Experimental Physics - II
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture – 56
Theory of photoelectric effect

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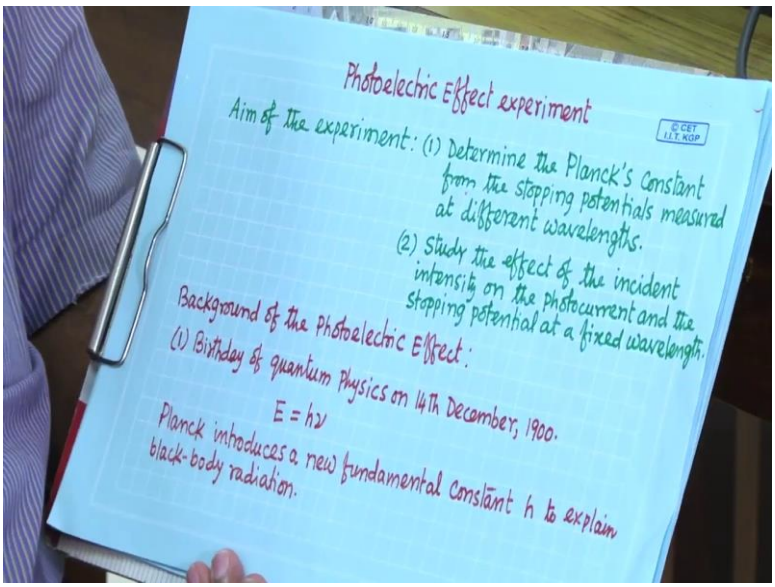

today I will demonstrate experiment on Photoelectric Effect. aim of this experiment is determine the Planck's constant from the stopping potential measured at different wavelength. And second aim is, study the effect of the incident intensity of the photocurrent and the stopping potential at a fixed wavelength.

we will find out the Planck's constant, this is the universal constant that we will find out from this experiment. Also we will study the effect of light intensity on the photocurrent and corresponding stopping potential at a fixed wavelength. background, this is a historical background is there for these photoelectric effects as you know. birthday of quantum physics is 14th December 1900, E equal to h nu, h is a. this relation was given by the Planck. Planck introduces a new fundamental constant h to explain black body radiation,

that is why the, this was the starting of the quantum mechanics, quantum physics. that is why we take this date, this date 14 December, 1900 as the birthday of quantum physics so; but this photoelectric effect was explained by Einstein in 1905, after 5 years.

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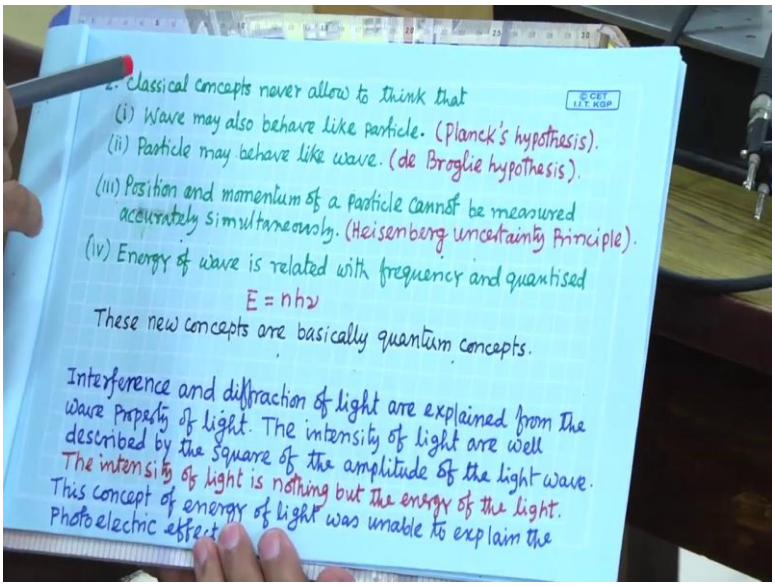

what was the importance of this Planck's equation E equal to h nu as well as the Einstein's explanation or Einstein's equation for the photoelectric effect, what was the importance at that time? at that time people are only familiar with the classical concept,

classical concept never allows to think that, wave may also behave like particle that is the Planck's hypothesis; particle may behave like wave, that de Broglie hypothesis; position and momentum of a particle cannot be measures accurately simultaneously, so Heisenberg uncertainty principle; energy of wave is related with the frequency and the energy is quantised that is E equal to n h; h nu 2, h nu, 3 h nu or h nu 1, h nu 2, h nu, 3 nu 1, nu 2, nu 3 these are different energy

this whatever I mention four points here, so classically we cannot think this facts, these new concepts, but it happens, because these are hypothesis based on that many physical phenomena was explained so; that means, this hypothesis are real, it is not just it is a. hypothesis generally verified with the fact ok, with the experimental observation etcetera.

