The Physics of Interplanetary Space

Lecture by John W. Bond
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55 minutes, 16 seconds

Speaker: John W. Bond

Transcribed by: Sherry Yin

Time	Transcription
00:00	Mrs. Marian Longstreth: It gave me a great deal of pleasure to welcome so many students who have what [Albert] Einstein has called so beautifully, holy curiosity. That means that you can have just as much fun if not more fun learning something when you have a little free time. These lectures have been planned for you by the Theatre and Arts Foundation of San Diego County in cooperation with Convair, General Atomic, and the Scripps Institution of Oceanography. They have planned to bring you in contact with the many able scientists who are now making their home in San Diego County, men who are working here on some of the most challenging problems that man has posed to himself. They are very busy men and men to whom time is precious but they are anxious to help the scientific education of young people along in any way that they can. They want you to understand the age which you are living in now and to prepare you for the age which they are working on now. We don't know what's going to happen from year to year with the problems that are now being researched.
	Mrs. Marian Longstreth: Our speaker today is the chief of physics at Convair and it is due to him that the series of five lectures which you are going to have this fall has been planned. He selected the speakers and consulted with them on the topics about which they were to speak. He did his graduate work at the University of Chicago and received his Ph.D. in theoretical physics from the University of Mexico. During the war, he worked on the Manhattan Atomic Bomb Project, doing research on gaseous diffusion. Later going on to Los Alamos where he worked on neutron diffusion. Before coming to Convair, he was at Lockheed, concerned with the problems and physics involved in the development of the hypersonic missile. He’s going to talk to you now on the physics of interplanetary space. I take great pleasure in presenting to you, Dr. John W. Bond Jr., Dr. Bond.
02:40	[Audience Clapping]
02:51	Dr. John W. Bond: Thank you, Mrs. Longstreth. A year ago, if one had asked the average scientist what problems are, what problems, what physics problems are connected with flight in outer space. He’s apt to have scratched his head and, and said there aren’t really many problems. It's a vacuum up there. During the past year, the situation has changed considerably. I’d like to quote to you from a translation of a Russian document chain dated March 21, 1958. Soviet scientists, engineers, technicians, and workers constructed for the first time in the world an aircraft capable of operating for a prolonged length of time and reaching interplanetary space. Such aircraft are the intercontinental ballistic rockets which were successfully tested in August 1957, and also the Soviet artificial Earth satellites. The first Soviet artificial Earth satellite was successfully launched on 4 October 1957, and the second significantly improved on 3 November 1957. The ballistic rocket and the first satellite were carried to distances from the Earth approaching 1,000 kilometers.

04:33 Dr. Bond: The farthest point of the orbit of Sputnik 2 was at a distance of 1,700 kilometers from the Earth. Here's the significant part of this. These events opened up a new era in history, the era of the conquest of interplanetary space by man. From this viewpoint, the recent achievements of Soviet science and engineering may be compared with such events as the invention of the steam engine, the invention of radiotelegraphy by AS [Alexander Stepanovich] Popov, and the utilization of nuclear energy. This ends the quotation. To scientists and especially physicists who have been working in basic physics, these facts, and they are facts, have had a particular significant impact. The launching of Sputnik one year ago truly did start a new era in science and in particular, in physics. It pointed out to people, the scientists who are considering space flight, that space is not a vacuum, that there are a lot of phenomena in outer space that must be considered if one is to attempt to launch a rocket or satellite in outer space.

05:58 Dr. Bond: It was as a result of Sputnik, of the Sputnik launching that scientists began to seriously consider the physics of outer space. Now, I don't want to say that no scientists have been working on problems of outer space. People have been thinking about stars and planets and meteors and cosmic rays for a good many years. What I want to talk about today is some new phenomena that while we were aware of some of these things a year ago, we didn't consider them as being serious and now the situation has changed quite a bit and it's, I want to point this out today. I want to make it clear that there are these new phenomena in outer space about which we know very little and about which we hope a lot of you will eventually someday start to think about.

