welcome all of you for the third lecture in the series of lectures on what we call as modern physics we have been preparing the ground for discussing photoelectric effect and the kind of challenges that it threw open and the radical explanation or the description given by einstein of course we have not started the discussion of the experiment per se in the first lecture what i did was essentially to give you the broad framework and in the second lecture we revisited the experimental evidence for the wave nature of light there was a slight deviation that we made compared to what you study in your textbook in your textbook in class 11 or class 12 when you study interference you study it as a generic phenomena common to all wave phenomena but here we specialized that study to electromagnetic waves made use of the fact that light consists of electric field magnetic field electric field is perpendicular to the direction of propagation and the direction of the electric field is also important for the interference effect

so by manipulating by tuning the direction of the electric field you can alter the interference pattern and that would conclusively establish that light is a wave phenomenon in the manner that is exactly anticipated by maxwell that is the most important thing for us and our analysis also showed that whereas the pattern where the maxima or the minima will occur will depend on the frequency and of course the path difference but the brightness itself will depend on the square of the electric field the magnitude of the electric field greater the light greater the energy therefore again in agreement with natural properties of waves that the energy carried by that wave is proportional to the amplitude squared we are also able to get an experimental evidence

so we are on really secure ground when we say light is a wave phenomenon

so it automatically almost says that the corpus color theory of light propounded by newton is incorrect because the corpus caller theory explains neither reflection nor refraction nor evanescent phenomenon nor double slit experiment none of them can be explained where by the corpus color theory whereas the wave theory does that and this is where the importance of the photoelectric effect comes because it started springing up surprises almost the same time probably even a little bit earlier that maxwell wrote his famous wave equation

so let us discuss the experiment today

so let me repeat the timeline that i gave you at the end of the last lecture

so 1887 is when hertz discovered photoelectric emission he could not make very detailed studies of this phenomenon all that he observed was that when these intense x-rays actually they went and fell upon a metallic surface electrons were rejected and you could actually identify them to be electrons by subjecting to an electrostatic field and they got deflected as negative electrons should do that of course requires the knowledge of an electron hertz could not have decided that he could have only said that it is a negatively charged particle but in 1897 jj thomson discovered the electron and now you can look at the current you know the electron and you can actually decisively establish that the current that is being produced is by the electron 1888 onwards even before the discovery of the electron all the way up to 1902 haravak and lenard made a series of experiments trying to find out the properties of these photo electrons

so what are we saying the electrons that are emitted when radiation impinges falls upon a metallic surface is called a photoelectron and the current that is produced is called as the photo current

so a good question to ask is what does this photo current depend upon that is where the surprising results started we will describe that in great detail this is only the timeline that we are interested in and in order to understand these results in 1905 einstein gave his theory it is really not a theory we should

