# Transcript from Epic of Evolution: Life, the Earth and the Cosmos (BEP 210A)
## January 24, 2000 - Lecture by Claude Bernard

Okay, let's get started. Anybody know why the moon was red during the eclipse?

[Student: Does it have to do with light reflecting off Mars?]

No. That's a good guess though but no, not Mars --- something else that's red.

[Student: Was it light refracting through the atmosphere?]

Yeah, it's light coming through the Earth's atmosphere. The Earth is in the way of the sun but the light can go through the Earth's atmosphere and bend a little bit, get around and hit the moon. And I'm sure you know that when you look at the sun when it's low down in the sky at sunset or sunrise the sun is red. [In fact, we can explain that too but that's not part of this course. I won't go into detail of why that is. It has to do with the fact that the lowest frequency light (red light) is what can get through the atmosphere when it grazes through.] And so it lights up the moon with red light and what you're seeing in that red light is really all the sunsets and dawns around the Earth. Those sunsets and sunrises are in places about 6 hours different in time zone from where you are, which is in the middle of the night. So you're seeing sunsets and sunrises from around the Earth. Okay, that's not part of this course, but I thought it was cool anyway so I wanted to tell you.

I got some questions after last time, and I thought it would be worth going back and hitting a few of the points over again maybe in a slightly different way before I go on. One thing I wanted to emphasize --- because physicists get used to talking in a certain way, and we forget that other people aren't used to talking in that way --- is that when I say what we "see" out there I don't just mean when we look with our naked eyes. I also mean "seeing" with telescopes, but not only just ordinary optical telescopes where you see with ordinary light, but also all kinds of telescopes that we have available to us today: radio telescopes, infrared telescopes, gamma ray telescopes, X-rays, a whole range. And, in fact, being built right now are telescopes that can look for gravitational waves coming from distant parts of the universe. They're not finished yet but soon there will be another way of observing the universe by means of gravitational waves. And so when I say observable I mean in all these ways, not just what we see with our naked eyes. So I may use the words "what we can see" but I'm using it metaphorically --- I mean what we can observe in all these different ways.

Another point I thought was unclear was Olbers' paradox, the statement that if the universe was infinitely big and had been here for an infinitely long time, then the night sky would be completely white with all the lights from all the stars. As I said, if the universe were infinitely big and you looked out in any direction --- pick any direction at all --- eventually that direction would hit a star. And I think maybe the following analogy might help you understand why that would be true if the universe were infinitely big. Let's talk about a different situation: playing the lottery. Imagine you're playing the lottery, and they sell a million tickets. If you buy one ticket you have one chance in a million of winning. Now, suppose you play that lottery, and then the next day you play the next lottery, and you also buy one ticket. You again have one chance in a million of winning for the second lottery.  Suppose you keep playing every day.  Eventually if your money holds out, if you play let's say a million times, you start to have a pretty good chance of winning at least once in those million times.  It's not perfect.  You could lose every time if you're unlucky, but the chances are about 2 out of 3 that you're going to at least win once if you play a lottery a million times.  If you played the lottery 10 million times your chances of winning at least once would start to be very, very good.  If you played it a 100 million even better, and if you played the lottery an infinite number of times your chances of winning would be certain.  You would certainly win sooner or later.  Now, this is not a way to make a quick buck here.  The way lotteries are set up, obviously, so that the total amount of money you paid, in playing it a million times is going to be less than your winnings.  They're not stupid so on average they're going to make money on the lottery and you're going to lose money --- it's not a scheme for a quick buck here.  But it's true that if you kept playing, let's say you had a friend in the lottery business and the tickets were free and you kept playing once a day.  Then if the chances were one in a million, playing a million lotteries would give you a pretty good chance to win at least once.  And if you'd play an infinite number of times you would certainly win at least once.

