Physics I: Oscillations and Waves
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Lecture No - 13
The Electromagnetic Spectrum - II

Good morning. In the last class we had been discussing, the electromagnetic spectrum.

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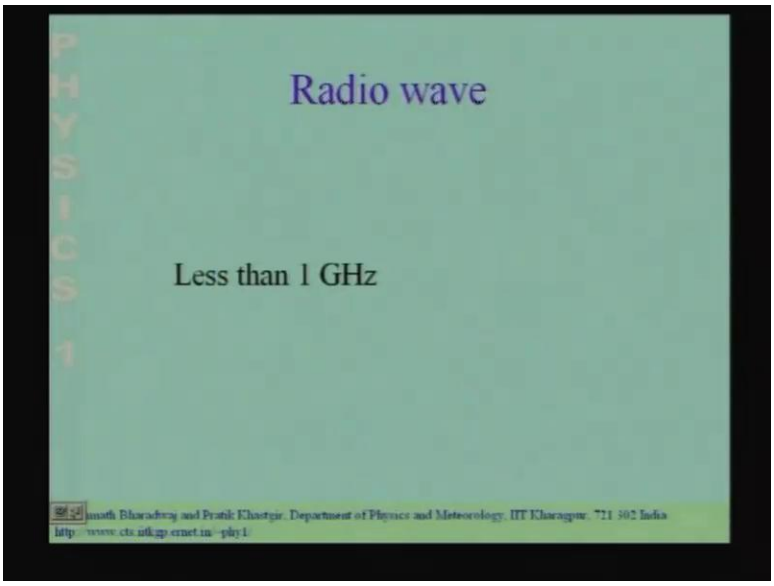

And I told you that, the lowest frequency electromagnetic waves at frequencies less than 1 gigahertz. These are referred to as radio waves.

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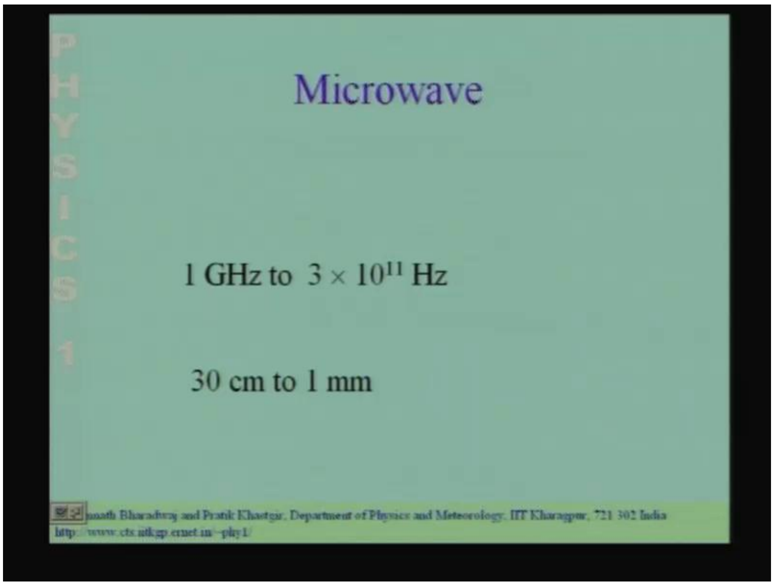

Then, we shifted on to a slightly higher frequency band; the range from 1 gigahertz to 3 into 10 to the power 11 hertz. This is referred to as microwave.

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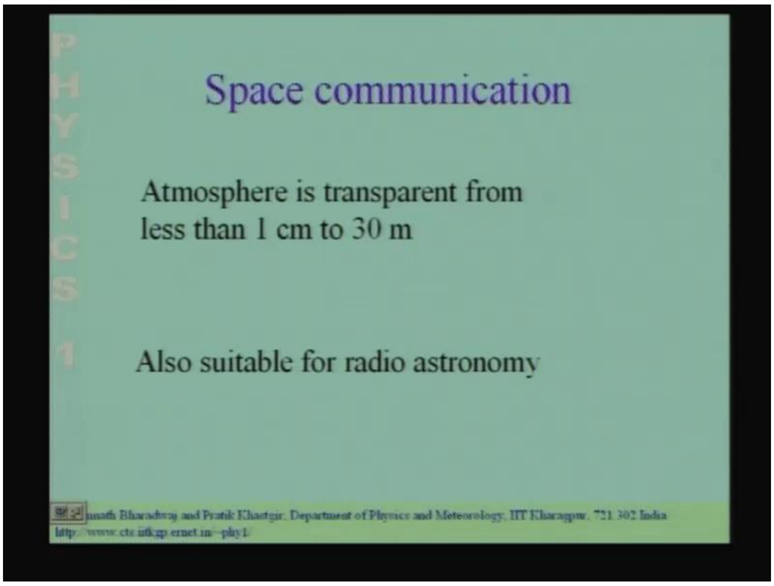

And radio microwaves and the upper part of the radio band has got several applications. For examples, space communication, even communication terrestrial communication; radio astronomy.

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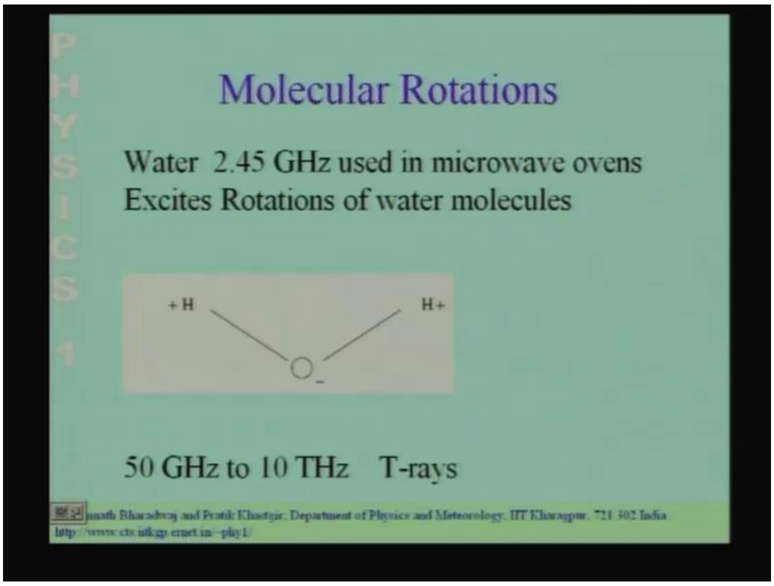

And then, I told you about the blackbody radiation and we were discussing the molecular transitions at the end of the last class. So, let me recapitulate what I told you about molecular transitions. So, for example, water molecule is shown over here, we have the oxygen and the hydrogen 2 hydrogen atoms. The water molecule has a permanent net permanent dipole movement.

So, if there is an incident electric field, the water molecule the dipole movement of the water molecule, tries to align itself with the direction of the electric field. And if the electric field oscillates, it can set the water molecule into rotation and these rotational levels are quantized. So, whenever there is a the transitions between 2 different rotational levels, gives rise to radiation at specific frequencies. And there is a rotational transition corresponding, to the frequency 2.45 gigahertz, which the microwave oven utilizes.

So, in the microwave oven you have incident microwave electromagnetic radiation at 2.45 gigahertz. This radiation causes the water molecules to rotate. This rotational motion gets converted into the random translational motion of the molecules through collisions and this causes the water to get heated up. So, the point to note here is that, in an microwave in an microwave oven, it is only the water molecules which get heated up.

If, I have for example, a piece of dry paper and I put in an microwave oven, it will not get heated. It is only the substances which contain water. There are a large variety of molecular transitions; I just spoke about 1 of them. And these could be rotational or vibrational. And these transitions typically occur in the microwave or in the infrared part of the spectrum. Let me now, go onto another band; the upper part of the microwave bands starting from 50 gigahertz and extending to the lower part of the infrared that, is to 1 terahertz. So, this frequency range 50 gigahertz to 1 terahertz is often referred to as T-rays.

So, this is a band in which there is at present considerable development because, this band; electromagnetic waves in this band are do not propagate through water, water absorbs this band. And this, but this band can be transmitted if there is no water vapor present. So, if it is a dry atmosphere this band can be propagated can propagate and is absorbed if there is water and it can be reflected if by metallic plates.