call it as a model the real theory comes much later when schrodinger a rotis wave equation
so einstein gave his model for the emission of the electrons this model not only explains photoelectric effect it can also explain thermionic emission terminology commission is the phenomenon where the electrons are ejected when you heat because you are going to supply enough energy whether it is radiation or temperature it really doesn't matter but the most decisive experiments came in 1915 1916 when milikan made very very careful measurements we should understand that the basis for einstein's model was actually given by planck in nineteen hundred planck was forced to give that explanation because otherwise black body radiation which is not there in your syllabus cannot be understood there is no way to make sense out of it
so planck had introduced this planck constant but for five years between 1900 and 1905 nobody took that seriously including planck himself it was einstein who boldly believed in the concept of the photon he did not coin the word photon that was coined by actually by a chemist that is a different matter altogether but he believed in that quantization of the electromagnetic field that radiation comes in packets of energy it is not a continuous phenomenon that is what einstein said we will learn a lot about that in the next lecture
so he proposed the theory but then everyone was rather lukewarm to that in fact hostile against that because they thought the whole thing is against common sense and whatever we know experimentally but once in 1915 16 milligan made his performed his famous experiments very very carefully one could see that one could not escape the conclusions of einstein that was the only viable model that is something that we have to remember
so what i am going to do in the next 45 minutes or 50 minutes or whatever is left of me of this lecture is to discuss these experiments slowly and describe to you what kind of a crisis that this experiment precipitated it cost that is what we have to do
so here is a picture from your ncrt textbook
so you have a source which powerful source which hits on a surface which will produce x-rays or wavelengths of very very large frequency
so you put a quartz window here
so which allows only the radiation to escape and stop everything else and that comes and hits the photosensitive plate which is a metal and it produces the electrons
so this is the cathode and it is connected by the anode now you want to gather all the electrons that are emitted by this metallic surface
so what you do is you put a voltage
so that will allow you to measure the current
so greater the voltage then more of the more and more of them will be gathered because you are going to accelerate them or you can do even something better you could apply an opposing voltage which will if the electrons are coming in this particular direction you can apply a voltage in the opposite direction that will produce an electric field between cathode and anode the electrons will experience a force from anode to cathode is that right because the electrons are negatively charged and you ask what is the voltage at which not a single electron reaches the anode and that is what is called as the stopping potential
so photoelectric effect has a very important concept or quantity and that is the stopping potential your textbook denotes it by phi naught you could also denote it as v naught it is done many many times
so if you look at this stopping potential what is that this is the minimum potential difference required to stop the electrons from reaching the anode if the potential difference is less than the stopping potential some of the

electrons will manage to sneak in if the potential difference is greater than that then they will be repelled and they start going back
so stopping potential is the suspension potential electrons come to rest
so this is the potential required to stop the electrons
so what we are doing is to look at the maximum kinetic energy of the electron
so you have your cathode you have your anode light is hitting it electrons are coming
so let us say this electron has an energy k1 kinetic energy this electron has a kinetic energy k2
so on and
so forth
so there will be one electron with the maximum kinetic energy k max
so what should be the stopping potential it is not sufficient for me to stop k1 or k2 i should stop the electron with maximum kinetic energy k max that is what i should do therefore my charge of the electron into phi naught must be equal to maximum kinetic energy of the electron we are employing the notation which is given in your that are emitted
so the quantity of great interest is this k max and let me define that for the sake of completeness maximum kinetic energy
so that is what we have
so this is the experiment
so on how to manipulate the potential difference is shown through the commutator and the voltage and the potentiometer
so you people have done enough number of experiments in your laboratory hopefully otherwise please go and perform these experiments request your teacher that you should all be taken to the lab and they should do experiments involving potentiometers and resistances
so that you understand that insist on that and then you will get a complete picture of what is happening you of course need an evacuated glass tube because you do not want any dust which will stop you don't want any resistance for the motion of the electrons and there could also be stray ions which can actually corrupt your data
so what you do is to have evacuated glass tube create as good a vacuum as possible and then you perform this experiment
so this is a very nice schematic picture and that is what we have shown
so as you can see it is figure eleven point one in your textbook class cbse class 12 textbook
so now if you want to appreciate what is happening in this experiment one very important ingredient in analyzing any experiment is to know what are the relevant parameters and what are the irrelevant parameters
so you want to study a phenomenon and i should be able to find out which of them are important for what i am studying which of them are not important for what i am studying because in an experiment there will be all kinds of things that are going on and not all of them are equally important and some of them are actually completely unimportant
so for us here since energy is being transmitted to the electron that is very very important energy is being transferred to the electron intensity is important because my expression for the energy carried by radiation the energy density is nothing but epsilon naught e squared is the energy density on the other hand if you are studying thermionic emission temperature would be important because when you heat it is the temperature that dictates how much of energy is transmitted to the electron because again by equi partition theorem if the metal is at the temperature the mean kinetic energy will be given by three by two kt