thus the capability of this hypothesis it is a initially it was assumed and if it can explain everything then it is a accepted assumption. that we tell hypothesis. these new concepts are quantum concepts, it is not classical concept; from classical concept we cannot accept them. it is a new area of science, new area of physics ok, so that quantum concepts. these are the things beginning of the quantum physics,

in case of interference and diffraction of light; we have seen those phenomena are explained from the wave property of light and their the intensity distribution of interference effect or interference fringe, diffraction fringe, that intensive distribution that was explained taking the intensity as a square of the amplitude of the wave ok, square of the amplitude of the wave.

when two waves are meeting, interfering, or there is a diffraction, so then following the superposition principle. we add the displacement of individual one then we are getting the resultant amplitude of the resultant wave. intensity square of that amplitude ok, in that amplitude there may be phase term also then we have seen for interference and diffraction. amplitude square of the light wave gives the intensity.

intensity of light is nothing but the energy of the, and also intensity of light is nothing, but the energy of the light ok; more intense light more energy are there, is supplying more energy. that is the concept we used for the explanation of the interference and diffraction property of light and that it is a wave concept of light, But this concept of energy of light was unable to explain the photoelectric effect. What is photoelectric effect?

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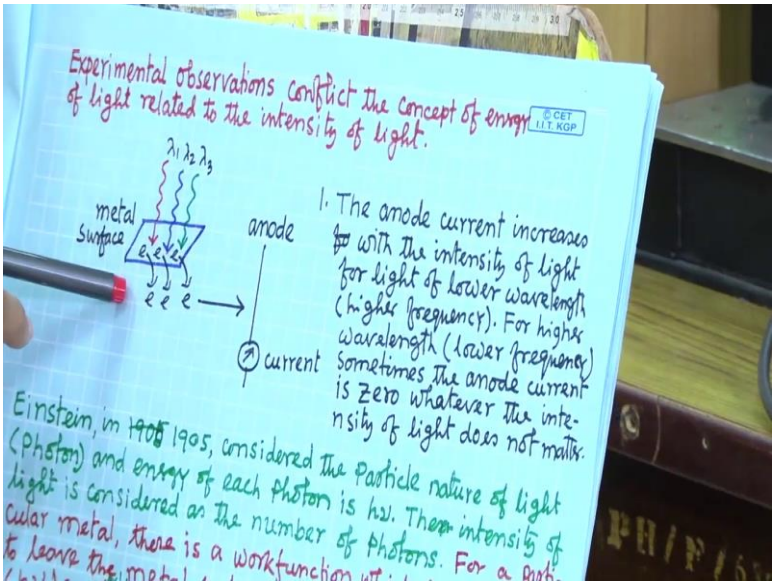

what was the observation ? on a metal surface if light falls, it can be say monochromatic light; either red light or blue light or green light that means their wavelengths are different. if you just consider one by one. light is falling on this metal surface, the wavelength of this light is lambda one red one wavelength is higher than the green and blue one. higher wavelength light is falling on this.

Now, when light is falling on it, so electron. this light is absorbed by the metal electron, free electron ok, and it come out from the surface. it come out from the surface, so these electrons we tell photo electron; because these electrons are generated from the due to the photon sorry, due to the light ok, that time photon concept still was not there, so with the light, now, if you put the anode and apply positive voltage ok; so these electrons will move towards the anode and these electrons will reach to the anode and will get anode current.