Now, let's get back to Olbers' paradox.  If you go out in any one direction, let's say if you go out a billion light-years there might be one chance in a thousand of hitting a star.  But if the universe is infinite go out another billion light-years.  Again you have one chance in a thousand.  It's like playing the lottery again.  You have a new ticket for the next billion light-years.  You're playing the lottery again.  You again have one chance in a thousand.  If you go out a thousand billion light-years you'll start to have a pretty good chance of hitting a star.  And if you can go out infinitely far, if the universe continues infinitely, then your chances are certain that you'll eventually hit a star in any direction you go.  But note that you'll only get Olbers' paradox if the universe is not only infinite in space but has also been here for an infinite amount of time.  You've now gone out very, very, very far and eventually have hit a star, but for the night sky to be completely light it must be true that the light from that distant star has had a chance to get here.  So if the universe is young, not old enough for the light to have a chance to get here, it wouldn't matter that you'd eventually hit a star.  The night sky would still have lots of dark places.  But if the universe is infinitely old the light has a chance to get here from everywhere.  So under those two conditions the night sky would be completely white.  And obviously it's not completely white; therefore we deduce that either the universe is not infinite in space or the universe is not infinite in time (that is, it had a beginning, at least what we see had a beginning).  Or both.  It's possible that both could be true.

[Student:  Is there a possibility for multiple universes and would Olbers' paradox account for those?]

There is a possibility for multiple universes.  There could be somewhere else a different universe.  It's kind of hard to discuss it because we'd probably have no way ever of knowing whether such existed or didn't exist.  Olbers' paradox doesn't really say anything about that because if another universe existed, the light in that universe would be confined to it and can't get to ours.  And I'll kind of make some noises about that kind of stuff towards the very end of the semester.  But that doesn't really relate to Olbers' paradox because the light couldn't get to us from other universes --- only from our own.  Other questions?

[Student: What I don't really understand is wouldn't it be theoretically possible for there to be a point in the sky where you could go up forever and ever and not have a star there and still everywhere else have it extend forever?]

Well, not under the conditions that if the universe is really infinite and it's homogeneous. In other words, it's sort of the same everywhere. I mean if the universe ended, there were no more stars after a certain distance and it's just empty beyond that, if that were possible then what you're saying could happen. But if the universe really continued like it is out to infinity, having more and more galaxies and stars and so forth out to infinity, then the chances are zero that you would ever miss. Because sooner or later, you're playing the lottery an infinite number of times so sooner or later you're going to win, no matter what direction you pick. It's kind of a funny thing about infinity. It kind of stretches your brain. Yes, sir.

[Student: The question with infinity though, you used the example of the night sky being white and the thing is that a star does not live an infinite amount of time and so even if you could have the infinite possibility of in any direction finding a star wouldn't it be true that for there to be a star at any point at a given point in time so that the night sky could be white . . .]

I hear what you're saying. In other words, yeah, if the star died out after a certain time and was dark, then it wouldn't contribute to lighting up the night sky. But the assumption of Olbers' paradox is that the universe is the same everywhere as it is around us. Of course if the universe had been around for an infinite amount of time, an infinite number of stars already would have died out, but there would still be roughly the same number of live stars in every place that we have around us, and those are the ones we're talking about seeing. So you can't quite get out of it that easy. It's tricky though. In fact, the night sky ***is*** dark, and you don't really have to think about infinity so much because --- as I said at the end of last time --- the universe did have a beginning, the Big Bang. And it hasn't been like this forever, always the same. It's been changing; our universe is evolving. It's changing. There's a history, a story to it. It started, and then there were things happening. So that's what I wanted to say about Olbers' paradox.

Let me talk a little bit more. Right at the end I blew up this balloon, which was supposed to represent the expanding universe. On the balloon are little dots that represent the galaxies. As the balloon expands, as you blow it up, the galaxies get further and further away from each other. Well, let's do it. [balloon demo] As the balloon expands galaxies are moving away from each other. Every galaxy is moving away from every other one. Galaxies that are far apart from each other move away faster. Galaxies that are close move apart less rapidly. Now, let me emphasize that this is an analogy. The universe obviously is not a balloon, but there are lots of features of this that are true --- that correspond to the real universe --- and lots of features that are not true. So let me emphasize this, and then I'll take your question, if that's okay. Let me emphasize what's true about this, what part of it really represents the way things are and what doesn't. I think that'll help clear up some confusion about what I'm saying today and what I said on Friday.