So, this band has got several applications in imaging and there is at present considerable interest in developing imaging using T-rays. T-rays refers to 50 gigahertz to 1 terahertz.

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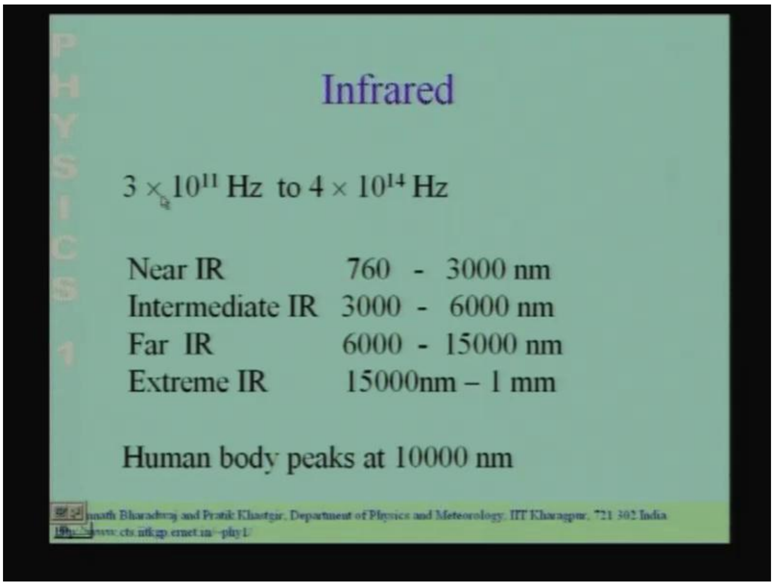

Now, let us move on to a to the next, so up beyond microwave. So, microwave goes up to the 3 into 10 to the power 11 hertz, beyond microwave we have infrared, infrared ranges from 3 into 10 to the power 11 hertz, all the way to 4 into 10 to the power 14 hertz. The T-rays which I just told you about, is some is a band which overlaps. So, it covers the higher part of the microwave and the lower part of the infrared. Infrared refers to the part of the spectrum, which is the wavelength, where the wavelength is just slightly larger than the visible wavelengths that is, the largest visible wavelength is red.

So, wavelengths which are just slightly larger than that are; where infrared starts. The human eye cannot perceive infrared or in terms of frequencies these are frequencies which are just a little smaller than the red. The red is this lowest frequency that we can perceive with their eyes, the lowest frequency that is visible. So, infrared means it is the frequencies smaller than red. So, the frequencies smaller then red, extending all the way to microwave are referred to as infrared.

Infrared has been further, the whole infrared band has been further classified into different sub band. So, we have near infrared and this shows you the bands in terms of the wavelength. So, you have the near infrared. The near infrared goes from 760 nanometers to 3000 nanometers. So, this is the part of the infrared, which is closest to the visible band. Hence it is called near infrared.

Then you have the intermediate infrared, which goes from 3000 nanometers to 6000 nanometers. Then you have the far infrared 6000 to 15000 nanometers. And then you have the extreme infrared which goes from 15000 nanometers to 1 millimeter, which is where the microwave starts. So, this is the whole infrared band. Now, where do we encounter infrared radiation, objects which have a temperature of the order of a few hundreds of Kelvin? The blackbody spectrum from such objects peaks somewhere in the infrared band.

So, the human body for example, has a temperature of around 300 Kelvin. So, the things the atmospheric temperature of the earth is around 300 Kelvin. So, things of the earth, the blackbody radiation from such things such objects, peak at in the infrared. We can have a look at the blackbody spectrum.

So, let us take a look at the blackbody spectrum.

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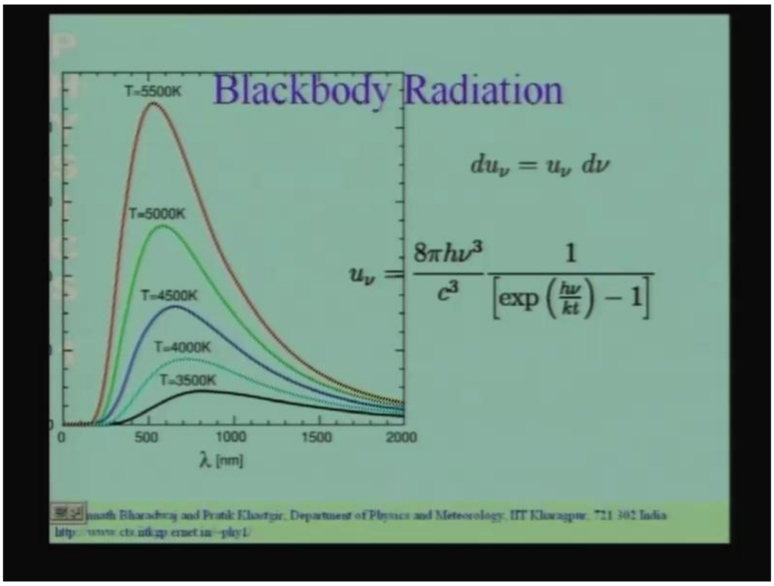

So, notice that for low temperatures, the peak is at quite low wavelengths and here you see that, in this range where you have a few hundreds of Kelvin to thousands of Kelvin. So, in this range you have the peak occurring in the infrared. So, this is in nanometers. So, somewhere over here 7000 700 infrared start. So, is anything that peaks over here, which is a temperature in the order of few hundreds of Kelvin, you would have infrared as a peak occurring in infrared. The human body, which has a temperature of around 300 Kelvin, it is radiation peaks at 10000 nanometers. So, 10000 nanometers would be in the far infrared.

So, the human body peaks the radiation the blackbody radiation. The radiation from the human body peaks, at 10000 nanometers and which is in the far infrared. So, this has got several important applications. In the daytime, we have the sun light and we see all vision, we perceive other human beings and other objects or through the reflected sunlight so, the when you see a reflected light from other sources.

So, when you for example, when you are seeing me here, yours the light which is responsible for the image is, actually light from some other sources which are reflected off me. But at night in a dark place, such light is not present. If you want to image a human being in the dark, which is referred to as night vision, you can then use you will have to use infrared cameras. If, you use infrared cameras which are sensitive to radiation at 10000 nanometers, you can use these to image human beings at night. And this is used for night vision, which has got several defense applications for example.

The another source of infrared, is the incandescent lamp that we use. So, this the incandescent bulb has a filament inside it, the filament inside gets heated up. The main purpose of the bulb is to produce visible light; we would like to use it to see. But, the hot filament it a it turns out that, the hot filament is not all that hot. And around 50 percent of the radiation from incandescent lamp comes out in the infrared.

So, all hot objects which are not so hot; if, you had an object which is around 5000 Kelvin and so, 1000 of Kelvin it would be emitting not in the infrared, but at higher wavelengths. Objects which are in the order of hundreds of Kelvin to the thousand let us say, would be emitting the maximum amount of radiation. The peak of the radiation would be somewhere in the infrared.

So, if you have atomic explosions for example, occurring somewhere and if the explosions are underground, they would still emit a substantial amount of heat and you could detect these, if you are to take an infrared image of the region, you would detect the atomic explosion has a sudden increase in the heat, which would give rise to a certain burst of infrared from that location.

So, infrared has got several applications and the difficult part in infrared is to make in infrared detectors, which are used for detecting the heat sources. There are also large number of molecular transitions, which occur in the infrared part of the spectrum.