06:59 Dr. Bond: If I could have the first slide. This slide summarizes a few of the phenomena about which we are concerned today. One of the important things to keep in mind here is that the vacuum that exists in outer space is a far greater vacuum than can be achieved in a laboratory. This is one of the reasons why so many of these phenomena are new. Now, listed on this chart are first of all the density and now we have to consider not only the density of neutral particles but also the density of charged particles and I'll come back to the definition of these concepts in a few minutes. Secondly, we have to consider the temperature and what it means in outer space and there's two temperatures we have to consider now, no longer just one temperature. These are called the plasma temperature and the electron temperature.

08:04 Dr. Bond: The third point here is that space and let me define now what I'm talking about when I say space. I'm talking about the atmosphere above something like a few hundred kilometers and I'm not going much past in the present talk, much past maybe 4 or 5,000 kilometers. So we are talking about the space close to the Earth but between the Earth and the Moon. Next item here is radiation. Ultraviolet radiation exists at only a very low level at the surface of the Earth and it's very intense in outer space. And then there's charged particle radiation about which you've been reading in the newspaper lately, a new phenomenon found by the satellites. The fifth item that must be considered is the effect of magnetic fields, the Earth's magnetic field in particular. And the sixth is what is the drag on a satellite or rocket in outer space. It is not zero. It's not negligible and there are two types of drag. There's a free molecule drag and charge drag and I'll explain these phenomena in a few minutes.

09:23 Dr. Bond: Now, before discussing these items and I'll try to adhere to the order indicated, I'd like to explain a few fundamental, fundamentals of atoms and molecules. Can we have the lights, please? If we consider a solid first, a solid let's, let's take iodine for example, iodine used to, as a disinfectant, as a medicine. Iodine exists in three states. It exists as a solid, as a liquid, and as a gas. Now, if we consider the solid state and perhaps try to draw what it may look like, it would be a crystalline structure and perhaps you can't see that. What I'm drawing here now are the molecules that exist in the solid state of iodine and this is just schematic. I'm just indicating this type of diagram to show you that in the solid state, the atoms can be considered as billiard balls and they are almost right next to each other. We're now considering a solid and this is iodine, for example, and we're considering the atoms as billiard balls and the size of the billiard ball here is approximately 10 to the minus 8 centimeters in diameter. This means if 100 million of these atoms lined up side-by-side would fit in one centimeter, which is about a third of an inch roughly. Now, if we go into the next state, this state is a solid. If we go into the next state of matter which is a liquid, these atoms just separate a little bit but not much different than this except now they're free to, to move around.

11:38 Dr. Bond: However, if we go to the gaseous state, then these atoms separate quite a, by quite a bit. And on the same scale for example, in a size like this perhaps there might be one, one atom, something of this sort. Actually, in a solid, we might say there is, there would be about a hundred million of these per centimeter in a gas at sea level conditions, of conditions exist here in the room today, there might be something like a, like one million of these atoms to the inch, to the centimeter. Now as one goes up in altitude, the pressure drops and the number of atoms per cubic centimeter decreases. Let's go back to this a little bit more. Now, I indicated iodine here as a diatomic molecule. That is there are two atoms of iodine per molecule and it really looks something like this in a gaseous state the two atoms are stuck together with something like glue. I'll go into that a little bit more later on. Now, this is similar to an air atom, an oxygen atom, or a nitrogen, not an oxygen molecule or nitrogen molecule and also the density conditions for air are as I just quoted, about 10 to the 19th of these molecules per cubic centimeter at sea level. Now, as one goes up in altitude, the pressure decreases and the number of particles per cubic centimeter decreases.