What's true about it? Well, it's an example of a space. The surface of the balloon is a space. It's a two dimensional space. If you were sitting on the surface of the balloon --- imagine you're a little ant on the surface of the balloon --- you can move in two directions. At any place on the balloon you could move this or this way. You can only move in two directions, so this space on which these so-called “galaxies” are located is a two-dimensional space. Our world is a three-dimensional space so our galaxies aren’t like on a surface like a balloon expanding that way. We have a three dimensional space and our three dimensional space is expanding. That means in all three directions the space is expanding, things are getting further apart from each other as the expanding space carries them along. And in the balloon case as I expand the space that these so-called galaxies are on, they get further and further from each other. And the analogy is to our universe where, as this space expands, galaxies get further and further from each other. So one big difference between this example and the real thing is this is a two-dimensional space expanding, and ours is a three dimensional one. The reason I use a two-dimensional one is there are no examples we can see of a three-dimensional space that expands because it would have to expand into other dimensions. We can’t really picture that; whereas this thing as this surface expands it’s moving out as you see it into the third direction. We expand it by allowing the balloon to get bigger moving out into the other direction. In three dimensions, we don’t have an extra direction to look at so it’s hard to picture in your mind. In fact, nobody can picture it --- I certainly can’t picture how a three dimensional space expands. But a two-dimensional one you can picture. Okay, so that’s one big difference.

Another big difference is that I drew these galaxies on here. They’re drawn on this balloon. They can’t move on the balloon. The only motion that takes place is because the balloon itself expands. Now, in the real world, galaxies are not just carried around by the expansion of the universe. There’s also some motion through space. We can move through space. You do it all the time; I do it all the time. When I walk around, pace back and forth in front of the class, I’m moving through space. And galaxies can move through space also. So although this shows what the expansion of space would do, their complete motion would involve not only something like this but also movement on the balloon. Really a better example --- if I could train them to do it --- would be to have some trained ants sitting on this balloon instead of painted-on galaxies. The ants could walk around while the balloon is blowing up. And what you’d find then is that two ants who happen to be nearby could walk towards each other and actually approach each other. Even though the space underneath them is expanding, if they walk fast enough they can get closer to each other. Since the ants are close, the expansion of space doesn’t carry them apart very rapidly, and they can overcome that effect by walking towards each other. Two ants that are very far apart on the balloon, however, won’t be able to move closer together even if they try. They’re so far apart that the expansion of space is carrying them apart very rapidly, and they can’t possibly overcome that effect. Remember that Hubble’s law says that the speed at which objects move apart due to expansion of space is proportional to their distance apart. If they’re far apart already, the expansion increases their separation so rapidly that no matter how they walk around, they won’t be able to get closer. They’re going to get further and further apart.

So when you talk about things that are very far apart what’s going to matter is the expansion of the universe. Their own little motions, like the motion of an ant walking on the balloon, are what we call “proper motion” in physics. Their little proper motions might make a difference if they’re close to each other. They could overcome the expansion. In fact we’re overcoming the expansion of the universe all the time. This room is not expanding, which means that, very slightly, it’s actually moving through space. As the space expands, the forces that hold the room together (for example the forces exerted by the steel beams in the floor and ceiling) keep it from expanding with the universe. Those forces keep it at what we call a fixed size. If everything in this room were free, if there were no forces on anything in this room, everything would be slightly moving away from everything else because of the expansion of the universe. But of course we don't see that. We have extra forces on things that keep them from moving apart. As I mentioned last time, we're actually moving closer to Andromeda, our neighboring galaxy, not further away. And the reason is again we're like two ants nearby. We can overcome the expansion of the space between us. Our gravitational attraction towards each other is so great that we're actually getting closer and the expansion of the universe has a smaller effect. If you recall, Hubble's constant tells you how fast something is moving away because of the expansion of the universe. Hubble's constant is 20 kilometers per second for every million light-years. Now, Andromeda is only 2.5 million light-years away from us, so because of the expansion of the universe alone, it would be moving away from us at 50 kilometers per second. But on an astronomical scale that's not a very big velocity. In fact, because of our gravitational attraction to Andromeda, of the Milky Way with Andromeda, we're actually moving towards each other at 140 km/sec (= 500,000 km/hr), bigger than the effect of the expansion of the universe. So when things are close it's different. They can be moving around; our little ants can be walking around the balloon. But when you talk about things that are very far, nothing can overcome this very rapid expansion of the universe. So things that are far away are going to be moving very rapidly away from each other. Now, I had a bunch of questions.