so in the case of thermionic emission it will be temperature that is what we have the experiments were performed with different wavelengths why do i perform experiments with different wavelengths in the case of the double slit experiment wavelengths are important because that is what dictates where the maxima and minima are in the case of photoelectric effect we perform an experiment with different wavelengths because we want to show wavelength is an irrelevant parameter that is very very important wavelength is not an important parameter ok this is not an important parameter as far as stopping potential is concerned phi naught is concerned but is it not important at all the answer is no because the way you understand the ionization of the electron is that imagine my electron is straight to the lattice through some simple harmonic interaction

so it is like a spring now when the electromagnetic wave comes and falls upon the metal my electromagnetic wave is an oscillatory electric field

so let me write that

so what you have is an oscillatory electric field therefore there is a time dependent force which is acting on the simple harmonic oscillator namely the electron

so you have forced oscillations in your mechanics course i am not going to get into that you have learned that under the forced oscillation if there is a resonance condition if the applied frequency matches the natural frequency the amplitude starts increasing

so what is happening imagine my electron is trapped in a potential like this actually it is going to fall off because it is going to get ionized for very very small displacement it will be simple harmonic motion but as the displacement becomes larger and larger it will not be simple harmonic anymore and as soon as the amplitude hits this particular point then the electron will get liberated and you can easily compute the time required for the electron to get ionized in other words the energy supplied is one particular aspect which is coming from the amplitude of the radiation but the time taken in terms of the language of the forced oscillations there frequency would be an important thing

so it is very well that the early experimentalist actually made use of that

so this is another very very important parameter for us now the third quantity which you can see that i have listed here is the material that is used

so we speak of metallic surfaces metallic surfaces have what are called free electrons they are rather loosely bound compared to the dielectric media that is why we have dielectrics it is not easy to move the electron that is there the response is

so weak if you apply a potential difference between the two ends of a dielectric medium no current will flow because the electrons will slightly get displaced but the attractive force is

so strong it will simply go back it will find a new equilibrium position whereas in an in a metal or in a conductor if i apply a potential difference these are very very loosely bound therefore they start moving and they produce a current

so you should actually impinge radiation or make the radiation fall on a metallic surface but then there are metals and metals and conducting materials that is what we need

so it depends on the material that is used you people might have heard of something called hall effect for instance when you apply cross electric and magnetic field the hall voltage that is developed depends on the material depends on the temperature depends on the density of the electron

so there are many many properties of the material that we have temperature density of the electrons etcetera etcetera

so what we are studying is assuming that the wave theory of light is correct we

want to use photoelectric effect as a probe to understand the properties of the material and this is a superior probe compared to what you study in the case of dielectric media or conductors because you are really not probing deep into the material you are only asking you know what is the conductivity what is the permittivity what is the polarizability but here you are actually able to get the electron out of the surface

so this is a better probe

so we can imagine that all these gentlemen herds holloway lennard and later miliken were actually trying to use this as a probe and that is what even though solid state physics people or the condensed matter people do

so these are the relevant parameters that are involved and we want to find out what the photo current and what the stopping potential depend on how does it depend on the intensity of radiation how does it depend on the wavelength of the radiation and how does it depend on the material that is used before getting into the detail it is actually good to give you a preview of whatever we are going to do

so for this reason i call this sneak peek you know what a sneak peek is if there is a movie the producer of the movie puts a trailer on the net on the youtube

so you watch that and you get a flavor of what is happening that is a sneak peek

so we will give you a sneak peek and we will tell you what the results are and then we will go on to study them in detail

so basically what the experimenter is found was that you take the maximum energy as you can see here of the electron you add the potential phi naught now i have made a mistake here obviously because they do not dimensionally match and that is unfortunately because we are many times used to putting the charge of the electron equal to one

so when you come to higher studies it is better to measure all charges in the unit of electric charges rather than measure the electric charge in the units of coulomb coulomb is a definition whereas we know every charge is a multiple of electrons charge in fact even proton is a multiple of electron charge with a factor minus one

so let me correct the expression correct this light

so what i am going to do is to look at k max plus e v naught

so this is my famous electron volt the energy required to get acquired by the electron when it is taken over a potential difference of whatever v naught is