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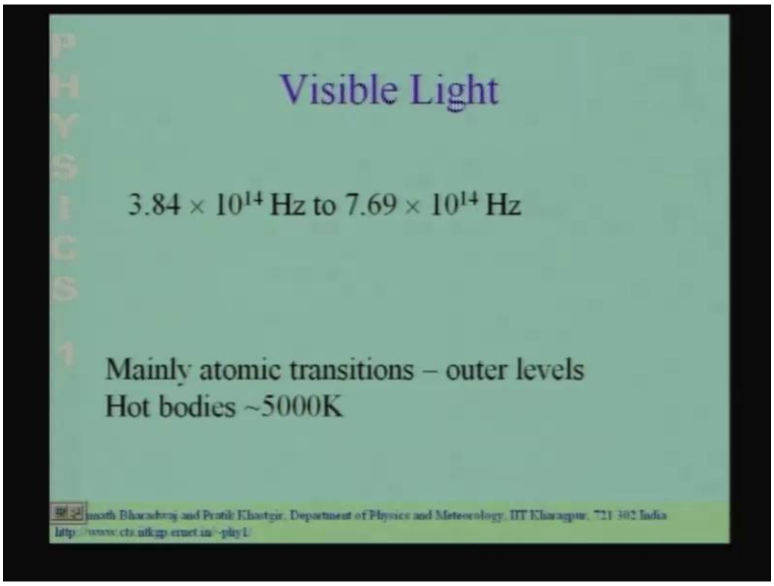

Now, once you go to frequencies which are slightly smaller than infrared so 1, you have now crossed over to the visual part of the spectrum. And this visual part of the spectrum, the part where our eyes are sensitive to radiation, it spans from 3.84 into 10 to the power 14 hertz to 7.69 into 10 to the power 14 hertz. So, this is a very narrow band in frequencies, does not span a very large range. The other bands which we have considered span much larger ranges in frequency. So, the human eye is sensitive to radiation, only in a very small than the frequencies of the order of the 10 to the power 14 hertz.

Now, the atmosphere of the earth; the earth's atmosphere is transparent to radiation in this frequency range. So, earth's atmosphere is transparent in this frequency range. The earth's atmosphere is not transparent to infrared and this is responsible for an important effect the green house effect. The earth receives radiation in the optical; it is the earth's atmosphere is transparent to radiation in the optical. The sun is at a temperature of around 6000 Kelvin 5800 Kelvin and at 5800 Kelvin the blackbody radiation of the sun peaks in the optical band. You can see here, at 5800 Kelvin somewhere around 6000 Kelvin, the radiation peaks in the optical band.

So, the sun emits copious amounts of radiation in the visible band. The earth's atmosphere is transparent to this radiation, which is possibly why our eyes developed vision in this particular band of radiation, you can see things here. You can see the not only can you see things on the earth, but you can also see things outside the earth because, the atmosphere is transparent and the also the sun emits large amounts of radiation in this band.

Now, the earth that absorbs this radiation and reemits this in the form of infrared because, the temperature of the earth is much lower than the temperature of the sun, it is around 300 Kelvin. So, the sun the earth absorbs the radiation from the sun reemits it in the infrared. The earth's atmosphere is not transparent to infrared. So, the heat cannot escape. So, this results in the atmosphere of the earth, getting heated up which is called the heat is retained in the earth, which is referred to as the green house effect.

So, the atmosphere of the earth is visible which is possibly, why we developed vision in this frequency range. Now, visible light is produced in atomic transitions for example, in outer level atomic transitions for example, in sodium when you have an electronic transition, so the electron in the sodium atom, if it goes to an exited state and then comes back to the ground state. So, the transition from the excited state to the ground state releases energy. This energy is released in the form of radiation and there are many transitions in the outer atomic levels of atoms, in the outer electronic levels of atoms, which release radiation in the visible range, sodium being an example.

And I have already told you that, blackbody bodies with temperature of the order of few thousands of Kelvin for example, the sun has the temperature of the 5800 Kelvin, they emit large amounts of their blackbody radiation in the visible band. So, visible that is another source of visible radiation for example, the incandescent lamp or such hot sources, also emit large amounts of visible radiation.

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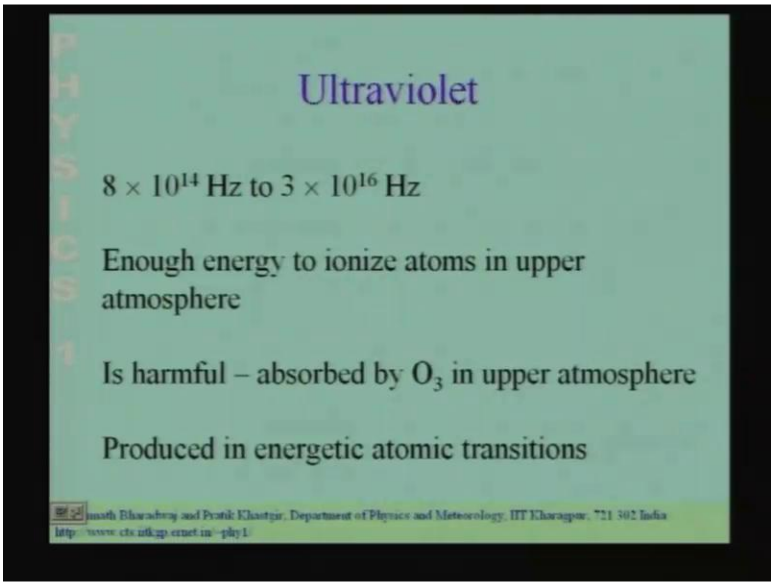

Now, once you go to frequencies which are slightly higher than the visible, you are in the ultra violet range of the spectrum. So, ultra violet means; the violet is the highest visible frequency. So, once you go to frequencies which are higher than violet, you are in the ultra violet part of the spectrum. And the ultra violet band extends from 8 into 10 to the power 14 all the way to 3 into 10 to the power 16 hertz. So, it is quite a large band, unlike the visible band it spans from 8 into the power 14 to 3 into 10 to the power 16 hertz.

Now, the ultra violet photons are considerably more energetic than the visible the photons of the visible light. So, the sun also emits ultra violet radiation, in addition to emitting visible and infrared, it also emits significant amount of ultraviolet radiation. This ultraviolet radiation from the sun has sufficient energy, to ionize the upper atmosphere of the earth. So, the ultra violet ultra violet photons have, each photon has sufficient energy to ionize atoms in the upper atmosphere. And the radiation from sun has sufficient intensity in the ultraviolet, to keep the upper atmosphere of the earth ionized. This is what results in the upper atmosphere of the earth, the part of the upper atmosphere of the earth being ionized, this is called a the ionosphere.

So, this is maintained in the ionized state, by the ultraviolet radiation from the sun. Ultraviolet radiation incidentally is quite harmful to life. Ultraviolet radiation is used for example; it is used for water purification. We have these aqua guard water purifiers which we use quite often or such similar water purifiers. And all of these water purifiers use an intense ultraviolet beam, to kill bacteria in the water. So, the water is made to pass through beam of ultraviolet light, which kills the bacteria which is present there.

Ultraviolet is harmful to light. So, the sun emits significant amount of ultraviolet, if this radiation where to pass through the atmosphere and reach the surface of the earth, it would considerably damage life on the earth. The human beings are prone to get skin this is I mean, the skin of the skin would get burnt if it is exposed to ultraviolet light or eyes get damaged if it is exposed to ultraviolet light. Fortunately, there is an ozone layer ozone O 3 there is a layer of ozone in the earth' atmosphere and ozone absorbs the ultraviolet radiation.

So, earth's atmosphere is not transparent to at ultra violet radiation. A large part of the ultraviolet radiation gets blocked in the ozone layer and it does not reach the surface of the earth, which is what makes it safe for you, for different types of life. The issue of the ozone layer is quit important and there is evidence that, there are certain gases produced by different industries on different industries, which react with the ozone layer and cause the ozone layer to get deeply hit. And there were fears that, there are holes in the ozone layer from which through which, the ultraviolet is coming through.

So, this is an issue of considerable environmental concern. Because, if there is an, if there is a whole in the ozone, then the ultraviolet will come through and it will damage life in the region where the ultraviolet penetrates through. Ultraviolet photons are produced by hot objects, very hot objects. And they are also produced by outer electronic outer shell electronic transitions in atoms.

So, for example, if a hydrogen atom is the electron in the hydrogen atom, if it is excited to the first excited state and then it by some means, say through a collision to hydrogen atoms collide and in the process 1 of the atoms the electrons get excited to the first excited state. And if the electron then comes back to the ground state, this will emit some radiation. This is called referred to as a Limen alpha line and this radiation, will this the frequency of this radiation lies in the ultraviolet band.