13:27 Dr. Bond: As one reaches an altitude of something like 300,000 feet or higher, the molecules are separated by a distance which is roughly comparable to the size of a vehicle that may fly at those altitudes. And this means that at some altitude above something like 300,000 feet, the flow of these particles about a missile moving at high velocity through air is quite different than it is below some altitude like this. In the next slide, I've shown a picture of a hypersonic missile flying up out of the atmosphere in the lower regions, that is below 300,000 feet. Can we have the next slide, please? This is a schematic diagram of a hypersonic missile moving up through the atmosphere. The definition of hypersonic means very roughly something, an obstacle, an object that goes faster than five times the speed of sound. In this case, this missile here might be going at something like Mach 15 or Mach 20. Again, Mach 20 means simply 20 times the speed of sound, speed of sound being very roughly 1,000 feet per second at sea level in the atmosphere.

14:55 Dr. Bond: Now, I don't want to go into much detail on this diagram. The missile itself is depicted in the middle in the shady area; it looks like a bullet. And the black region around the outer edge is a shockwave that precedes any missile that moves faster than the speed of sound through the atmosphere. But the important point I want to make in this slide here is you notice close, sticking close to the missile there is what's called a boundary layer. Now, this boundary layer consists of molecules that adhere close to the surface, stick to the surface and they form a layer that exists around the hypersonic missile below altitudes like 300,000 feet. Now above altitudes like 300,000 feet, this boundary layer no longer exists and this flow field as we see it here no longer exists. The flow conditions are quite different. Again, this is a situation we have not been able to realize in the laboratory yet. If we may see the next slide.

16:14 Dr. Bond: This slide indicates how the number density of the particles, that is the number of atoms or number of molecules per cubic centimeter varies with altitude. At sea level, you can see that the number of particles and this is the number of oxygen and number of nitrogen molecules, the total number is a little bit greater than 10 to the 19th per cubic centimeter. Now, as the altitude increases, this number decreases very significantly until, at altitudes like 2 to 300 kilometers, the number density has dropped to something like 10 to the 7th or 10 to the 8th particles per cubic centimeter. This is one very significant difference and at still higher altitudes, at 600 kilometers and higher, the number density decreases quite a bit more. Now, if we may see the next slide, please. Another thing that happens to the atmosphere as the altitude increases is that at some altitude like 90 kilometers, the oxygen, the oxygen molecules start to dissociate. This dissociation now is due to radiation from the Sun and this does not reach the surface of the Earth because, because it goes into the dissociation of the molecules. Now, you'll note here over at the zero end of the scale, the molecular weight is 29. What is the molecular weight?

18:01 Dr. Bond: This is the, this is a number indicating the amount of mass that the molecule, in the molecule and it's not, it is dimensionless here or actually in here it's grams per mole. That's 29 for the average air, air atom and this is based on an average of 28 for nitrogen, molecular nitrogen, and 32 for molecular oxygen. At 90 kilometers, the oxygen starts to dissociate so now the gas, the air above 90 or 100 kilometers is composed of atomic oxygen and molecular nitrogen until we get down to something like 120 to 160 kilometers. And here the molecular nitrogen starts to dissociate so that at very high altitudes like 400 kilometers for example and above, most of the molecular gases in the atmosphere are dissociated and there's left only atoms, oxygen and nitrogen atoms. Now, before we go to the next slide, I'd like to talk a little bit about ions and electrons. Could we have the lights, please?

19:38 Dr. Bond: Now, the first approximation that we made here was that atoms and atoms can be considered as billiard balls. Now, the next approximation I want to make is the Bohr atom, this may be something that most of you have not heard discussed so I'll try to make it very simple. Now, an atom is not really a billiard ball. It's primarily a nucleus which is positive and the nucleus consists of neutrons and protons but we won't go into details to that. Symbolically, revolving about this nucleus are electrons. These electrons revolve in specified orbits about the nucleus. The nucleus is charged positive, the electrons are charged negative. It's somewhat similar to the gravitate, to the, to the solar system, the planets revolving around the Sun. The only difference is that the, in the case of the solar system, its gravitational attraction between the planets and the Sun that keeps them in the orbits; in the case of an atom, its electrostatic attraction between the electrons and the positive charge nucleus that keeps them in the atom.

