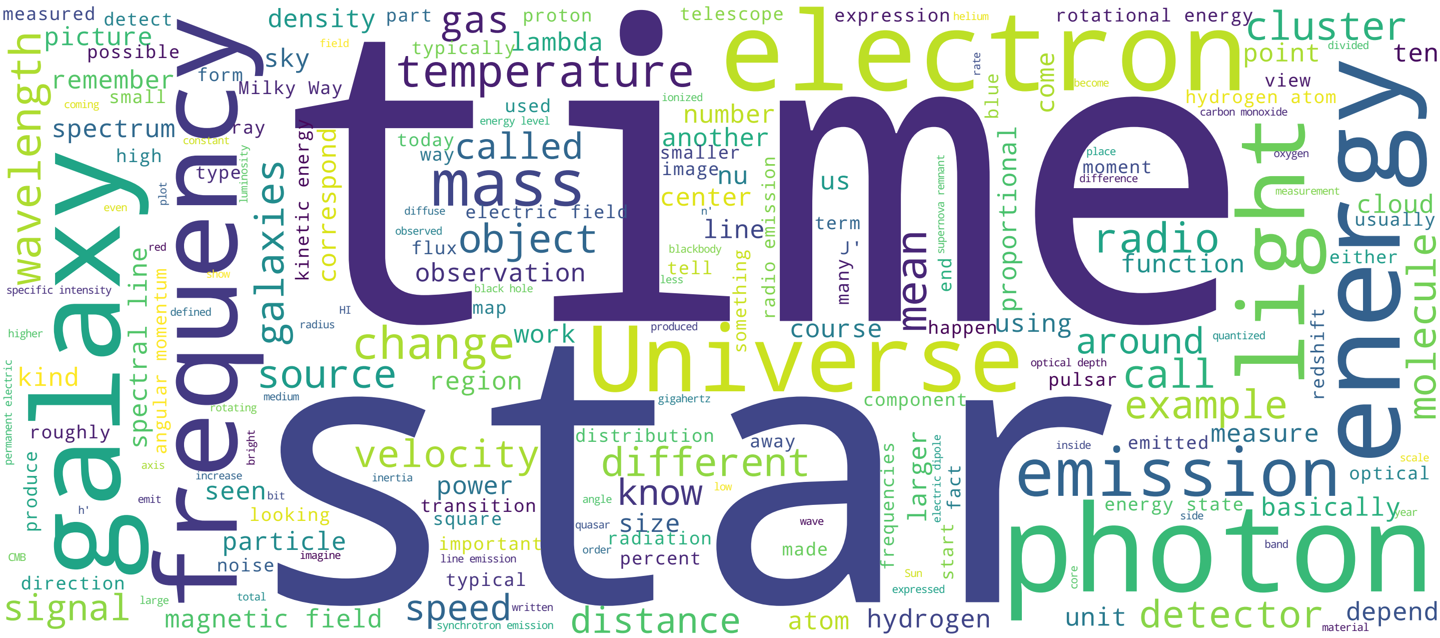

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