So, there are electronic transitions in the outer levels of atoms, which give rise to ultraviolet radiation. So, outer level transitions, electronic transitions in atoms give rise to both kinds of radiation, depending on the atom it can give rise to optical, it can also give rise to ultraviolet radiation. Electronic transitions usually do not give rise to microwave or radio microwave or infrared. Microwave or infrared arise from, as I have told you they arise from molecular transitions, the rotational levels of a molecules or the vibrational levels of molecules. These correspond to the transitions in these rotational or vibrational states correspond to, lines in the infrared or in the microwave region.

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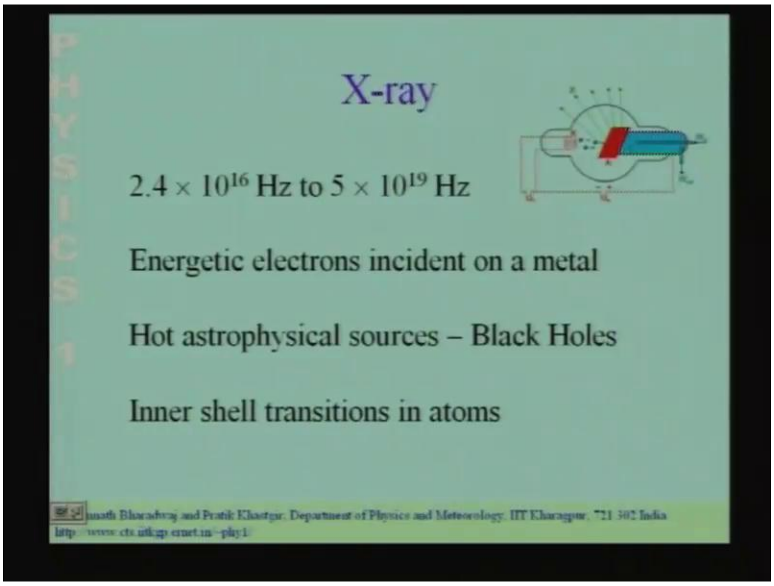

Now, if you go to even higher frequencies, you are in the X-ray band. So, the X-ray band it spans from the range 2.4 into 10 to the power 16 to 5 into 10 to the power 19 hertz a very large band of frequencies as you can see. Now, the whole band over here is referred to as X-ray. So, the first question is how are X-ray s produced? So, X-ray s are usually produced on earth I mean; the devices which produce x-tray on earth and these devices typically have an electron beam.

So, this diagram over here shows you electron an X-ray source. You have an intense beam of high energetic electrons, these highly energetic electrons are incident on a metal sheet for example, could be a copper sheet. So, let me draw picture and explain this to you.

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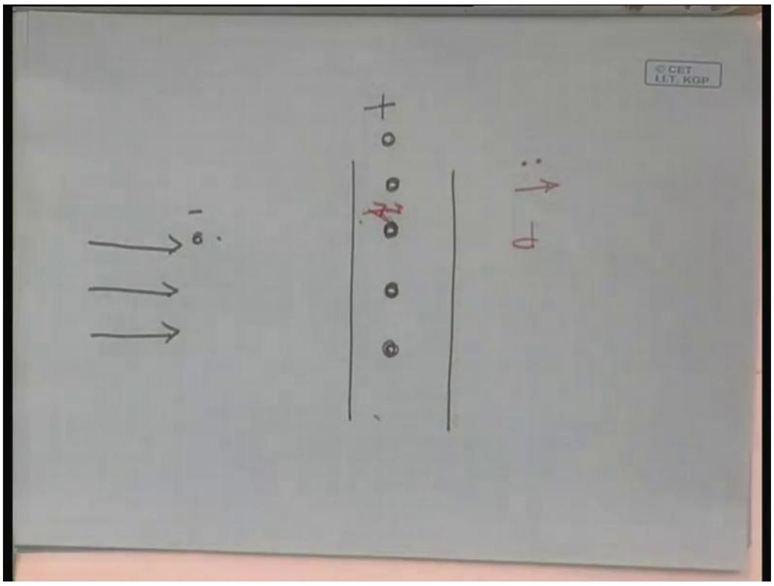

So, we have a copper sheet over here, on which you have a beam of highly energetic electrons which is incident. So, these electrons remember, are charge particles and the copper sheet over here contains copper atoms. So, the copper atoms has a nucleus which is positively charged and it has these electrons which are bound around the nuclear. So, I am just drawing a few nuclei, just to give you a picture of what is there inside the copper atoms, so copper sheet.

So, these are positively charged and the electron is negatively charged. Now, when this highly energetic electron enters the copper sheet; so you have a highly energetic electron, entering the copper sheet, let us say it comes over here. So, this negatively charge particle will now be attracted by this positively charged particle, which will cause it to accelerate downwards. And it will encounter a series of such positive particles, which will cause it to accelerate in different directions. In the process the electron will lose its energy and will finally, come to rest inside this metal copper metal sheet.

So, the electron when it enters this copper sheet is going to experience a random acceleration from these positively charged protons nuclei. It is the proton in the nuclei which causes the acceleration, because they have a positive charge. Now, if you have this electron and the proton, it is going to be a the nuclei over here. It is going to be a dipole because, the nuclei electron has a negative charge and the nucleus has a positive charge.

If, the electron accelerates there is going to be a rate of change of the dipole. So, you will have the d double dot or you can think of it as the electron accelerating. If the electron accelerates, we have learnt that it is going to emit radiation. So, this very highly energetic electron when it enters the copper sheet, it is going to lose this energy in the form of the radiation. The electron is going to accelerate due to the copper nuclei, attracting them and it is going to emit radiation.

So, it is going to emit some of it is energy in the form of radiation. Some of the energy will be converted to heat inside the metal sheet and the electron will come to rest. This radiation, a large part of the radiation comes out in the form of X-ray, if the electrons which are incident have very high energies. So, this is how this X-ray tube over here works. It emits out X-ray when the very energetic electrons fall on this metal plate over here

X-ray is also produced in very hot astrophysical sources; an example is a black hole. A black hole as you know is a very compact massive object. And it has the property that if, something enters the black hole it can never come out. So, even light enters the black hole the light does not come out. Now, if you have if you have a black hole over here.

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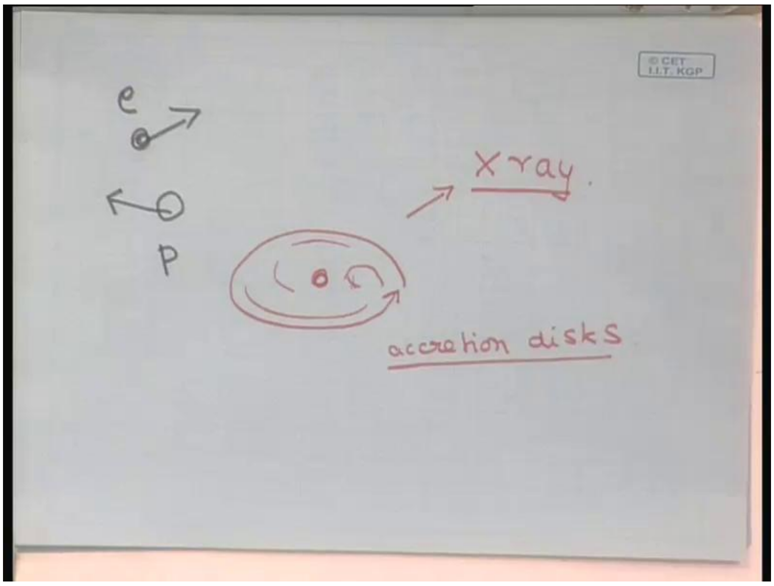

And if the black hole is embedded in some material, which is usually the case, the material which is around the black hole which is flowing into the black hole, will form something called an accretion around the black hole and it will slowly spiral in to the black hole. Now, this material over here is extremely usually extremely hot and you get large amounts of X-ray coming out, from the accretion disks of black holes or such massive other massive compact objects. So, these are what are called accretion disks.

And you have large amounts of X-ray coming out from such hot astrophysical sources. Let me show you another astrophysical source which emits copiously in X-ray.