21:10 Dr. Bond: Now if something happens to this atom here, for example, a photon from the Sun, a high energy photon from the Sun can strike this atom and it can knock out this outer electron so that one would be left with a positively charged ion, because the negative electron is now lost, and a negative electron. Now, this is a phenomenon that happens at high altitudes. The atoms that we saw on the last slide at very high altitudes above 100 kilometers are hit by the ultraviolet radiation from the Sun. This has high energy, it has enough energy to knock off the outer electrons of the atoms. The reason I want to bring this up is because the electrons in outer space play a very important role. Now, if we could have the next slide, we'll see how the electron density increases with altitude.

22:31 Dr. Bond: Plotted here is the altitude versus the number of electrons per cubic centimeter. One can see that below 100, below 100 kilometers, the electron density is, is quite low, particularly at night, in daytime it goes up quite a bit. Now at higher altitudes above 100 kilometers, the electron density reaches a fairly constant value of about 10 to the 6 electrons per cubic centimeter and this stays fairly constant up to about 600 kilometers and from there on up. If one goes all the way to the Moon, for example, it goes down to about 1,000 electrons per cubic centimeter. Now, this plays a very important role. These numbers, this number density of electrons plays a very important role in satellite phenomena. In the next slide, we can see the ratio of the number of electrons to the number of neutral particles. Now at low altitudes on this slide below something like 200 kilometers altitude, we see that the ratio here, remember this is the ratio of the number of electrons to the total number of particles is less than 10 to the minus 4. That’s less than one part in 10,000.

24:04 Dr. Bond: At approximately 250 kilometers altitude, the electron, the ratio of electron density to neutral particle density is about 10 to the minus 3. That’s one part in 1,000. Now, it turns out that it's right at this point if the, if, this is called the degree of ionization, if the degree of ionization is greater than one part in 1,000, then the gas can be considered as a plasma. If it's less than one part in 1,000, then it can be considered essentially as a neutral gas for purpose of discussion here. Now, you’ve heard a lot in recent months and years about plasmas. You've heard about the new field of magneto-hydrodynamics, thermonuclear fusions, and so forth. Plasmas play a very important role here, plasma. The plasma state of matter has been called by many people a fourth state of matter. We had solid, liquid, and gas and now we have plasmas. One of the reasons for calling it the fourth state of matter is because not very much is known about plasmas and, so we don't know much about the characteristics of upper space, of outer space, of the ionosphere. The ionosphere now starts about where this, where I’ve indicated on the chart here, plasma characteristics exist. And as one goes up in altitude, you notice that the degree of ionization continues to increase until somewhere between about halfway between the Earth and the Moon, the degree of ionization is about one. That is about one electron to each neutral atom.

25:53 Dr. Bond: Now, I want to discuss just a little bit a rather complicated concept which is called plasma shielding and this plays a very important role in the phenomenon which I want to mention a little later. Let’s have the next slide, please. Now, what happens when you’ve got a gas with electrons and ions in it? As I already indicated the electrons are attracted to the ions. That is negative and positive charges attract each other, like charges repel each other. This is a schematic diagram, again and indicated in the center, that is the, there's a positive charge with a circle around it, that attracts negative charges which are indicated by the minus sign, they surround it. Now, these negative charges in turn attract positive charges which surround them and so on. Now there will be some distance from that particle in the center, that is from the positive charge with a circle around it at which this phenomenon is no longer important. Now, this distance is called the Debye shielding distance. I'll write it down here when the lights go on. D-E-B-Y-E, the Debye shielding distance.

27:23 Dr. Bond: Now, this plays an extremely important role in plasma problems. Just to review what I've said that above something like 250 kilometers, the gas, the air, and outer space, and ionosphere can be considered as a plasma. It has plasma characteristics. One of these characteristics was this shielding phenomenon. I'm going to discuss a little bit later some of the results that have been observed. But the next item on the chart was temperature. Temperature is really a measure of the velocity or the energy if you like of individual particles. At sea level, there are so many particles per cubic centimeter that it's a collective sort of phenomenon, one isn't puzzled by any concept of temperature but in outer space where the particle density is very low. It's a little difficult to understand what temperature is and here one should consider it as, as a measure of the energy of the individual particles. Could we have the next slide, please?