[Student: Is the expansion going to continue forever, or is there going to be kind of an end? Does anybody know the answer to that?]

That's a very good question. Well, from the latest measurements it looks like the expansion will continue forever. We'll talk about this at the end of the semester. Now, this is not definite because these are new experiments, new measurements, and things can change, people can make mistakes. We don't know for sure, but it actually even looks like the expansion is accelerating. The rate is even increasing, which is surprising (but not impossible to explain). That's what it looks like. So it's not completely clear, but it looks like expansion will continue forever.

[Student: When we talk about expansion could I say then this is correct that the Earth itself is pulling apart?]

Well, the space that the Earth is in is pulling apart, but the Earth is being held together by forces of its own gravity as well as structural forces, which are preventing it from expanding like that. It's being held together. Although it looks like it's just sitting there, it's actually moving through space because it's not expanding with the universe. It's sitting there with the same radius as always. I'm going to take maybe two more questions because otherwise we'll spend the whole day doing questions. Yes, sir.

[Student: Would you say that the Earth is moving through a fourth dimension . . . like moving through time?]

I haven’t really tried to bring in the idea of time being the fourth dimension yet, but certainly everything is moving in time, and in many ways we think of time as being a fourth dimension. Yes?

[Student: But can things move like against time. I mean with black holes…]

Probably not, although even that is not 100 percent sure. There are some serious scientists who have thought about things like time machines. Probably it’s impossible is the general consensus, but it’s not 100 percent clear. As soon as you start talking about time machines you get all these contradictions. You come back and you kill your parents before you’re born and then what are you going to do? It gets very confusing and probably it’s impossible, I would say, but there are a lot of questions that we don’t know really the answer to. I’m sorry, I’m going to take just one more. Yeah.

[Student: I mean how strong is this sort of force pushing everything away? I mean it’s not strong enough to lift like my pencil off the table.]

On the scale of this room it’s extremely weak. Just remembering what the Hubble constant is. It’s 20 kilometers per second for a distance of a million light years. 20 km/sec is a pretty fast speed but that’s for a distance apart of a million light-years. So the effect in here, where the distances are just a few meters, is a very tiny amount of speed. A tiny, tiny force can overcome that. So this is not something you could ever measure for example in the laboratory or see in your everyday life. It’s something that we only can measure when we look at galaxies that are millions and millions of light-years or even billions of light-years away. Then we can measure it. By plotting how fast galaxies are moving versus how far away they are we can determine this thing called the Hubble constant. Okay, I’m sorry, we could this forever. I’d love to actually, but I do want to go on, so let me postpone questions. Some of these questions you can ask in discussion section. I’ll be there this week as well as next week, so if you have more questions we can keep going then.

Okay, so that’s my repair of my last lecture. Hopefully things are now a little bit clearer. Let me just show a very small snippet from a video called “Cosmic Voyage.” It’s an IMAX film. I’m just going to show about 2 minutes. They start with something one meter big and then show you 10 meters, 100 meters, 1000 meters, going up by powers of 10 all the way out to the edge of the universe. Unfortunately, this is not the biggest screen in the world but hopefully you’ll be able to see it. We’ll see other parts of this movie later on in the class. [Cosmic Voyage video clip.] I had trouble hearing that; last time it sounded like they said there were 100 million stars in our galaxy. There are actually 100 billion. They did say billion, okay. My TV at home, I heard it about three times saying 100 million and I said oh, no, that’s wrong. Good, they got it right, 100 billion. One comment: When they said the edge of our observable universe was 15 billion light-years away --- and I said the diameter of the observable universe was 80 or 100 billion light-years --- that difference has to do primarily with the subtle thing I was talking about last time. Fifteen billion light-years is about the distance that light has traveled from the furthest things we can observe. Fifteen billion light-years, that’s the distance the light has traveled to come to us, and that’s what they called the radius of the universe. On the other hand, you could ask a different question: “That furthest thing we can see, how far is it away from us *now*?” That’s a different question because in the meantime it's been moving --- while the light's been coming to us it's been moving away very fast. So if you asked a different question, how far away is it now, it's more like 40 or 50 billion light-years. That you be the "radius" of the observable universe, and the "diameter" would be twice that, or 80 to 100 billion light years. Yes, sir.