so v naught is equal to phi naught never mind about that and then i am going to divide it by the frequency

so this is my frequency and this is a constant

so c is a constant this is the great experimental result what is it a constant in what sense is it a constant that is something that we are going to elaborate upon in great detail but since i am showing you some kind of a trailer or a sneak peak c is independent of the material c is independent of the frequency c is impli independent of the amplitude therefore it is independent of the intensity but this is all what we have therefore and that means c is a universal constant what does not depend on any experimental condition is a universal constant does not depend any experimental condition except one electrons should be produced if electrons are not produced at all then there is nothing to measure but the minute the electrons are produced and you plot this curve that means k max plus cv naught is this constant multiplied by the frequency this is a universal constant and every time there is a universal constant the antenna of a physicist goes up and says i have found a new physical phenomenon nature is giving me glimpses of some new truth something that i did not know earlier that

is exactly what maxwell did when he found that one over root epsilon naught mu naught epsilon naught is the number mu naught is a number it matched with the speed of light that means immediately there was a flash of brilliance he said array optics cannot be different from electromagnetic phenomena that means there must be a new fundamental physics that is emerging

so in that case we should quickly do a dimensional analysis because new physics comes not when there is a dimensionless number but always when there is a dimension full number relativity came when there was a new dimension full number what was that the speed of light thermodynamics comes with your what with your concept of your dimension full number can be taken to be the boltzmann constant in fact the const of atom temperature is related to energy through the boltzmann constant

so in a similar manner here you have a dimension full number

so you are dividing energy by frequency if you did the calculation that is nothing but energy into time

so again there is a mistake in that slide the let us correct the expression in this slide the dimension is m l squared t minus 1 which is energy into time

so this pdf file is not easily editable it is going to interrupt our whole discussion since we do not want to lose continuity please remember this is missing in this slide ok

so we have corrected that

so now first of all we have to know what this word function is the work function i have defined for you depends on the metal obviously not all conductors are the same

so if you go across the periodic table you start with sodium potassium you have all kinds of materials

so what you do is to shine light and you look at the verb function and you will study a lot deal about these word functions and contact potentials when you do semiconductors your pn junction npn junction transistors everything is dependent on the fact that the work functions for the two materials is different and it creates what is called as a contact potential that is what you are going to study and that is responsible for the exotic properties of these many of these semiconductors

so you know how great those properties are because we put them into very very good use

so it is good for us to know what these work functions are

so go and google open up wikipedia for example they will give you the work function now this is arranged in the alphabetical order not according to the periodic table

so the advantage is that if you want to know what the work function of any material is you can go quickly if it were according to periodic table then you would have to remember the periodic table

so it starts with a g silver gold aluminum etcetera etcetera sodium is somewhere here for example at 2.
36 electron volt

so some of them are very large see for example my gold has a very large work function ranging from 5.
1 to 5.
47 probably that is the highest

so the advantage is that when you arrange these work functions for various elements in the alphabetical order you can look up the work function in an easy way if it were arranged according to the periodic table it would be difficult however if you want to understand the physics behind we should arrange it according to the periodic table because we would like to know how the work