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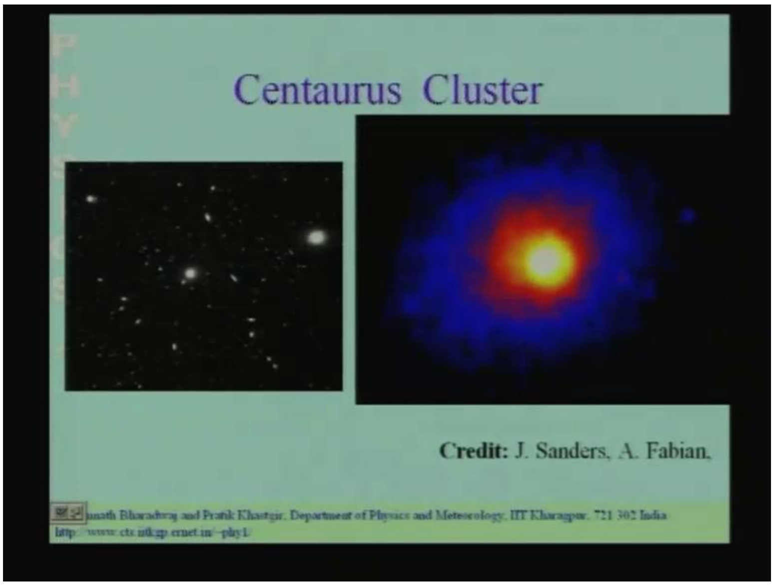

So, this shows you the centaurus cluster. The centaurus cluster is a collection of galaxies. So, each this is a picture visible in the band. In the visible band if, you take a picture of this part of this sky, you can see a large number of galaxies over here. So, each of these extended object over here is a galaxy. You can see a large number of galaxies concentrated in a particular region of the sky.

So, all these galaxies; a galaxy is a concentration of stars collection of stars and we live in a particular concentration of stars, which we call our galaxy. There are other concentrations of stars like this, which are there beyond our galaxy. And you can think of the universe as being made up of such distinct concentrations of stars called galaxies. And there are regions of the universe, where there are more galaxies than the average; these are called clusters of galaxies.

So, the centaurus cluster is 1 such cluster of galaxies and here I show you a picture of the centaurus of the cluster. There are more galaxies than average in this part of the space. Now, if you take an image of this part of space in X-ray, the image looks like this. So, this image tells us that, in addition to the galaxies you have some very hot gas in this region. When you have a very hot gas,it is ionized. So, it is called a plasma such gas is called a plasma. You have the electrons and the positrons in this gas and they are moving around at very high speeds.

So, you have this very hot gas and inside the gas you have the electrons and you have the protons and these are moving around at very high speeds because, they are very the gas is very hot. The whole gas is ionized and it is very hot. So, the electrons and protons are moving around at very high speeds. The speed of the electrons is much more than the speed of the protons because, electrons have a smaller mass.

Now, when an electron moves past a proton, you have a dipole movement. Further, the electrons gets accelerated because, the 2 particles have opposite charges. So, you have a dipole movement whose value is changing with time and this gives rise to radiation and the radiation comes out in x-tray if, the energies of the electrons and of and the protons is quite large. So, the temperature of the gas, the temperature tells you the kinetic energy of the gas.

If, the temperature of the gas is quite high then, the bulk of the energy in the gas comes out in the form of X-ray. So, this is an X-ray picture of the centaurus cluster.

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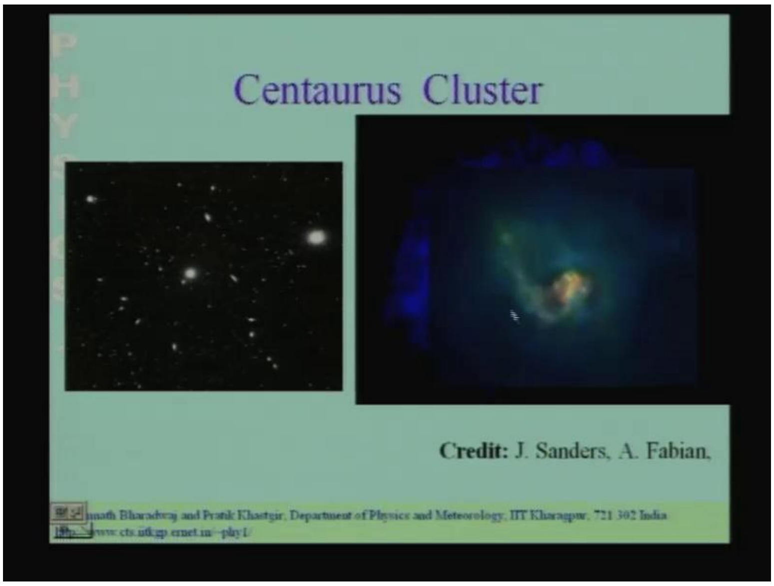

This is another X-ray picture of the same centaurus cluster and this picture was is courtesy of these people over here and this picture was taken of using a NASA satellite. Much of X-ray astronomy has to be done from outside the earth’s atmosphere. The earth's atmosphere absorbs X-ray from outside the earth. So, you have to send up satellites to satellites of balloons to do X-ray astronomy.

X-ray as we all know, has got several applications or they will there are large number of medical applications, you can use them for medical imaging because, the bones and the flesh in our body, they have different they are they have opacity to X-ray. So, you can distinguish the bones and the flesh in X-ray. And X-ray can pass through both of them, some of it is absorbed in the bones and some of it absorbed in the flesh. The amount that is absorbed in the bone is different from the amount that is the absorbed in flesh, but it is still some of it passes through. So, you can actually make images inside our body using X-ray.

X-ray has another very important application. It allows us to determine crystal structures. We shall discuss this in later lectures, when we discuss diffraction. How does X-ray radiation arise? So, I have already told you that, hot gases very hot gases in the temperature of the order of 10s of thousands of Kelvin to million Kelvin. Such gases emit X-ray. X-ray lines; X-ray lines also originate in inner atom, in inner electronic level transitions in atoms.

So, in large atoms in addition to the outer electronic shells, you also have inner shells of the electrons. And if you have transitions in the inner shells, in the inner electronic levels then, many a times these transitions give rise radiation in the X-ray band.

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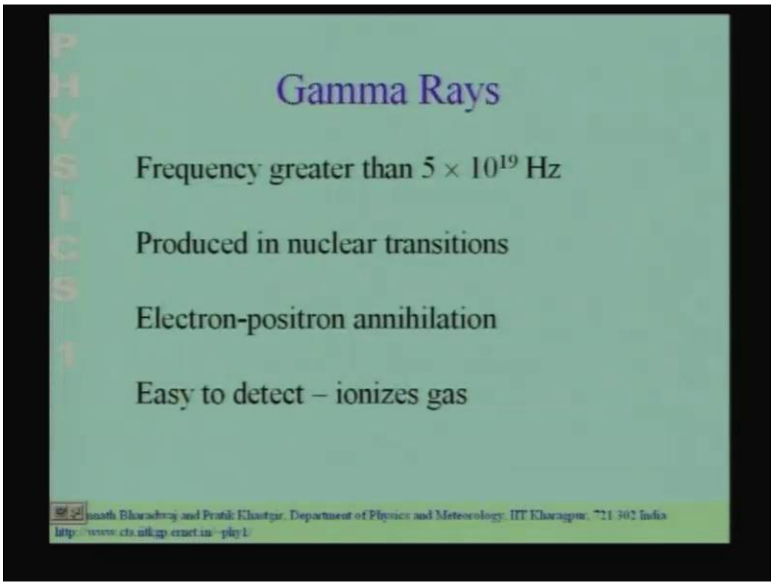

Now, if you go beyond the X-ray band then, you are in the gamma ray part of the spectrum. This is the highest frequency part of the spectrum; electromagnetic radiation with frequencies greater than 5 into 10 to the power 19 hertz is referred to as gamma rays. So, this part of the spectrum is called the radiation is referred to as gamma rays and it refers to electromagnetic radiation with frequency more than 5 into 10 to the power 19 hertz.

Now, we know that the radiation, electromagnetic radiation comes in a packets called photons. We shall go into this in more detail; towards the end of this course. Right now, let us just make an estimate. So, we know that the electromagnetic radiation comes in the form of packets and these packets are called photons.