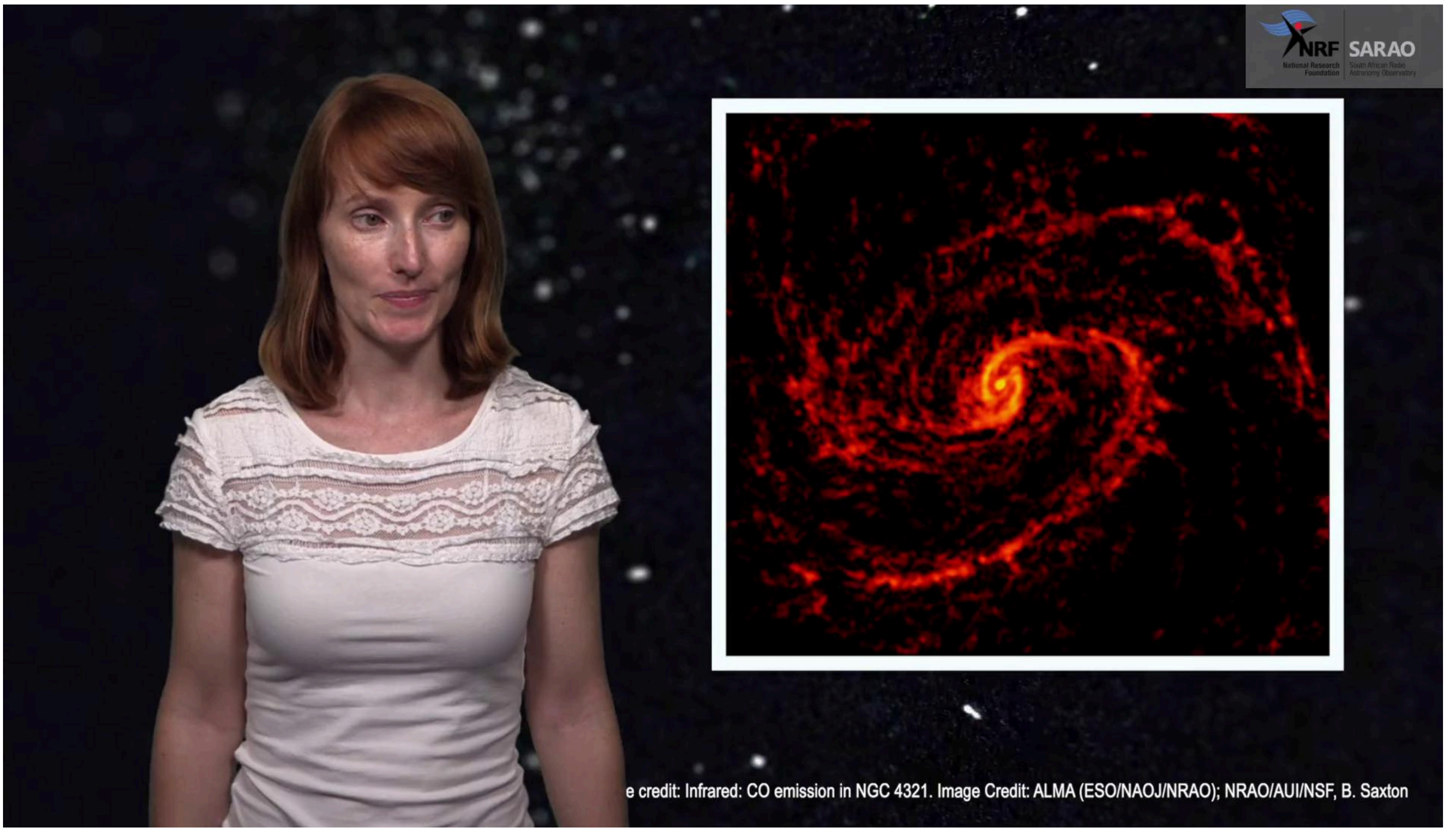