28:43 Dr. Bond: Now in this slide, it's showing the temperature, the, the altitude versus the atmospheric temperature. It starts in at 100 kilometers on the ordinate and there the temperature is about what it is at sea level, roughly a few hundred degrees Kelvin. That's roughly zero degrees Centigrade. Now going up in altitude, however, aside from the little kink there at between 100 and 200 kilometers, the temperature seems to increase roughly linearly. Now again, we have a new concept which I'll mention in a moment. This is atmospheric temperature. This is the plasma temperature. It's the temperature of the molecules of the atoms. It's a measure of the energy of the individual atoms, of the individual molecules. Dr. Bond: Now, you remember from one of the previous slides that at something like 250 kilometers, the number density of electrons becomes quite large, and at higher altitudes, it becomes, it approaches the number density of the neutral particles. However, there's a different phenomenon as far as regards to the temperature of the electrons. At something like 300 kilometers and in the daytime, the electron temperature is of the order of 7,000 degrees. That's quite a bit higher than the temperature of the atmosphere here and if one goes still higher, say at 600 kilometers altitude, the temperature goes on up to 13 to 14,000 degrees Kelvin.

30:25 Dr. Bond: Again, almost a factor of 10 higher than the atmospheric temperature. This is another new phenomenon that must be taken into account in calculating satellite effects and rocket flights in outer space. Now, another phenomenon that we must consider is the magnetic field of the Earth. Could we have the next slide, please? Now, this rather complicated diagram indicates the, an idealized picture of the magnetic field of the Earth. Now note the scale, the Earth is the, that's one-quarter section of the Earth indicated by the shaded region in the lower left-hand corner. Now distances are indicated in megameters. That's one million meters. Let me indicate here. This is, where I pointed there was one megameter; that's one million meters above the surface of the Earth. So, we're going at quite a distance out in this, in this magnetic field. Now, this is the field of a dipole. It's a sort of field that you would observe if you had an iron bar magnet and you sprinkle iron filings around it and shake the glass; you've probably seen this demonstration. It will form in lines of force as indicated by the heavy lines there. Those are called magnetic lines of force. Now, these play a very important role and I'll indicate this in the next slide.

32:09 Dr. Bond: Radiation exists in outer space. This mysterious radiation discovered by some of the satellite measurements of [James] Van Allen. It was also discovered by some of the measurements of the Russians. Now what happens here is that the radiation in outer space - that is the charged particle radiation now, which consists of electrons and protons - these charged particles interact with the magnetic lines of force of the Earth. First of all, let me say these charged particles probably come mostly from the Sun although some of them may come from other stars and other solar systems. Now, the phenomenon, the interaction phenomenon here is indicated by these equations. The first equation gives the formula for the force on electron if it interacts with a magnetic line of force, after the force and that's equal to evB. E is the charge on the electron, V is the velocity, and B is the magnetic field. That is an attracting, attractive force.

33:27 Dr. Bond: Now, the next equation over, that is on the same line, mv squared over r. This is the centrifugal force. Now, force is a vector and it has direction and that is not indicated in this equation here. However, the force will be perpendicular to the direction of the magnetic field and to the plane of the direction of magnetic field and of the velocity of the electron. And the direction of the centrifugal force is towards the attracting center. This, this, the combination of these two types of forces makes the electron revolve about that magnetic line of force. B indicates the magnetic line of force and is like those solid black curves shown on the previous slide. Now, one can solve this equation, the first equation, for the radius and that's shown in the next equation. The radius, that is the distance as indicated on the curve there, the radius of revolution of this electron about the magnetic line of force is given by the mass of the electron times the velocity divided by the charge on the electron times the magnetic field strength. Now the frequency is given in the next equation and the Greek letter there is omega. That's equal to the ratio of the linear velocity, v, to the radius r. And again, substituting from the above equation, this is equal to the electron charge times B divided by the mass of the electron.