function changes when you move along a row and when you move along a column because that is how the electrons are filled in shells but never mind we have not yet even arrived at the bohr model let alone understanding an atomic system
 so for us the alphabetical order should do very well
 so we start with silver which varies from 4.
26 to 4.
74 this is very important for us that there is a certain variation
 so you should already start wondering what is this variation if there is a variation how will i find a constant slope there is a natural question of course there are some materials which don't have that for instance calcium has a good number 2.
87 you can see that here where is calcium here cadmium has four point zero eight chromium has four point five and our favorite material namely sodium has two point three six one of the smallest in fact on sodium even visible light would do if you send blue radiation you don't need ultraviolet or you don't need the x-rays but on the other hand if you look at osmium which is the largest in this particular table it is 5.
93 you would require higher energies
 so we could keep going down the table
 so this is the list one there is a continuation in the next list two
 so again you have you see variations for rubidium which goes from 2.
261
 so somebody has measured it to a great accuracy people have taken great pain whereas this measure this material ta has a large variation between 4.
00 to point eight zero uranium has a variation from three point six three to three point nine zero
 so we have a reasonably good information in fact an extensive information on the were functions of various materials
 so what we want to see is what happens when i perform an experiment by impinging light on these materials and look at the photoelectric current and also the scopic potential as a function of frequencies that is what we want to know
 so this is the list that we have i wanted to show you and i wanted you people to appreciate how painstakingly these experiments are done because we should never forget that physics is an experimental science it is not metaphysics
 so let us move to the next slide
 so i told you that we have to worry about the fact that for many materials there is a certain variation
 so let me go up and to the previous page and show you the information again the very first entry silver varies from 4.
26 to 4.
74
 so there is a difference of about something like 0.
5 electron volts that is what we are saying which is not insignificant
 so what i have done is to write down the work potentials for various surfaces
 so it is not as if silver is one homogeneous material uniform in all directions and there is an experimental error and we are writing something between four point two six to four point six four there are various phases after all it is a crystal
 so if you look at this silver
 so they are labeled by the synthesis one zero zero one one zero one one etcetera
 so you can look up on them as some kind of coordinates it is not very important for us now you see different surfaces are showing different work potentials it

is very very important for us
 so these faces will all be adjacent to each other
 so we are looking at a crystal let us say
 so that is what i have there is no correlation between what is shown in this table and what i am going to write
 so let us say this was 4.
64 and let us say this was 4.
52 and let us say this bottom face whatever this bottom face was 4.
74
 so what are we saying if i want to ionize an electron from this particular surface and take it to infinity that is how we define the work function you will require about 4.
52 electron volt whereas if i look at the upper surface you would look where 4.
64 electron volts
 so that means if i took this electron took it to infinity by infinity i mean all interaction has ceased
 so i take it here and i bring out here then you see it has not come back to its original energy although it is the same material because there is a mismatch of 4.
64 minus 4.
52 that is what it is it is about 0.
12 electron volts that means at this point at this contact there is a potential difference now every time there is a potential difference there is an electric field and mr coulomb will tell us or gauss's law will tell us divergency equal to 4 pi rho there must be an accumulation of charge at that particular point how is it produced no if you take a crystal and put it in great ultra vacuum or some such thing in a very pure atmosphere maybe that thing will be there we cannot imagine that the early experimental is created such a thing
 so every time there is such an electric field you know there is a lot of dust that always gets attracted to this
 so the dust will settle on these surfaces especially at these corners therefore your experiment will actually get compromised if you do not pay attention to this in fact one of the great accomplishments of milliken was to pay attention to this and do very very careful experiments
 so when i will discuss that in a little bit more detail not in complete detail when i discuss millicans experiment
 so we should remember that when we say that people saw a universal slope it is not like the graph in fact i wanted to put the graph here i did not put that where that straight line is shown in a qualitative way
 so your textbook says here is my frequency and here is my energy that is what they say and they draw a line and the x axis and the y axis have no entries that is not going to help us if we want to appreciate
 so we need entries we need numbers that is very very important for us and that is the reason why i gave this piece of information
 so here is the experimental apparatus of militant i am not going to discuss all the experiments that the other people did because if you go and look up the original paper of milikan in physical review it is an eminently readable paper published in 1916 the results were obtained in 1915
 so you can see the cathode ray tube the collecting anode etc etc
 so we will not spend time on that i just wanted you people to get the flavor of the whole thing and then you know the vacuum is created in the chamber etc
 so what we shall move on is to discuss the most important thing for us and that is the universality
 so as i told you in one of the lectures in my slide if there is a world called

ack that means acknowledgement
so we are acknowledging milikan this is from millikan's result which is reproduced and this information of color wavelength frequency and photon energy is from wiki commons
so you can go and verify that if you feel like
so here is the experiment that you have
so this experiment is done for various frequencies you can see the frequency is changing here in units of 10 to the power of 14.