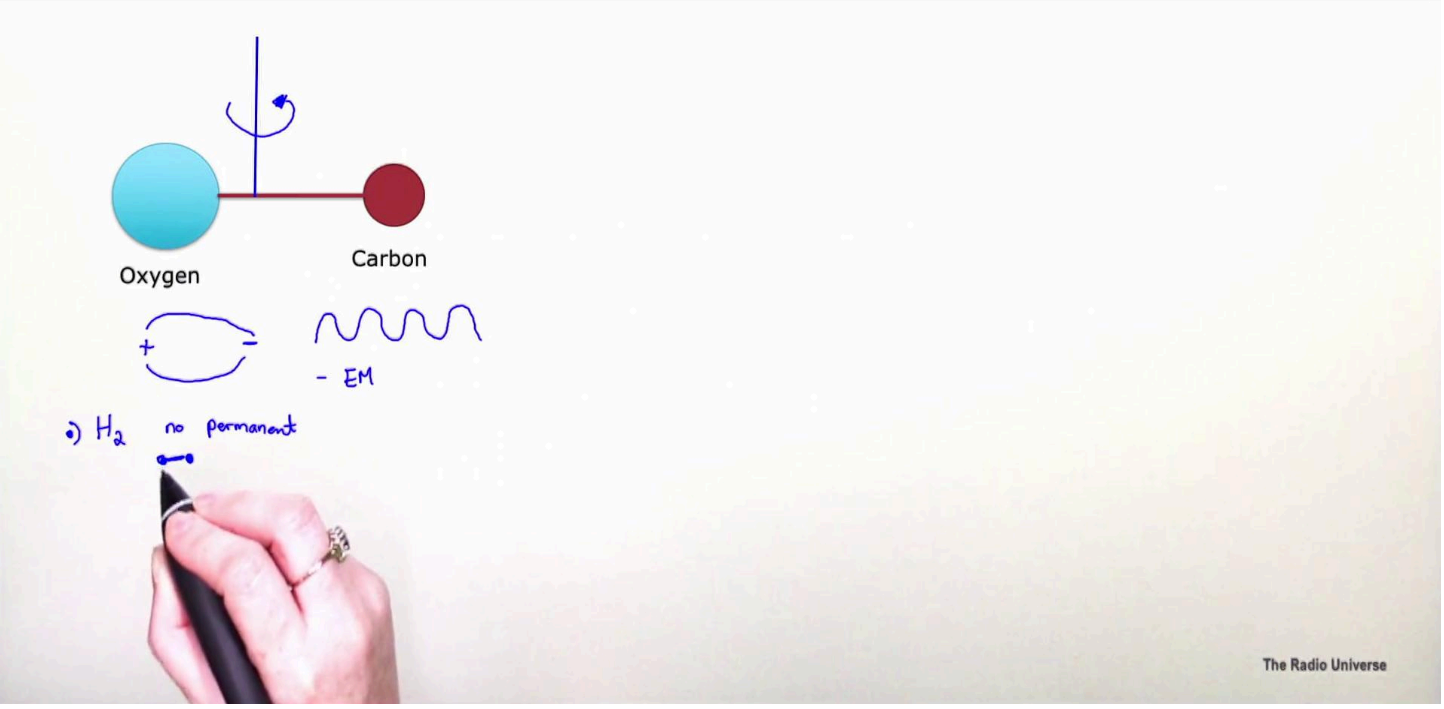
Previously we learned about spectral line emission that comes from an electron changing energy levels within an atom but it's also possible to get spectral line emission from molecules which are changing their rotational and vibrational states. So if you have a molecule which consists of more than one atom that is rotating around some axis and it changes its speed of rotation that is a change in the energy state of that atom. Similarly, if these molecules that make up the atom are vibrating then that's also a change in the energy state of the atom and today we will focus on learning about spectral lines associated with the change in a rotational energy state of a carbon monoxide molecule.