35:30 Dr. Bond: And finally the period, that is the time required to make one revolution, is given in the last equation as 2 pi divided by omega, which is 2 pi times the mass of the electron divided by the electron charge times the magnetic field strength. Now, the reason this is of importance is because when these electrons come in from the Sun or wherever they may come from, their, they hit the magnetic lines of force of the Earth which we saw in the last slide. They are stuck on these magnetic lines of force and you can see the direction of velocity has changed so they must follow the magnetic lines of force. Now, they follow these lines of force on down to the polar regions and you remember the slide showing how the Earth's magnetic field lines converged at the poles. Well because of this converging effect at the poles, the electrons or other charged particles that have been spiraling around the magnetic field lines are reflected. They are reflected near the poles and they go back to the other pole. For example, an electron following a magnetic field line down to the North Pole will be reflected and go back to the South Pole and back and forth, back and forth until eventually it will be absorbed in the outer reaches of the atmosphere, that is the ionosphere.

36:55 Dr. Bond: This absorption process causes radiation, The inverse of the, one of the first, well still, this figure of the Bohr atom I had, I indicated a photon, a particle of light if you like coming from the Sun knocking an electron off of an atom. Now, the reverse happens in ionosphere. An electron comes in on one of these magnetic field lines hits an atom or molecule in the polar regions and is, and sticks to the atom. And in the process of sticking, a photon of light is given off and this is what one observes when you see the aurora. Well, there's one other point I should mention before closing. Many of these phenomena that we've talked about today are of importance - perhaps we could have the lights - are of importance to satellite and drag, to satellite and rocket flights in outer space.

37:56 Dr. Bond: One of the interesting phenomena is the drag on a satellite in outer space. What happens here is that the electrons and ions that exist in outer space stick to the surface of a satellite as it passes through the, passes through outer space, and the surface becomes charged, turns out it becomes charged negatively. Now the interaction between this charged satellite and the plasma in outer space sets up a new kind of drag, which we call charge drag. Not much is known about this phenomenon except that it's probably more significant at these, at higher altitudes than is the free molecule drag which exists at say above 300,000 feet. These are some of the new phenomena that people are thinking about today and there is an enormous amount of work to be done on all these as well as many more which I haven't even touched on. I can only hope that a lot of you people here will someday become interested in some of these phenomena because there's a lot of things to be done. Thank you.

39:07 [Audience Clapping]

39:21 Speaker 1: When a photon hits an atom and knocks lose an electron and when the electron recombines to create a photon, is the photon of the same original nature?

39:37 Dr. Bond: Well, in general, it will be a photon of somewhat different frequency. It depends quite a bit. If, if the electron as it comes in, well one has to conserve energy. I don't know whether you've had conservation of energy in your physics yet but if you conserve energy and momentum then, I think the answer to your question is it it depends on the energy in the, but if energy is conserved, then the answer would be yes. The last question here was what happens if an atom which is dissociated above some altitudes like 100 kilometers, what happens if this dissociated atom now all of a sudden exists at lower altitudes? The answer is it recombines into a molecule again.

40:39 Dr. Bond: Well, the question here was to explain the energy levels here. Well, I will try to, I'll try to explain it satisfactorily. Now the Bohr theory of atoms which I've indicated here says that the electrons revolve in certain specified orbits. These orbits are specified by what we call quantum numbers and by the energy, so that a particular energy level here, which could be indicated by a quantum number say n equals 1, would have a certain energy. This, the electron revolving in this orbit here would have a certain energy which can be symbolically indicated by the quantum number n equals 1. An electron revolving in the second orbit might have a quantum number n equals 2. This has a different energy than this. Now as to the level of the energies, I think perhaps you want to reverse the order. Rather the electrons in the outer shell here have less energy than the electrons in the inner shell; however, it's a negative energy. In other words, it takes less energy to knock an electron out of this outer shell than it does from that of the inner shell.