so look at this 400 terahertz tera is 10 to the power of 12 400 is 10 square
so you have something like 10 to the power of 14 it is in this range you start all the way from red and the way you go all the way up to violet
so you have about how many points you have 1 2 3 4 five six points they are roughly lying on a straight line in fact it is an excellent straight line it is a pity that there are no error bars but the paper certainly has information on the error bars never mind about it
so the bins are also given for you because it is not like two points define a line three points define a plane that is only in mathematics in experiments if you want to show that some experimental numbers are falling on a straight line you will have to take as many points as possible
so let us say the theory predicts that they should fall on a straight line your experimental numbers will typically fall like this there may be some errors also larger the number of points better it is for us
so here you have as i told you about six points never mind about that the bin is also very very important if they are very very widely separated then that experiment has no significance
so he gave a delta nu of 3 into 10 to the power of 14 and he was able to go all the way up to 12 which goes beyond the visible range probably because the violet is already something like 6 into 10 to the power of 14.

so you have gone by a factor of 2 above that in frequency
so this is the experiment as a function of frequency that is something that we have to remember
so we should never forget i told you that the parameters are frequency intensity of the radiation and the material and this is on sodium metal sodium we said has a potential what was the work function that was 2.
36 electron volt or
so and it is falling right in this this one okay let us move to the next slide what millican did was to actually explicitly measure verify that it is independent of the frequency
so you can also keep the frequency and change the other parameters and he measured the slope
so these numbers on the left hand side are given in the angstrom units 10 to the power of minus 8 centimeters
so you can convert them into the nanometer range if you feel like
so that will make it 312.
6 nanometer
so on and
so forth and he determined the slope and look at the remarkable agreement here in terms of 10 to the power of minus 15 volt frequencies if you multiply it by the electron this one then it will be very close to what we call as the planck constant four point one one four point one four four point one zero
so on and
so forth three point nine eight four point four and the mean turns out to be 4.

13 in 10 to the power of minus 15 volt frequencies considering the experimental conditions of those days it is quite remarkable it is there in the 1916 paper you could of course do a slightly better analysis than what i have shown in this particular picture you can even compute the standard deviation take the mean subtract each of these numbers from the mean square them add them all up divide by the total number and take the square root that is the definition of the standard deviation you will find that it is a pretty small number

so this is the next evidence for the universality

so let me give you the results then i will show you some more results these are directly lifted from millikan's paper and these sentences are

so well returned i was taking up some books we have essentially lifted those sentences and nobody will accuse us of plagiarism because they are written very very well your 12th standard textbook is actually also no different

so milligan says that there exists we conclude that is the sentence above that there exists for each exciting frequency nu above a certain critical value a definitely determinable maximum velocity of emission of corpuscles

so he uses the word corpuscles he does not use the word electron he concludes that there is a linear relation between the voltage and the frequency then he says that the slope dv by d nu or the slope of v v line is numerically equal to h by e remember planck introduced the planck's constant in 1900 for black body radiation einstein made use of that in 1905 content scattering was probably sometime around in 1911 where the concept of the momentum of the photon was also introduced by making use of the planck constant prank constant had been determined experimentally from the black body radiation now if you believe in the einstein hypothesis this should also be experimentally determinable and we should compare the numbers and that we are going to do when we discuss the theory that is what we are going to do

so this is in anticipation of whatever we are going to discuss

so p equal to h nu naught that the intercept of the vv line is the lowest frequency at which the metal in question can be photoelectrically active and that the contact emf between any two conductors is given by this equation i told you a lot about the contact potential

so this is also something that he did if you read this experiment his experimental paper carefully which does not require a knowledge much more than what you have studied in year 12 standard you may require a little bit more there is a very extensive critique discussion of the earlier experiments and he points out why the results obtained by the earlier experimental layers were not very accurate including those of lennar actually because of the points that i mentioned there was deposition on the surfaces because of the contact potential it was difficult to clean them there was not enough vacuum

so on and

so forth but milikan over a period of 10 years dedicated his life to the cause of investigating photoelectric effect and please remember miracan did not believe in the einstein explanation therefore being an adversary he had a great great motivation to do the experiments carefully it is always the believer who will be a little bit sloppy but the non-believer will look at everything with a fine comb with a powerful lens

so we should be grateful to millikan for that

so here is a result which is on zinc which was performed in 2013.