Notes

Summary

0m 04s

Molecular Transitions

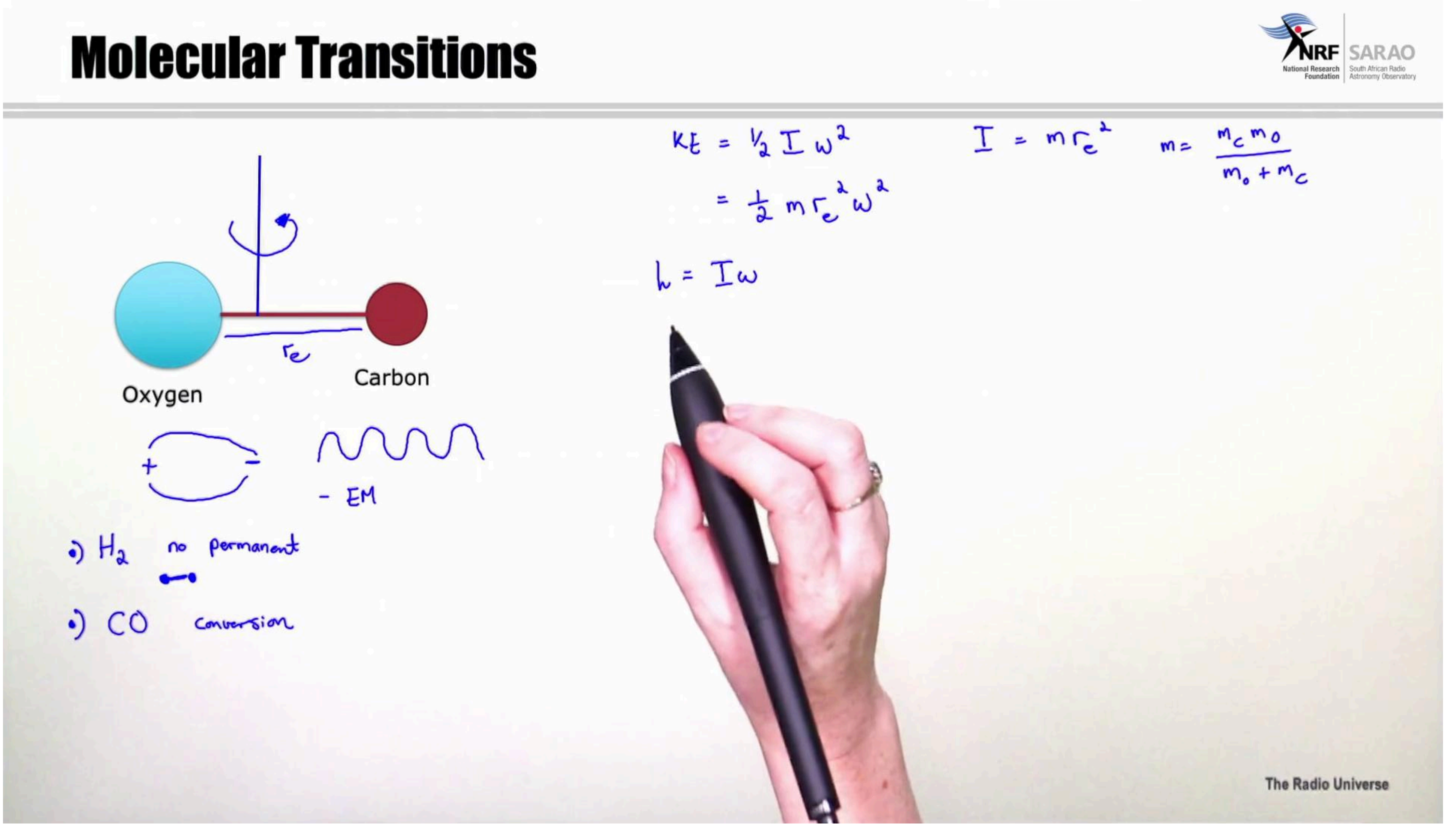


Another important type of radio spectral line is the one that comes from molecules. If you imagine that you have a carbon and oxygen molecule a CO molecule like this one, you can imagine that this entire molecule might rotate around its center of mass. Now for some molecules if they have an uneven charge distribution what that means is that they'll set up some kind of permanent electric dipole so that there will be a permanent electric field that's set up because of this uneven charge distribution and when this molecule rotates with a specific frequency, that will cause the electric field to rotate and that will mean that there is a sinusoidally varying electric field which then, you'll remember, will lead to electromagnetic radiation considering Larmor’s formula. Unfortunately, not all molecules have a permanent electric dipole and unfortunately for us, H2 does not have a permanent electric dipole because it's symmetric. So this is a bit of a blow because H2 is the most abundant molecule that stars form out of and H2, remember is when the temperature and density is high enough that two hydrogen atoms combine to form a molecule.

