PROFESSOR: OK. So I need to move on a little bit now, and I want to talk about in fact, the earlier way that nature developed to make energy using proton gradients. And this part actually preceded the development of respiration as you'll see. It's what I somewhat flippantly refer to as photosynthesis release 1.

In my first lecture, when I was giving you a sketch of evolution. Who knows, I mean these are very rough numbers, but may have evolved about $3.4 billion years ago and early life had begun to exhaust this sea of chemicals that had been produced. And it's known as cyclic photophosphorylation. And it's a way of taking the energy in sunlight and making ATP.

So whatever organism figured this out, this was a really big deal. Because now instead of having to use the sort of natural reserves like the way the food around is a depleting resource just like our petroleum reserves, this was able to take the abundantly-available sunlight and use it to make energy.

So that's the principle. It uses the energy in sunlight, and the way it does it, is it uses the sunlight to establish a proton gradient just as we've been discussing earlier, and then uses that to make ATP. And there's a special molecule that's involved in absorbing the energy from the sunlight. We've all heard it I'm sure, chlorophyll.

There are a couple of two major variants of this molecule. Here's one of them, chlorophyll a, and you don't have to memorize the structure. But I want you to notice a couple of things. One is there's a metal in the middle, a magnesium, and then it's coordinated with the cyclic ring system. And notice all the conjugated double bonds.

So this chlorophyll was tuned to absorb energy from the visible range of sunlight. And when it absorbs a photon of energy, it kicks an electron up to a higher orbital. And if the electron's in a higher orbital, it's more easily lost. And this has a consequence. So the way this system works is you have a molecule of chlorophyll, that's what I'm abbreviating here.

Oh, let me tell you something else too. It's more sophisticated than this. So this is the molecule that absorbs a particular wavelength from sunlight. But this is embedded in a multi-protein structure that has a bunch of other molecules that absorb at different wavelengths and then funnel that energy down to the one the chlorophyll comes in.

So in fact, the whole thing is like a big antenna that's able to absorb quite a bit of energy from different wavelengths in sunlight and get it down to the chlorophyll. When the chlorophyll absorbs energy, it goes up to an excited state. And as I said, now that the electron's in a higher orbital, it's lost more easily. So this has become a better reducing agent. It's able to give its electrons to things that it couldn't do down in this energy state.

So we come down one of these thermodynamic hills that you're hopefully starting to get used to where it comes down in little hops to a carrier that has this set level of energy, down, free energy, down. And similarly, to the principle that we talked about in respiration, a proton is pumped from what I'm going to say, in this case, I'll show you what I mean, but I'll say from a proton that's out to a proton that's in. And by doing that, it establishes a proton gradient, and that gives rise to ATP.

At the end of this cycle, we have this chlorophyll minus the electrons. These come, flow back. That's why it's called cyclic photophosphorylation. The electrons go through these carriers, and then they return to chlorophyll. So wonderful system. I seemed to have accidentally advanced this. OK. There are still bacteria around that run this system.

So if you remember, we talked about biosynthesis, the need for energy. Well, here we are. We got ATP. But there is something else hopefully you now appreciate in that is that ATP is not enough to take carbon dioxide and make it into sugars or carbon compounds. We need a source of reducing power as well. Because remember, carbon dioxide is the most oxidized form of carbon.

So these early organism solved it by making reducing power from another source. Many of them used hydrogen sulfide as a source, and they used NADP plus. Now, this is a minor variation of NADH. It's got one more phosphate on it. You can look it up in your book. This variant of NAD is used preferentially for biosynthetic purposes. But everything I've told you about NAD in terms of banking electrons applies here.

So the electrons from here are grabbed. The cell makes NADPH, which you can use as reducing power for biosynthesis. You get elemental sulfur and hydrogen ions. So this process an organism that used this kind of photophosphorylation to make ATP would get its reducing power through a process something like this. And then it could make sugars, and then from that point on, they can be used to make all the other molecules that you need.

The key thing is to get from the carbon dioxide down into a more reduced form of carbon. So that works pretty well. However, a better system came up involved in evolution. This was the one I again somewhat flippantly called photosynthesis release 2, when I was talking. This is known as, probably came up who knows again but maybe 3 billion years ago, and it's known as noncyclic photophosphorylation.