those results were shown in for sodium but these results are shown for zinc

so you can go back and look up the work function for zinc i don't want to do that now

so this is the extrapolated line

so you see the visible spectrum is shown here between 4 and 8 that is what they

have done beyond that is the ultraviolet x-ray
so on and
so forth
so in the visible range you do not see that at all because the work function for zinc is much larger and again you see there are four points which are beautifully falling on a straight line
so this is again another example of universality it does not matter whether you look at zinc it does not matter whether you look at sodium or potassium or silver it doesn't matter which frequency range you look at and of course all these people used different intensities this slope is a universal constant and i should repeat every time you find a universal constant a physicist will say i have discovered new physics i will repeat when there was this universal constant c identified by maxwell it caused a unification of two different fields and what are the two different fields optics and electrodism until that time people believed they were two different branches of physics they became they got merged into one electromagnetic theory and optics as a branch
so some such similar thing some great revolution should take place here also
so we have a glimpse of what is happening
so what are the important points that we have to notice at this particular point the important points that you can notice
so i can go back to my previous slide and show you there is a minimum frequency
so the minimum frequency here is located at let us say 10.
4 okay that is shown here
so that is your work function right that is the potential the energy required to liberate an electron and if i probably went back to the earlier slide here it is something like close to five electron volts
so there is a minimum frequency below the minimum frequency you can vary your intensity you can do anything you want your electrons will refuse to budge they will stay put in the metal they will stay put in that whatever that surface is you cannot liberate them but we are going to we have been asserting that energy depends on the amplitude on the intensity but the electrons refuse to buy that argument that is what we have to notice what is the next thing that we have to remember once i cross the barrier once i am able to overcome that frequency barrier i go beyond that minimum frequency now they merely depend on the intensity it will be proportional to the intensity they start agreeing with maxwell who says the energy with which the electron is liberated depends on the intensity
so there is a kind of a double game that is being played by the electron electron does not acknowledge that the energy is proportional to intensity below a certain frequency it is as if suddenly maxwell's equations failed is that okay as if ah not really and the minute you cross the frequency everything becomes fine it it becomes proportional to the intensity
so for some reason i have written that again probably because i thought it is a very very important point no emission below the minimum frequency and what kind of a behavior is there between the frequency and the stopping potential it is a straight line and today with
so many
so many experiments that have been performed we can say without any doubt without any ambiguity that this experiment is as well verified as decisive as young's double slit experiment which have been repeated for a whole range of frequencies and intensities that is something that we have to remember
so we have young versus milliken this is the double slit experiment and this is the photoelectric you may say look here young did experiments in some visible region if you forget about sodium for all that you need higher frequencies

so is it possible that this wave description is valid only in the small window for example in the electromagnetic spectrum the answer is no because i told you the great experiments of hurts and jc boss showed that you find diffraction interference everything even in the infrared region okay where it in the microwave region

so verify it all over you must have heard of x-ray diffraction where it shows wave like property when you go higher up and the same x-ray

so let me write that x-ray diffraction you have already studied diffraction in your optics and the same x-ray is showing what a different behavior why is it a different behavior because it is change saying that depending on the work function either the electron will be emitted or it will not be emitted that is what we are saying

so this is what nowadays in modern world people call it as a conundrum in when we were students we used to call it a paradox or an apparent contradiction

so what is happening with millican experiment and how are we going to reconcile with the wave theory one of the distinct features of physics ever since galileo did this experiment both real experiments and thought experiments is that physics asks modest questions