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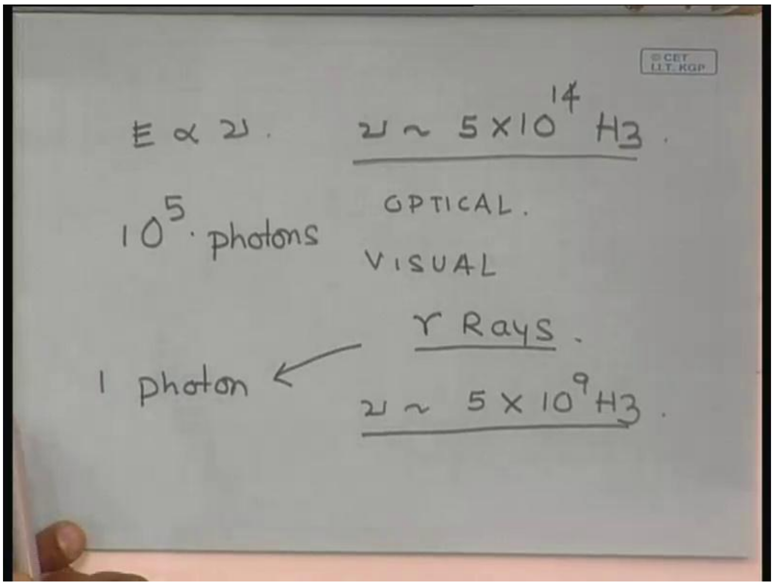

The energy in these packets is proportional to the frequency. So, when you have optical radiation, let us say a frequency 5 into 10 to the power 14 hertz, you have photons of certain energy. Now, the question is, this is in optical. When you have gamma rays, you have photons; the radiation has a frequency of the order of 10 to the power of 19 hertz. So, the point which I wish to make here is that, the gamma ray photons 1 gamma ray photon 1 photon here, 1 gamma ray photon has as much energy as 10 to the power 5 optical or photons 10 to the power 5 photons in the visual band. The frequency in the visual band is around 5 into 10 to the power of 14 hertz. The frequency in the gamma ray band is more than 5 into 10 to the power 19 hertz.

So, the point which I wish to make is that, a single gamma ray photon has as much energy as 100000 visual photons. So, these photons are extremely energetic. The gamma ray photon photons are extremely energetic photon. Each photon carries an enormous amount of energy as much as 100 1000 photons of the visual radiation, this is the first fact.

So, where are these very highly energetic photons produced? Gamma ray photons are produced in nuclear transitions. We know that, atoms have electrons outside and at the center, there is a nucleus, the nucleus is a collection of neutrons and protons, which are bound together.

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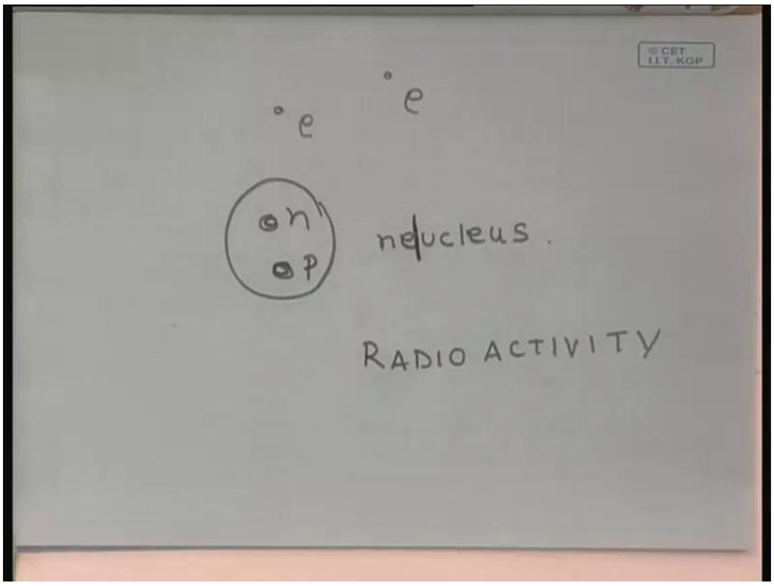

So, in atoms you have the nucleus, inside which you have the neutrons and you have the protons. There are many of them typically which are bound together and you have the electrons going around outside. Now, this bound collection of neutrons and protons is what is called the nucleus; this e should not be there nuclei nuclear and the nuclear. So, this is what is called nucleus. And if you have a nucleus which is in an excited state, so the bound collection of protons and neutrons, if it is goes to an if it is in an excited state and from this excited state of the nucleus, if it goes to a energy state which is slightly lower, then the excess radiation the excess energy comes out in the form of radiation. And this radiation is typically in the gamma part gamma wave band of the spectrum.

So, gamma rays originate from excited nuclei. So, this is what is called radio activity. So, there are excited nuclei which are found in nature, you can also produce atoms whose nuclei are excited in nuclear reactions. So, what you could do is, you could bombard 2 atoms the nuclei of 2 atoms so that, the merge into a single nuclei or if, they merge into single nuclei and then they break up again into 2 small nuclei. In the process you could produce nuclei which are excited. Just like you have atoms which are excited where the electrons are in excited states, you could have nuclei which are excited.

If, the nuclei goes into a lower energy state by emitting some energy, this energy comes out in the form of gamma rays. So, you can see gamma rays coming out from radioactive sources. In the radio source, the nucleus goes to a low energy state by emitting the gamma ray. So, very energetic photons are released. And these photons are very energetic so, they are quite harmful. If, they fall on some biological material for example, if they fall on the human body, they can destroy the human cells and they could also produce cancer. If, they destroy human cells, these cells could get damaged and they could behave in some erratic fashion. They can also be used to kill cells.

So, if you have if you wish to destroy certain cells in certain in a in the human body or anywhere you, could expose it to gamma rays and this is often used for treating cancer tumors. If, you wish to destroy a tumor, you can expose it to a gamma rays, which will destroy the cells kill the cells. We have to be careful very careful in handling gamma rays sources, especially particularly the natural sources of the gamma radiation. These keep on emitting gamma rays all the time and these rays as I have told you are harmful.

So, you have sources which radioactive sources which emit, gamma ray and these rays are dangerous. So, you have to make sure that, these sources are property shielded. So, put them some lead container, lead can absorb these gamma rays. Gamma rays are also produced when an electron and positron annihilate.

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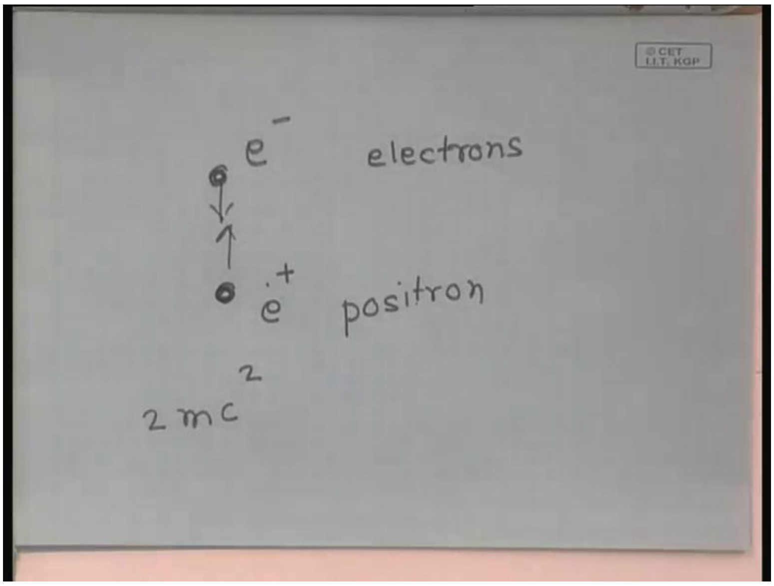

So, we know we have that there is a particle called the electron, it is a fundamental particle. Now, this electron also has an antiparticle called a positron. So, we have electrons and you have it is antiparticle called a positron e plus. Now, when the electron and the positron encounter each other, if these 2 particles encounter each other and if they meet then, they will annihilate and emit photons and these photons will carry away the energy 2 mc square.

So, the total energy which is there in the electron and positron, they both have the same masses, will be emitted in the form of photons. And these photons, these are carry the full energy of this electron positron combined energy of the electron positron. So, these photons are emitted in the gamma ray part of the spectrum. So, you have gamma rays which are emitted if in the electron positron annihilation.