Notes

Summary

0m 49s

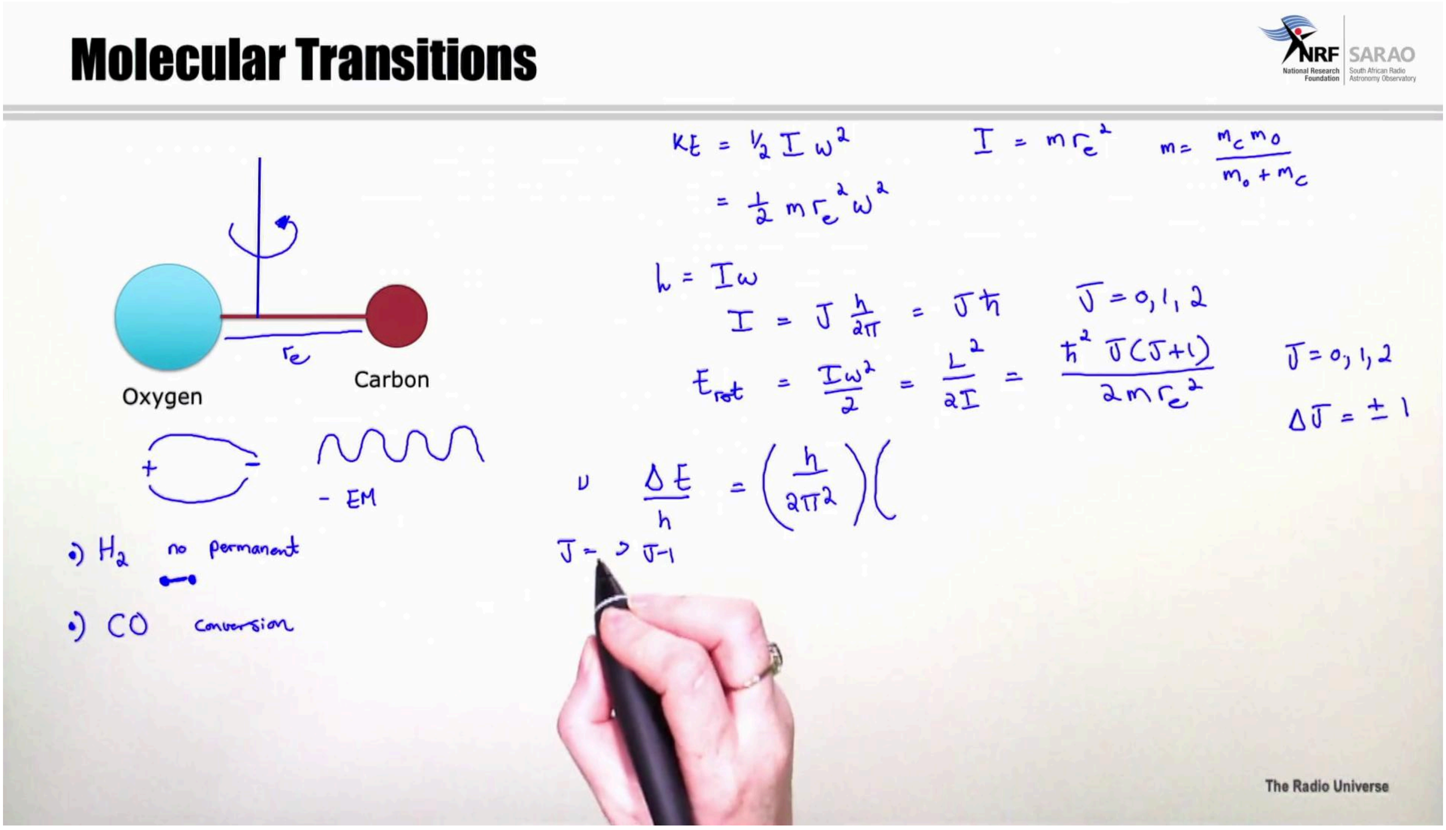


But as we're not able to directly probe spectral line emission from an H2 molecule, we have to look for other tracer molecules so other molecules that we think form in the same temperatures and densities as H2 which we then convert to some kind of probe of H2 using a conversion factor and a very popular molecule for doing this is carbon monoxide. So if we consider our carbon monoxide molecule that is rotating then we can say that this molecule will have a rotational kinetic energy which will be equal to a half times the moment of inertia times its angular speed. So this is just the rotational analog over the usual formula for kinetic energy and in this case, the moment of inertia can be given as being equal to the reduced mass of the system times the radius or the separation between the oxygen and carbon molecule. So here 'm' is equal to the mass of carbon times the mass of oxygen over the sum of the two. So that the rotational kinetic energy is then a half times 'm' 're' squared times the rotational speed. So angular momentum in a quantum system is also quantized so we can say that the angular momentum is given by the moment of inertia times the speed which is also a rotational analog of the normal linear momentum.