[Student: So does that mean there's a center of a universe. You said it was a radius so they'd be measuring from like the center of something.]

Well, that's a good question. There isn't a center. It's like this balloon (of course you have to ignore the little part where I blow it up). Think of it as just a sphere. Every point is the center because you could sit on any galaxy here and you would see your galaxy more or less at rest and other galaxies moving away, with a speed proportional to how far away from you they are. There's no difference between any one of these galaxies. Every point looks like the center but no point is any more special than any other point. That's a subtle idea. Yeah, we aren't the center --- even though if we look out we see everything moving away from us --- we're not the center. Every point is the center. Everything is moving away from everything else.

Okay, so things are moving away from us. As we go out further and further they're moving faster and faster. So if we see them moving away from us now that means in the past they must have been closer to us. We can imagine running the movie backwards. You see the things moving out. If you turned it around and ran it backwards you would see that in the past things were closer and closer to everything else. And we can run it backwards and in fact we understand the physics that describes the motions of these galaxies very well as we run it back, as they get closer and closer and closer. As what is now the observable universe gets smaller and smaller and smaller, we understand very well the physics that describes what they were doing. We understand the things that were happening until a point when the universe was extremely small. And at a certain point our knowledge of physics breaks down. We don't know what happens at that extreme density when things were very, very small, so we can't really know what it was like at the instant it began. Because at a certain point it's too small, too dense, and too hot for us to understand the complete physics.

Let me emphasize the following point: When things get compressed, when they get pushed together, they get hotter. You might know this if you ever have blown up a bicycle tire with a pump. If you felt the end of the pump after you pumped, you would have noticed that it was quite hot. You're compressing the air with the bicycle pump, and as you compress things they get hotter. In the past, when the universe was much more compressed, much smaller, pushed in a much smaller region, the temperature was much, much higher. So as we run the "movie" of the universe backwards, we know that it was hotter and hotter, earlier and earlier. But eventually it gets so hot and so dense that we don't understand the physics and don't know what happened earlier. So there's a question mark at a certain point.

Where is that question mark? Well, let me draw a little picture here. So let's go back in time. Imagine this is one of the galaxies on one end of what's observable to us. We're somewhere in the middle. If we look this way we see this galaxy is moving away from us now and this other galaxy in the other direction is moving away from us now. And in the graph I'm making, the vertical direction is time. Since the galaxies are moving away from us, in earlier times those two galaxies and our galaxy are all closer together. And as we keep extrapolating back eventually things get so close, so hot and so dense that our knowledge of physics breaks down. We don't understand the physics that describes how these things will interact at that point. So at a certain point here --- before they actually meet --- it becomes a question mark, and I'll say where that question mark is in a minute.

Just imagine for a second that we did know what happened at the question mark, in other words, that we could use just the physics we know now. Imagine we could extrapolate these things all the way back to a single point. (Probably the whole universe was never actually in one single point, although you'll read about that in various books that aren't very careful.) Let's say that the time when everything would have been right on top of everything else is the time we start counting. We call that time t = 0, the time equals zero, the beginning of the time of our universe. But in actual fact the time t = 0 is just the time at which we don't know what's happening. It's when we start counting: where everything would be at a single point if the physics were the same as the physics we've learned about already. But in fact we have very good reason to believe that the physics we know now doesn't apply then. So probably it didn't become a point --- we don't know what happened. There are question marks there. But we still call that time 0, and we call that instant the Big Bang. Really of course our knowledge starts a little bit after the Big Bang because this point where t = 0 is the time where we don't have knowledge about things. Our real knowledge starts after that.