so if you go back and read the earlier quote unquote scientists or philosophers they were all interested in deep questions ultimate questions what is the origin of the universe what is the nature of life what is happening what is the ultimate reality is the world real or unreal is the mind made of matter or is matter a projection of mind these are the great debates that raged all over the world but the great contribution of galileo newton etc is that they said that we will not ask all those questions we will ask simple questions we ask questions what is light made of when i do an experiment aristotle said that lighter objects go up and heavier objects come down obviously he was looking at leaves which were floating in air or scraps of paper which were floating in air and stone which was falling it was not made in some kind of vacuum it is not that distorted did not observe phenomena but that is what he observed but a very careful experiment was actually done by galileo what did he do he went up the leaning tower of pisa

so there is the leaning tower of pisa and he dropped two different materials of two different weights two different masses and he took a clock and asked how long does it take to reach okay you have to be a little bit intelligent you don't drop something for example like a cotton you know you had of cotton you know puffy cotton and you don't drop a stone we have to have that much common sense but you can take you know a nickel and gold or piece of nickel and gold or whatever and drop them and they found it is roughly the same and this very simple experiment contained the seeds of the most revolutionary theory theory of gravitation and we all use that when we write the motion of a particle in a gravitational field we write m a is equal to g m m by r squared and with impunity without batting annihilate we cancel the m on both the sides we say all particles irrespective of their masses have the same acceleration depending on what the gravitational force is

so what happened to the concept of inertia that newton told us newton told us that look here as you keep on increasing the mass inertia should change but here nature is playing a trick on us it is saying on the left hand side it is inertia on the right hand side it is the response to the force and they are exactly balancing counter balancing or cancelling each other

so this is the result of an experiment

so as i told you physics asks modest questions we don't ask very very deep questions

so for that reason when we want to reconcile what is happening with hertz

lennar millican hallowack experiments and what is happening with the experiments of young and his successors diffraction experiments nicole prism you know ordinary day extraordinary day and the interference printers
so on and
so forth when we are seeing there is a contradiction between them we should not immediately try to develop a theory because then we may get lost in wilderness first we should try to build a nice model for understanding this phenomenon then we will ask how to reconcile this model with another model they may appear to be contradictory with each other but never mind about that contradictions can be reconciled later in other words do not try to answer all the questions at once try to answer one question at a time that is what we want to do and that is what einstein attempted to do but before we jump to discuss what einstein did we need some numerical numbers as i told you physics is what yeah numerical size it is not numerology but it is a numerical science
so what we cannot calculate is not of much use
so let us go back to what maxwell told us i already made use of this in my discussion of the double slit experiment the energy density carried by a radiation u radiation is epsilon naught e square where epsilon naught is my permittivity that is what i have now of course i am interested in the average because we are interested in rms value
so on and
so forth which will give me epsilon naught by 2 into e naught squared
so what i have written here i have written my e to be a monochromatic plane wave e naught cos k dot r minus omega t that is what i have
so i think there is another expression here the important thing is there is no frequency dependence but from the principle of conservation of energy which is a very very sacred principle nobody would dare why write that principle of conservation of energy minimum energy required depends on frequency minimal energy required what for photo emission of electrons photo is light and this this we want to reconcile this is what we have to understand
so what i will do is since i am running out of time and it is also logically the correct thing to do i will discuss what kind of a contradiction we get i will show you that the order of magnitude difference between the prediction of maxwell theory with experimental observation is 10 to the power of 19 we are off by 10 to the power of 19 i am not very sure it could be 10 to the power of 16 a factor of 10 to the power of 15 to 16 please ignore 10 to the power of 19
so that means it is not a small correction to the classical theory it is going to be a very very drastic thing and we will take up in the next lecture please go back read your textbook carefully again discuss with your teachers and if you have a net and if i have an opportunity if there is a college nearby try to read milliken's paper we will all be much wiser and richer thank you you