And what's important about this system and why it's an improvement over the other, is it uses the energy in sunlight to make ATP just as we've learned, but it also uses the energy in sunlight to make NADPH. So in other words, this second version gives the cell simply from the energy in sunlight everything it needs to take carbon dioxide and make it into organic compounds.

And it's a pretty cool system evolutionarily. It's built on the older one, the first arising one. You'll still see the elements of the present but with a new variation added in, very much the way we do design when you're doing engineering. You get something that's working, and you can use that as a basis to move to a new and improved version. And naturally, if you get a new and improved version, and you get a little advantage over your neighbors, natural selection makes sure that that better system gets established.

So here's here how this noncyclic photophosphorylation starts. We take a chlorophyll and it absorbs the quantum of energy, and it kicks itself up to an excited state. The chlorophyll, as before, electrons come down, energetically downhill and remember that theme. I keep saying that's at least thermodynamic properties. If we think about free energy, it doesn't matter what path you take. Whether you come shooting right down or you come down through it, you get the same energy back.

What's amazing about the system, if it didn't have all this extra apparatus, you'd kick up the electron, and then it would just come right back and you'd get a little radiated, a little energy given off. We wouldn't have accomplished anything. And what's terrific about this photophosphorylation system, it's able to capture the energy that's in that excited chlorophyll.

So at this point, and as it's coming down as I said, we have H plus going from H plus, H plus in. I'll give you a picture of what I mean by that. Then we're getting ATP made. So this time the difference is instead of the electrons going back to that chlorophyll, it was missing its electrons, the electrons, instead, go to a chlorophyll, which is at a somewhat higher energy level than the first one. And it has just absorbed quantum of energy, and it's kicked itself up to an even more excited state.

And these electrons from this system come on and fill up this chlorophyll. So this one over here is called photosystem II. And the term used in the field to describe what I'm about to tell you here is now called photosystem I.

So what we have now from this system is an excited molecule, chlorophyll, that's even more excited than we were before. And so it's even more able to give off its electrons. It has more reducing power. In fact, it has enough reducing power that it can reduce NADP.

So NADP plus, electrons coming downhill, you get NADPH. So here we are, reducing power made by using the energy in sunlight, ATP made using the energy in sunlight. So by just using this noncyclic photophosphorylation system, the cell's got what it needs to take carbon dioxide and put it through a sequence of reactions that will let it make sugars and other things.

In this course, I don't have enough time to go through the biosynthetic pathway. It's in your textbooks. You might find it interesting to look at. We're not making a big issue of it in there. But it exists, and you can see that it obviously exists. So there's one more wrinkle here which might be sort of eerily reminiscent of one of the issue I posed for you when I asked about whether we could just keep on doing glycolysis.

I can't just let the system run. I forgot about something so far. Over here, this guy lost an electron. It can't get it back because the electrons went over there. They have to come from somewhere. Well, the energetics of the system now are such that it can get electrons from water. And what's left over when you take the electrons from water? We have half of an oxygen molecule.

So here's the class. It's a waste product, if you will, from this very efficient noncyclic photophosphorylation system, but it's molecular oxygen. And it was when this system developed that we started to have oxygen appear in this world. The organelle that carries out photosynthesis, actually, the first organisms that learned how to do this is called cyanobacteria, which they sometimes sort of rather incorrectly call blue-green algae because they're bacteria. But you see cyanobacteria all the time.

And similarly to what happened with the mitochondria, there's no abundant evidence that the way photosynthesis happens in plants is a cyanobacterium got trapped somehow inside a early plant cell, and is now a permanent part of the plant cell. And it's called a chloroplast. So it's derived from a bacterium. If you see plants are green. If you can look in and see the chloroplast inside, this shows the chloroplast coming in.

And here's their basic structure. They too have a double membrane. They have an outer membrane. They have an inner membrane. They have a part that's called the stroma, and that's essentially, like the cytoplasm of a normal cell. And they have something in here called a lumen. It's a space, and the membrane that bounds it is a special membrane called a thylakoid membrane.

And that gradient is established by pumping an electron from the stroma, which I called out, into the lumen, which I called in. Again, the point is this cell managed to establish a proton gradient, and it's able to make the chloroplast, able to establish a protein gradient, and make ATP.

And there's a transmission micrograph of a chloroplast. You can see the thylakoid membranes inside. It's not too hard to imagine that that was, in fact, a cyanobacterium that got in there. And there's quite a bit of additional evidence that supports that.