42:16 Dr. Bond: Well, we have to come back to conservation of energy here. The question was what happens to the photon when the electron is knocked out of the atom? Well, to answer this question, I have to perhaps go a little bit into conservation of energy principles. Nothing really happens to it except it's, it's energy that changes form. Now, there's several different types of energy that exist here on the diagram. One is the energy of the photon, the other is energy of the electron, and the other is the energy, which was asked about in the previous question, the energy that attracts the electron here to the positive ion. This latter energy is called potential energy. So that, there's a, one of those, one of the fundamental laws of physics is the conservation of energy.

43:18 Dr. Bond: This means that this says energy cannot be destroyed and it cannot be created. Therefore, if you write down the total energy of let's say what happened before the photon hit, it's going to be equal to the total energy of what happened after the photon hit. What this means is, to answer your question a little bit differently, if the photon has quite a bit higher energy let us say the energy of the electron, you might get a phenomenon perhaps called Compton scattering, where the energy of the photon changes but it's not destroyed. The photon still exists but it's changed energy. Otherwise, the energy of the photon goes, if that type of scattering doesn't occur, the energy of the photon goes into two types of energy. One, the potential energy of the electron in its orbit, and two, the kinetic energy of the electron outside here, the sum of these two must equal the energy of the photon.

44:25 Dr. Bond: To go into any more detail of what the atom looks like, now you see I have two approximations. A physicist can't, can't do any work at all unless he makes a model. It's got to be a very simple model and if he gets answers out of this model that agree with experiment, then he is happy. If he doesn't, then he changes the model. The first model of the atom indicated was that of a billiard ball. Now, the next approximation is the, this one here, the Bohr atom. Now, this is not a true picture of what the atom looks like. It doesn't really look like that and perhaps I can answer your question by saying this, the first course I took in quantum mechanics about twenty years ago, the professor, first thing he said, first lecture he says, up to now, this quantum mechanics course was given as a graduate course in the university. He said up to now, you've seen pictures on the board of what an atom looks like. He says you forget those pictures from now on. You can't draw a picture of an electron, it's indicated by a mathematical symbol. So my tendency to answer your question is that if I tried to draw any more detailed pictures of what the electrons look like in their relation with an atom, I wouldn't try to do it. I don't think you can draw a good picture.

The question I believe is regarding the radiation that has been observed by satellites in outer space. I'm not quite sure I got further.

46:02 Speaker 2: Essentially that man would not be able to survive.

46:05 Dr. Bond: Oh, the levels of radiation in the outer space, that is the radiation that has been observed by satellites have been estimated. Now, there's two problems though, however, or one problem. It's not known yet and I don't think it is whether these charged particles are really electrons or protons. If it's known now, it's only something new that's been found out in the last few weeks. If they are electrons, then the electrons impact on a solid, and well, what happens, the electron is light compared to the nucleus here. The electron is very light. This is very heavy. So when an electron comes in very, moving very fast, it's attracted in an orbit like this. Now, this is the way an electron would go about a nucleus, a heavy atom, like a piece of copper or a piece of iron in the satellite. Now you notice that the course of the electron has changed. That is its acceleration is changed now, it's accelerated rather and whenever an electron accelerates or decelerates, it emits radiation.

47:23 Dr. Bond: So, we have emitted here now a quantum of radiation. This is called bremsstrahlung. It's this radiation that's given off that causes the damage, the radiation damage. Now, the only thing is, well, let me go back. It's not known whether this is a, whether it's an electron or proton that's hitting the satellites up there. A proton doesn't do this. It's just absorbed in the surface and you don't get this radiation effect. So, if these particles are electrons, then there is a lot of radiation given off and it's a serious problem. If they are protons, it's not a very serious problem, that is let's say to a man in a satellite. Now to be a little more specific, if a man were in a satellite and this, he can last maybe a few hours in a satellite without being, without getting a lethal dose of radiation. Now this estimate is not perhaps a real good one but it's, it's rough. It gives you an order of magnitude.