Notes

Summary

2m 16s

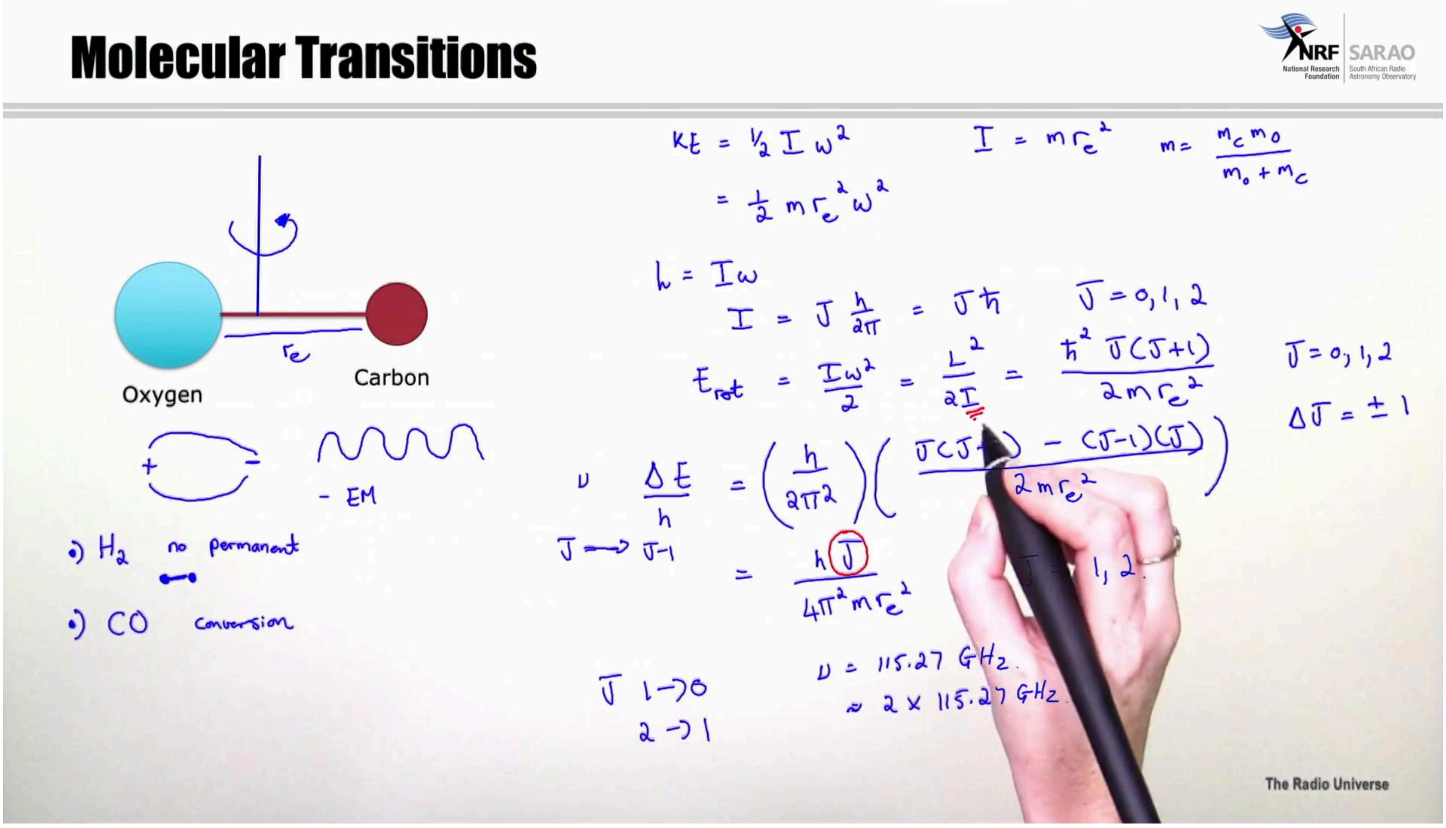


And in this case, we say that angular momentum is quantized just like the orbital angular momentum of the hydrogen atom was quantized and it's quantized according to the quantum rule that ‘I’ is equal to ‘J’ ‘h’ over two pi or ‘J’ times ‘h-bar’ where ‘J’ can be equal to zero one two. So from this we can work out the rotational energy of any given rotation speed which remember will now have to be a quantized property so you can't just rotate with any speed. So the rotational energy then will be equal to will then be equal to the angular momentum squared over twice the moment of inertia which was then equal to, so what we want to know is when we change, when we have a change in the energy of the system, what will be the frequency of the output photon. But we have a further restriction in this quantum world which says that the change in ‘J’ can only be either plus or minus one. So here if we say that this frequency that is emitted will be equal to the change in energy over 'h' then that will be equal to 'h’ over two pi squared and now we're going to transfer from 'J' to a level 'J' minus one which is fine. It doesn't violate this rule.