Now, let's ask, "When do we really know what's happening; how soon after the Big Bang do we really understand the physics?" Well, it depends a little bit on how well you want to understand the physics. If you want to really know everything and have everything completely calculated and so forth --- if you want to really say that we know everything about it --- you have to go back to maybe a hundredth of a second after the Big Bang, .01 seconds. At that point we really know what's going on. It doesn't sound like a long time, and it's kind of neat that we can really say something about what's happening at a hundredth of a second after the Big Bang, but at that point the physics is very clear to us. At that temperature and at that time we know what was happening. If you're less picky and you just want to say that you basically know what's going on, have good knowledge, then we can go back to something like $10^{-10}$ seconds. That's one 10 billionth of a second, which means .0000000001 (if you started with 1, you'd have to move the decimal point 10 places to the left). There we don't everything, but we have a pretty good idea of all the processes that take place.

We can even go back further --- this is the place I'm going to start, which is someplace about here in this picture --- where we understand the main features, but the details are quite hazy. That's a pretty early time. It's $10^{-32}$ seconds after the Big Bang, and that's the place I'm going to start. As I said, there's a fair amount of haziness between here and the next line, and a little bit of haziness between there and the third line, and after that we are pretty sure about what's going on. Before $10^{-32}$ seconds, it gets really speculative and I will talk in one lecture about what happened down to $10^{-34}$ seconds. There are some very interesting things that may have happened in that little time between $10^{-34}$ seconds and $10^{-32}$ seconds. So in that range there are some interesting things, but we don't know it that well, and I don't really want to claim that we can say what was going on. At $10^{-32}$ seconds, at that point, we have a pretty good idea, so that's where I'm going to start. I'll be giving in the next few lectures sort of a brief history of the universe, from $10^{-32}$ seconds till now. Then we'll go back and look in more detail at certain periods, certain epochs in the evolution.

All right, so here we are. We're at $10^{-32}$ seconds. How big is our observable universe? By that I mean we've been talking about what our observable universe is now, which is something on the order of 80 billion light-years across. All that stuff, how big was it at this time, $10^{-32}$ seconds? Well, it was the size of a beach ball, about like this. Our entire observable universe was the size of a beach ball about 30 centimeters in radius. Thirty centimeters is about a foot. So the entire universe is sitting here in a little beach ball. Of course to cram it all in there it had to be very, very compressed and had to be very, very hot. The temperature at that time was something like --- and just for the fun, I'll actually write the number out with zeroes --- 3 x $10^{26}$ degrees. Physicists use a scale of temperature called the absolute temperature, or Kelvin. Basically a degree Kelvin is the same as a degree Centigrade or Celsius. They're different in what you they 0. For most purposes it's basically the same as Centigrade -- most purposes in the early universe anyway. The amount of change in temperature that 1 degree Kelvin represents is the same as 1 degree of Celsius or Centigrade but the 0 is different. Centigrade calls 0 degrees the freezing point of water. Kelvin calls 0 degrees "absolute zero," where all motion ceases, and so 0 degrees Kelvin is actually -273 degrees Celsius. Here, we're talking about 3 x $10^{26}$ degrees, which I will now write out, 30,000,000,000,000,000,000,000,000 degrees Kelvin. Okay, I have 26 zeroes here I hope if I did it right. You don't have to copy it down. I just wanted to write it down for the fun of it. At that enormous temperature, the difference between Kelvin and Centigrade is totally irrelevant. It's extremely hot; it's extremely compressed. The time is $10^{-32}$ seconds after these question marks (which we don't understand), and that's where I'm going to start. And then we will trace this thing out to where we are now.

Now, in order to trace it I'm going to need to introduce a cast of characters, the important physical entities that appear in this story. So I want to start with a cast of characters and then trace what happened to these characters. I'm not going to give you all the minor characters, just the major players. One of the major players I already introduced, although I didn't tell you everything about it that I want to tell you now. The first player of my cast is electromagnetic waves, sometimes called electromagnetic radiation. And electromagnetic waves have regions of strong electric and magnetic fields followed by regions of weak electric and magnetic fields, one after the other, traveling along. They are similar to sound waves, which have regions of compressed air followed by spread-out air. In sound, the compressed regions arrive one after another at a certain frequency. And for electromagnetic waves what takes the place of compressed air is a region of strong electric and magnetic fields.