Now, how to detect gamma rays? The same principle could also be applied to detect X-ray s, but it is usually more efficient for gamma rays. As I have told you the gamma ray photons are very energetic. So, the gamma ray photons usually have enough sufficient energy to ionize a gas. So, if they if a gamma ray photon encounters some gas in some let us say, in a container then, the gamma ray photons contain sufficient energy to ionize the gas.

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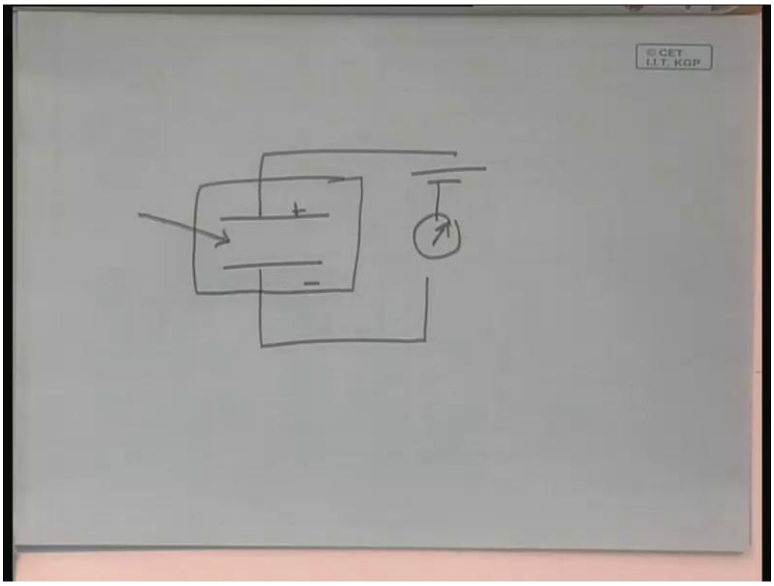

So, what you could do is you could take a cavity, a glass tube or something like that and have to 2 electrodes over here and fill it with some gas. Typically the electrodes are not shaped like this, but for our purposes it does not matter. And you connect it to a battery and an ammeter. So, this gas will normally be neutral and there will be no current flowing through the circuit because, this will act like a capacitor. But, the moment some gamma ray enters here, it will ionize the gas.

If, the gas gets ionized the electrons will move towards the positively charge plate. The remaining the ion will move towards a negatively charge plate and you will have current flowing in the circuit. So, you will know that the gas has been ionized because, the presence of a current will tell you that, the gas has been ionized and you can relate it to some kind of an ionizing ray which comes in and gamma ray is detected usually detected in this fashion.

So, this brings us to an end of our discussion of the electromagnetic spectrum. We started from the radio waves; the lowest frequency waves which have a frequency less than 1 gigahertz, enormous wavelengths and we went all the way to the gamma rays. So, let us just estimate the wavelength and stop. So, we have the radio waves radio waves.

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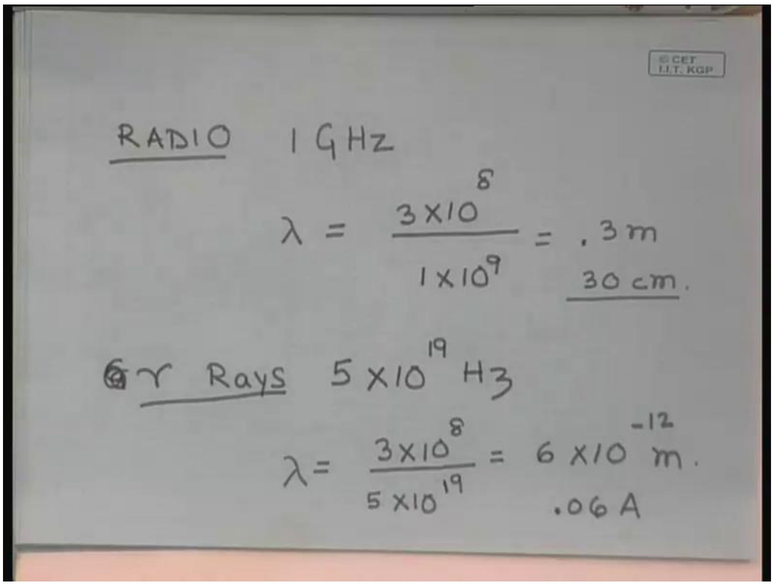

Radio waves; the highest frequency for radio waves is 1 gigahertz and the wavelength will be 3 into 10 to the power 8 the speed of light divided by 1 gigahertz would correspond to 1 into 10 to the power 9. So, this gives us 0.3 meters or 30 centimeters. So, the radio waves are larger than 30 centimeters. This is the lowest frequency part of the spectrum; the wavelength is larger than 30 centimeters radio wave.

Then you have the gamma rays gamma rays; this is the highest frequency part of the spectrum. So, thus frequencies are more than 5 into 10 to the power 19 hertz. Let us estimate the wavelength at this end of the spectrum; the wave length is 3 into 10 to the power 8 divided by 5 into 10 to the power 19 which gives us, how much does it give us? So, 3 by 5 3 by 5 is 0.6. So, we could write it as 6 and keep 10 to the power minus 1 in the mind. So, 10 to the power minus 1 is there from this 3 by 5 and then you have 10 to the power 8 divided by 10 to the power 19 which gives us 10 to the power minus 11 and then we had a factor of 10 to the power minus 1.

So, you have 6 into 10 to the power minus 12 meters or point 0.06 Armstrong right. This is the 10 to the power minus 11. So, we have we see that these, are the 2 extremes electromagnetic waves, ends of the electromagnetic spectrum, the radio wavelengths larger than 30 centimeters, the gamma ray with wavelengths larger than the smaller than the 0.06 Armstrongs or 6 into 10 to the power minus 12 meters wavelengths smaller than this. And the entire electromagnetic spectrum goes in between these 2 extreme ends. All of these in all of these situations that, the we have discovered all the way from radio to gamma rays, the radiation is essentially let me remind you again, the radiation is essentially a wave.

In most situation you can think of it as a plane wave sinusoidal plane wave

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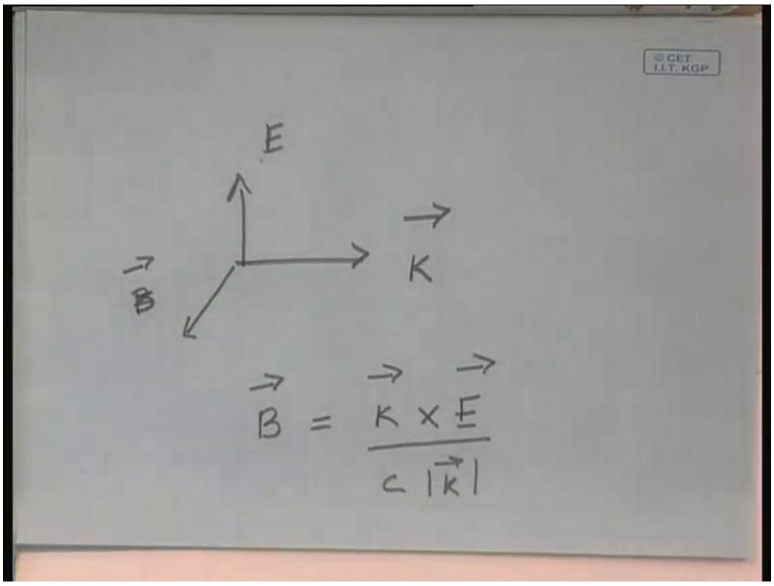

The wave propagates in a particular direction, the direction of the wave vector, you have the electric field oscillating in a, in some direction perpendicular to the direction of propagation and you have the magnetic field oscillating in a direction which is mutually perpendicular to both. The electric and magnetic fields oscillate in phase, the electric field is K cross E by c into the modulus of this vector wave vector. So, the magnetic field is always perpendicular to the electric field and the direction of propagation. And the magnetic field is of vector of 1 by c smaller than the electric field and it is and it oscillates in exactly the same field as the electric field.

So, you have the same thing taking place for radio waves for gamma rays and for everything it between. Now, having finished our discussion of the electromagnetic spectrum, let as take up a few problems on some of the material, which has been covered till now.