Notes

Summary

4m 07s

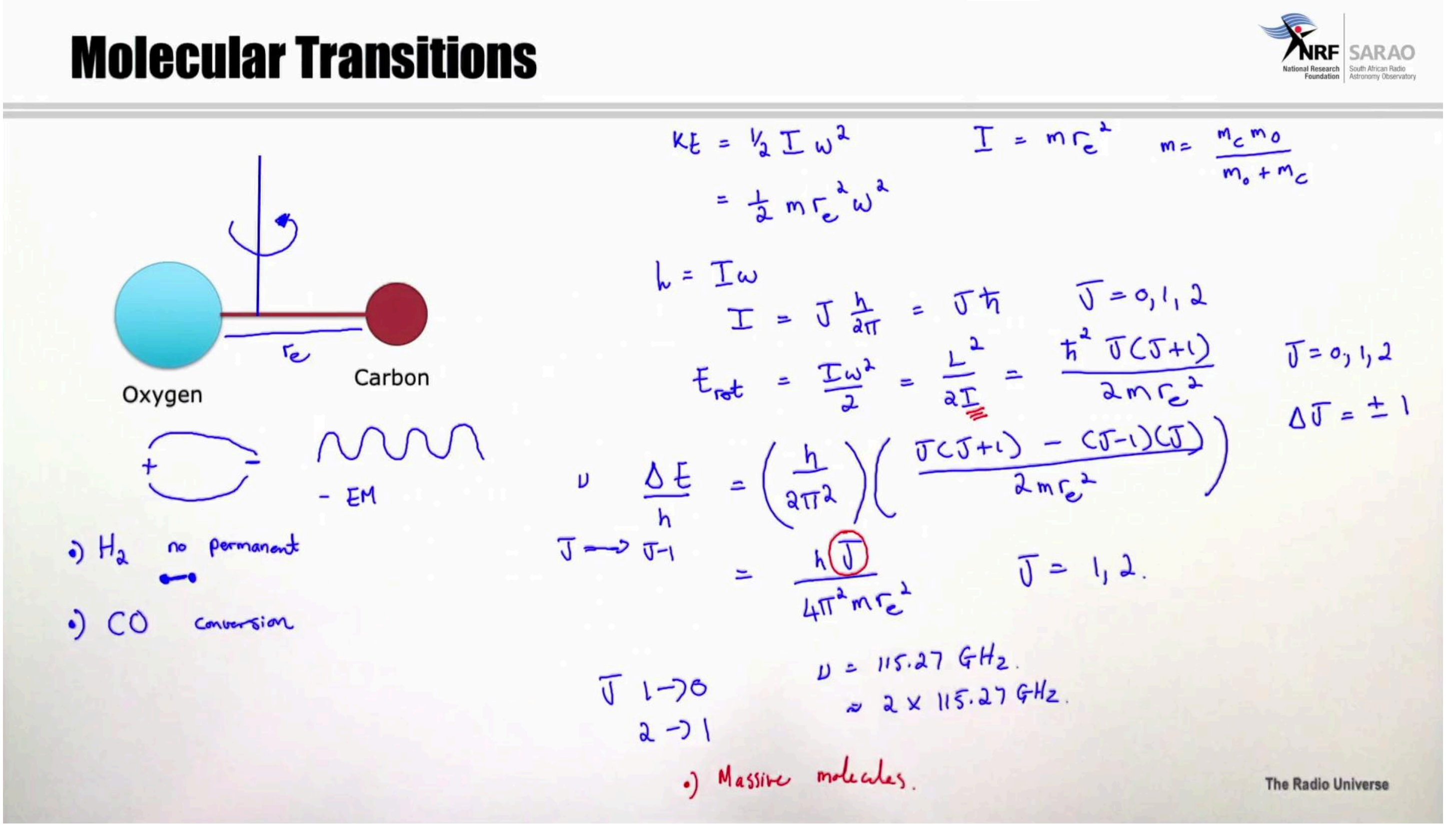


Then we can say that we've got 'J' 'J' plus one here minus ‘J’ minus one times ‘J’ all over the denominator. And all of this will then eventually cancel down to become where here the 'J' here will be the quantum number of the upper level in the transition. So from this you can say that if you want to look at the 'J' line, you can look at 'J' one to zero or you can look at 'J' two to one but remember it's not possible to go from 'J' two to zero because that is forbidden by the quantum rule. In the laboratory, this transition ‘J’ one to zero has been measured and it has a frequency of around 115.27 gigahertz. And from this you can work out then what is the equilibrium distance between oxygen and carbon using this given equation. So another thing to point out is that then when you've got this for the ‘J’ is equal to one to zero line, it's really easy to work out the J's two to one line because then it will just be the same but with two is the 'J' number instead of one so it will just be approximately two times 115.27 gigahertz. An important and interesting thing to note here is that the rotational energy here is inversely proportional to the moment of inertia.