We already talked about some electromagnetic waves. Some of the electromagnetic waves are what we call light. Visible light is an example of electromagnetic waves. As I mentioned last time it goes from smallest frequency of visible light is red and then red, orange, yellow, green, blue, violet. Some of you may have learned it with indigo sitting in there between blue and violet. Nowadays for some unknown reason, I don't know why, the books don't consider indigo a color anymore. It kind of got dropped so they go right from blue to violet. It's a matter of definition really, what you call a different color, and usually we don't use indigo anymore. So there's visible light, and this is high frequency of light and here is lower frequency. But electromagnetic waves are not just confined to having frequencies that we can see as visible light.  There's a whole range of electromagnetic waves with frequencies lower than what we can see and with frequencies higher than what we can see.  In fact, just below what we can see as red are rays that we call infrared.  You've probably heard of infrared rays, sometimes they're called heat rays but the better term is infrared.  Infrared means below red, they have a lower frequency than red.  So frequency is increasing to the right here and of course the other way is decreasing frequency.  Well, if lower than red is infrared, what's higher than violet?  Ultraviolet, that's right, so we have UV or ultraviolet.  Those are higher frequencies than we can see but they can affect us.  In fact, ultraviolet rays are what give us sunburn --- if you're vulnerable to it.  So ultraviolet is of higher frequency than visible.  Actually some creatures like honeybees can see ultraviolet light and they use that to determine where they are and where the sun is and navigate to the flowers.  But this goes on.  It goes on beyond ultraviolet.  There are electromagnetic waves which we call X-rays.  When you go to the dentist or you have a chest X-ray that's what they're using, electromagnetic waves of very high frequency.  And even beyond X-rays is something called gamma rays.  We use the Greek letter gamma for them or sometimes just write it out, gamma.  Gamma rays include anything higher in frequency than X-rays.  We don't bother with any new names: the frequency could be arbitrarily high, and we would still call them gamma rays.

Going the other way below infrared the next frequency are microwaves.  Remember we're going to lower and lower frequencies now.  Below microwaves, radar.  Those are also electromagnetic waves, just a lower frequency.  Below radar we have things like TV and radio.  First UHF TV, and then regular TV and FM radio, and then AM radio.  The electromagnetic waves that carry the signal in AM radio are down there at some rather low frequency, at least compared to light. I'm not going to write all the frequencies nor am I going to ask you to know the frequencies of these things. But just to give you some sense, down here at AM radio, KMOX is 1120 kilohertz. A hertz is one oscillation in a second, and kilo means a thousand, so it's 1120 thousand big and then small electric fields in 1 second.  It's 1.12 million oscillations per second.  By oscillation I mean going between a strong field and a weak field: strong field---weak field, 1.12 million oscillations each second.  That's a low frequency.  That's AM radio.  And you can have something called long radio, which is not really used for any commercial purposes, even beyond that and you can have frequencies also as low as you like.  At one time they were trying to communicate with submarines using electromagnetic waves of about 20 cycles per second. You can make them repeat as slowly as you want as well as rapidly as you want.  In visible light, the frequencies are about $10^{14}$ to $10^{15}$ oscillations per second --- just to give you some idea of the frequencies involved here.  So this whole range is what we would call the electromagnetic spectrum, the possibilities for electromagnetic waves.

So the frequency says how often you go between a strong field and a weak field.  There's something else that you can use to describe the wave, which is the distance in space between one region of strong field and the next one. That distance is called a wavelength.  So you can picture the wave as a train of these things moving along.  The distance between one and the next is called the wavelength.  How often these things arrive is called the frequency.  If you stand here and you see $10^{14}$ of them arriving per second then that's light red light.  If you see only a million arriving per second then it's something like radio waves, AM radio.

OK, more next time...