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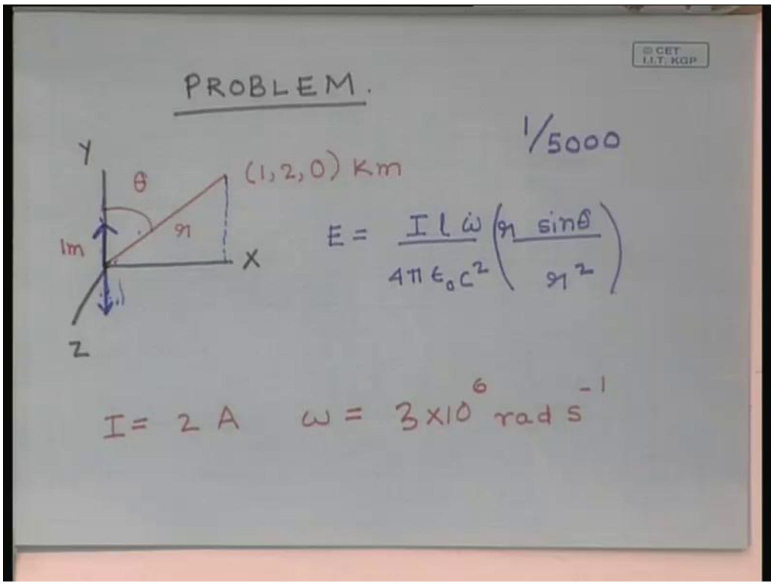

Problem which we will discuss is, we have a dipole which is aligned with the y axis, it is of the origin of the x y z axis and it is aligned with the y axis. The dipole has a length of 1 meter, it is being fed with an oscillating current and the amplitude of this oscillating current is 2 amperes. The angular frequency of the oscillating current is 3 into 10 to the power 6 radians per second.

Now, the question the question is, what is the magnitude of the electric field that will be produced at a point which has got coordinates 1 2 0. So, the x coordinates is 1 the y coordinates is 2 and the z coordinate is 0 in kilometers? So, we have to calculate the magnitude of the electric field at this point. So, let as calculate this. We know that E is equal to the amplitude of the current into the length of the dipole oscillator. The magnitude of the electric field is the magnitude of the current, amplitude of the current into the length of the dipole oscillator into omega; the angular frequency divided by 4 pi epsilon not c square and then you have a factor of sin theta by r.

Now, in this problem what is what does sign theta refers to? Sin theta is the theta refers to the direction between the direction, between the dipole and the line of site to the point, where I wish to calculate the electric field. So, this is the dipole this is the point, where I wish to calculate the electric field, theta is the angle between these 2 lines and r is the distance to the point, where I wish to calculate the electric field.

So, if you wish to calculate the magnitude, the electric field here is going to oscillate. If, you wish to calculate the amplitude of the electric field here, it has to be calculated like this; take the amplitude of the current, the current is also oscillating. So, the I is the amplitude of the current 2 amperes. The length is 1 meter; omega has a value 2 into 10 to the power 6 radians per second 4 pi epsilon naught the values are all known c square the value is known, sin theta by r we can write this as r sin theta by r square.

Now, r sin theta, so r sin theta is going to be this distance which is 1 kilometer and the distance r is r square is a square of this. So, it is a square of 1 plus the square of 2 which is 5. So, r sin theta this factor over here is; r sin theta has value 1 and r square has value 5000 in meters. So, we have to put in these values. So, all the values now are known; I is known, l is known, omega is known 4 pi epsilon not c square is known and this has the value 1 by 5000. So, you put in these values and you will get the electric field in volts per meter.

The next question is what is the direction of the electric field in terms of angle with respect to the x y and z axis? So, it is quite clear; first of all how do you calculate the direction of the electric field? So, the direction of the electric field at this point, if you wish to calculate it, you have to take the dipole; the component of the dipole perpendicular to the line of site to this point which gives us this. You have to take the component of the dipole in this direction. So, the electric field here is going to oscillate in this direction. So, it is the component of the dipole perpendicular to the line of the site

Now, both this and this are in the x y plane. So, this is also going to be in the x y plane. So, it has no it does not make it makes it is perpendicular to the z axis. So, it makes 90 degrees to the z axis, this electric field lies in the x y plane that is the first thing. How much what is the angle it makes to the y axis? The angle it makes to the y axis is 90 degrees minus theta and you can calculate the angle it makes to the x axis, I will not calculate it explicitly here.

Finally what is the total power emitted by this dipole? The total power emitted by a dipole, can be written in terms of

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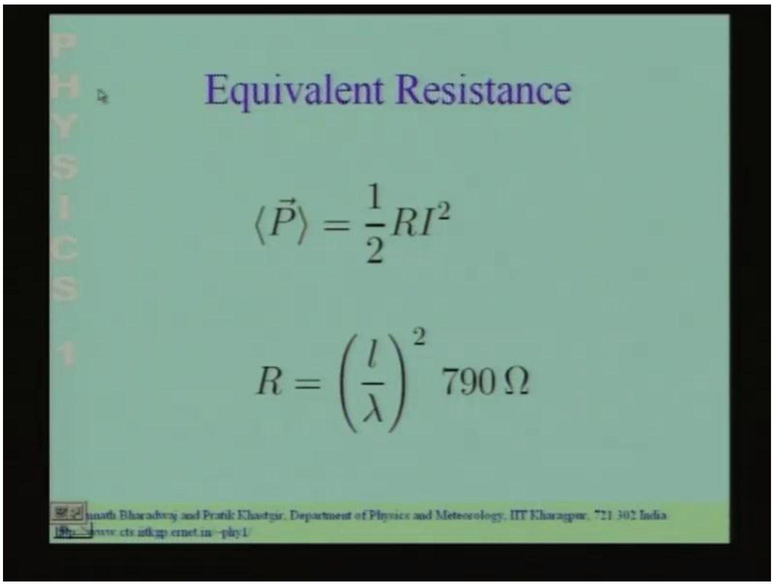

An effective resistance and it can be written as half I square into R where, R is the length of the dipole divided by the wavelength the square of this into 790 ohms. So, we know the value of the amplitude of the current. So, I is known half you have to put a factor of half, what you have to do is to calculate the resistance corresponding to this dipole. To calculate the resistance, the length of the dipole is known. What you have to do is you have to calculate lambda the wavelength.

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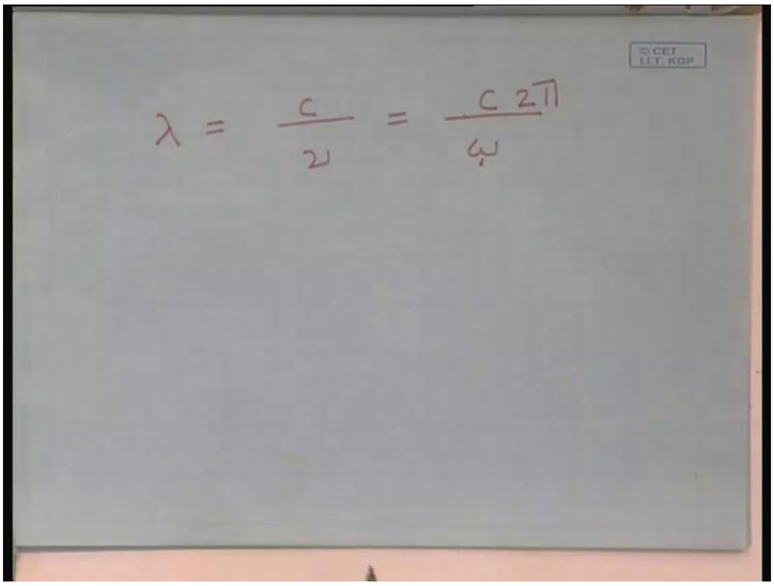

And the wavelength we know is c by the frequency mu, which we can write as c into omega by 2 pi. So, I can put the factor of 2 pi here. So, you can use the values of omega which value of omega which is given, the speed of light is known and put in the factor of 2 pi, it will give you the wavelength. Use the value of the wavelength in the formula for the resistance using the length of the dipole is 1 meter. So, once you have calculated the resistance, you can now calculate the power straight away using this formula. So, let us bring today's lecture, to an end over here and continue our discussion in the next class.