Notes

Summary

5m 57s

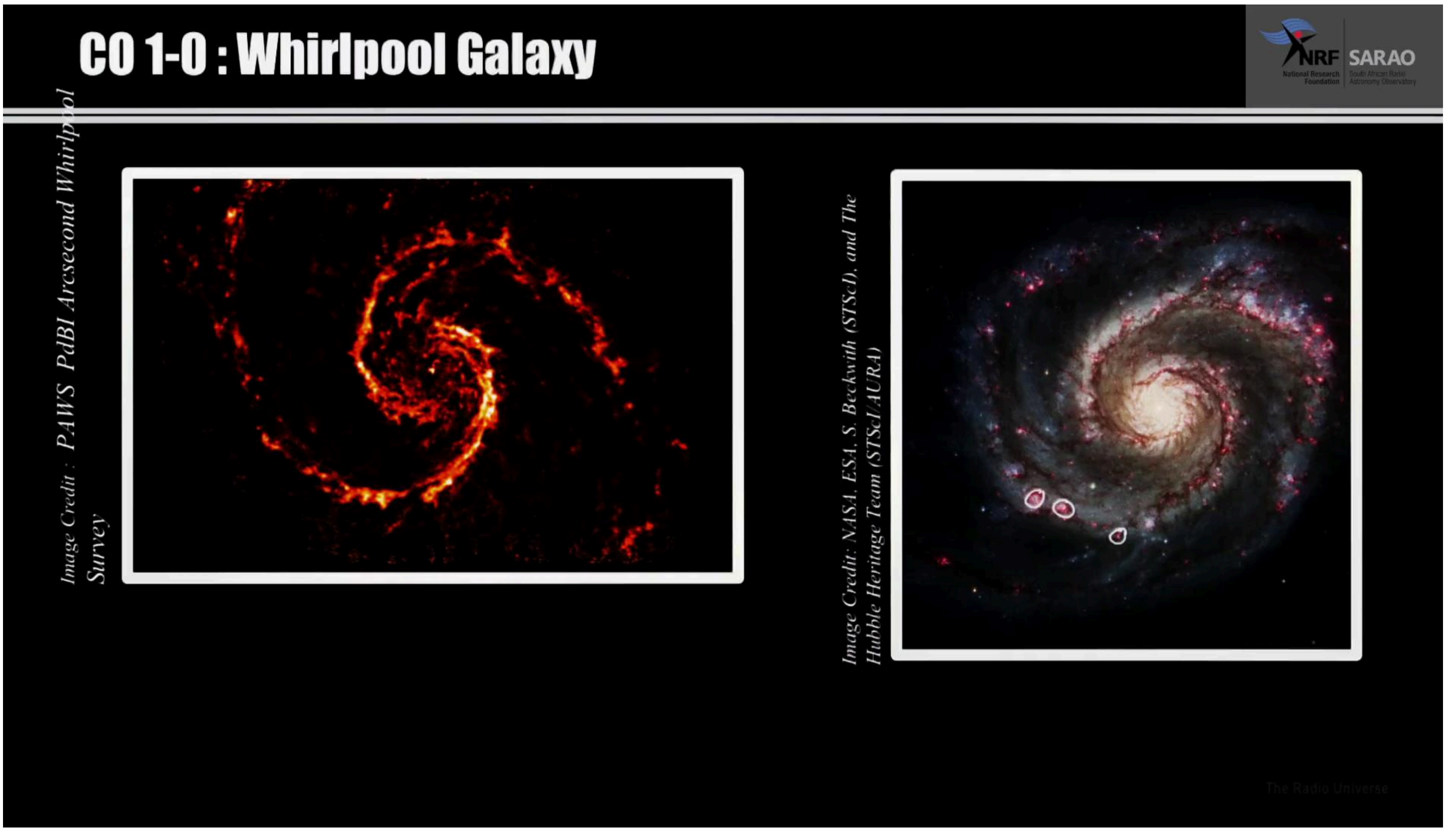


So the larger the mass of the molecule, the smaller the rotational energy and vice versa. And so in the very cold dense conditions that you have molecules in, remember, molecules will not survive if they're in a very hot environment. They'll be dissociated. So in the cold environments where these molecules are able to form and survive, you probably won't have enough energy to excite very low mass molecules to excited states because if you're a low mass molecule then you'll have a very high rotational energy and that will mean that you need a lot of energy to become excited. So in these situations it's only relatively massive molecules that are able to produce radio emission or spectral lines so that's another thing to bear in mind.

Notes

Summary

7m 44s



Here is an example of the CO one to zero line. So here what we have again are these regions that we saw before where we had 'H-alpha' so the red dots in this optical image are all the ionized gas. These are places where stars have already formed and have become hot enough to ionize the gas. We’re here when we look at the emission in the CO one to zero line. What we're looking at is very cold very dense gas where stars will eventually form but where they have not yet formed. This is the same galaxy just observed at different wavelengths.

Notes

Summary

8m 39s