48:39 Dr. Bond: The question is regarding cosmic rays and what happens when they interact with the atmosphere. When a cosmic ray interacts with the atmosphere, when it hits a particle in the upper reaches of the atmosphere, it's coming at very high energy and it's going to break this atom all up. Now, this nucleus here of the atom is, is really a complicated thing which we haven't even tried to draw but it's composed of neutrons and protons and in turn, there are other binding particles like mesons and so forth. When a high-energy cosmic ray comes in and hits this nucleus, it breaks this nucleus up in a lot of individual particles. Now, your question as I understand it is why aren't these individual particles important? Is this essentially what it is?

49:35 Speaker 3: The way I understand is they say the radiation in cosmic rays is higher, the higher the radiation the higher the altitude. But at a higher altitude, there would be fewer particles, than at a lower altitude.

49:36 Dr. Bond: Well, the energy, the energy per particle is higher at higher altitudes. At the lower altitudes, one just gets more particles but energy is conserved except for some radiation phenomenon which is loss. In other words, the cosmic ray hits these particles and breaks them all up but the total energy is going to remain the same. You just get more particles to less energy per particle. I'm not sure whether I've answered your question. Let's try this one. How many particles per cubic centimeter in outer space? Well, I mentioned this at a point approximately halfway between the Earth and the moon - if you call that outer space - there are about 1,000 particles per cubic centimeter. The question was regarding what happens to an electron, in one of the inner shells of the atom and what happens. I guess what you're saying is what happens when it moves from one shell to another.

50:46 Speaker 4: I was wondering whether the move from one shell [unclear] outer shell.

50:56 Dr. Bond: Well, I indicated, the question here is can it have a higher energy level and still, be in the same shell? And I indicated I think, or maybe I didn't, that an electron in one of these orbits is not specified by just one quantum number but by four. I didn't want to go into what these other four quantum numbers are but they're all different. Each quantum number specifies the energy. Now, each quantum number it has a can have several values. Actually, if it changes orbit, of course then n changes but the other three quantum numbers do not change and I mean may not necessarily change if it changes, if it stays in the same orbit. Let me repeat that. The other three quantum numbers which I have not discussed can all vary without the electron changing orbits. Now, when any quantum number at all varies, the energy changes. I hope this answers your question.

51:59 Dr. Bond: A photon is indicated symbolically by, by this expression here. H times nu. If you see this in textbooks this is, this indicates a photon. A photon has no mass and it moves at the speed of light. It's simply a light particle, if you like. Let me tell you a little more about this relation here. H is Planck's constant. Well, it’s constant which I won’t go into. But this other symbol here is the Greek letter nu and that indicates the frequency of the photon. For example, take light, take green light or light let’s say has a frequency of 5,000 angstroms. That’s what nu indicates, that’s the value of nu, 5,000 angstroms here. That, the h times this frequency gives you the energy of this photon.

53:14 Dr. Bond: Well, I’ll get around that question by saying the next speaker is going to talk about that but let me just say this, say a little bit on that. This is one of the postulates of Einstein’s theory. I mean Einstein doesn’t have a theory until he makes certain postulates. We indicated here simple models like the Bohr atom. We draw a simple model, from there we can get a theory. Einstein did the same thing, he drew up certain postulates. One of which said that the maximum speed of anything is that of light and it’s constant in a vacuum.

53:50 Dr. Bond: I’m not clear on what you’re really saying. But there are several things to keep in mind. One is that the energy per particle in a cosmic ray is higher the higher you go because when it interacts with a near particle, it loses energy. Now that’s one part. The second is that some of these cosmic rays are reflected by the Earth's atmosphere or by the magnetic fields of the Earth, which means that instead of the cosmic rays all coming into the Earth, some of them are reflected out so the radiation level would be higher in outer space. Let's have one more question. Now, the last I heard on this is that they were still uncertain as to whether these come from the Sun primarily or from outer space. Now, I'm sure that the next lecture, one of the next lectures will spell this out for you in some detail but certainly, there's a lot to be known about what cosmic rays are, where they come from, and so forth.

55:05 [Audience Clapping]