Now, we are observing these anode currents; so more electrons will reach to the anode and more current will get, for a particular anode voltage, we will get current. current that current should depend on the intensity of light of on the intensity of light, if I take red light and then if I increase the intensity of light; then what will happen, I would expect we are expecting that we will get more and more currents, because more energy are falling on this metal surface. more electrons will come out and they will reach to the anode and we will get more current,

it should be independent of the colour of the lights. if I take white light, I should get the same thing; if I get say monochromatic light say red colour, I am doing experiment; then if I take this blue colour, then I am doing experiment. for same intensity of light, that intensity I am talking about the square of the amplitude of the light wave. that is the intensity of the light, we will expect the same current for all wavelength for a particular intensity,

If I intensity increase the intensity, so current should increase, it should be independent of the wavelength of the light, it should depend only on the intensity of the light that was the concept, we that was the result people are expecting; but the result was is different. What was the result? The anode current increases with the intensity of light for light of lower wavelength, ok and for higher wavelength lower frequency, sometimes the anode current is zero whatever the intensity of the light does not matter,

the result is just showing opposite, it does not sometimes it does not depend on the intensity of light; whatever the intensity of light, no electrons are coming out; it depends on the wavelength of this light falling on the metal surface, in this experiment whatever observation that is that anode current means the number of electrons. sufficient anode voltages given, it is assume that all electrophile reach to the anode,

this result is showing that the number of electrons will emit from this metal surface, it does not depend on the intensity of light, it mainly depends on the wavelength of the light, frequency of the light. why it should depend on the frequency of the light; why it should not depend on the intensity of light, ok? that was the puzzle, that from classical concept this result was not possible to explain. that is the difficulties people face and then this Einstein came forward and Einstein in 1905, he considered the particle nature of light that is called photon, and energy of each photon is h nu, he considered the energy of each photon is h nu,

The intensity of light is considered as the number of protons present in the light beam, it is a completely different concept then the wave concept of light, wave concept when it is wave concept, then amplitude place the role amplitude related with energy Einstein considered it the light as a particle, it is a just like cathode ray, you know this beam of electrons, beam of electrons that is the cathode ray.

Similarly, this light ray is the beam of photons, it is that it is not wave gives the continuous this sense of continuation, continuity . something is continuously moving and photon or particle it gives the individual entity. they are moving in a series ok, then we tell this that is a beam of photons. intensity how many photons are coming or falling, so that will be taken as a intensity of light and energy of the light is energy of each photon and this total energy you can take summation of them of course.

that was the, so wave concept of light could not explain this observe this experimental observation. Einstein considered the particle nature of the wave; of course, he took this Planck's energy quantization E equal to h nu, he took that one and used for explaining this result.

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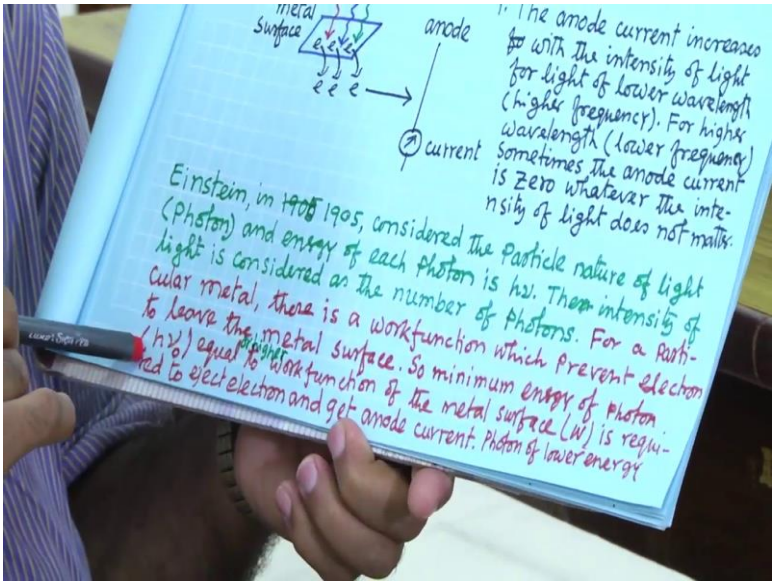

that is why for a particular metal there is a work function; means, electrons are free in the metal, but it cannot come out from the surface you need minimum energy to release the electron from the metal surface.

that energy is call the work function of the surface of the metal. there is a work function which prevent electron to leave the metal surface. minimum energy of photon that is say h nu 0 equal or higher to the work function of the metal surface, so that is the work function W is required to eject electron and get anode current,

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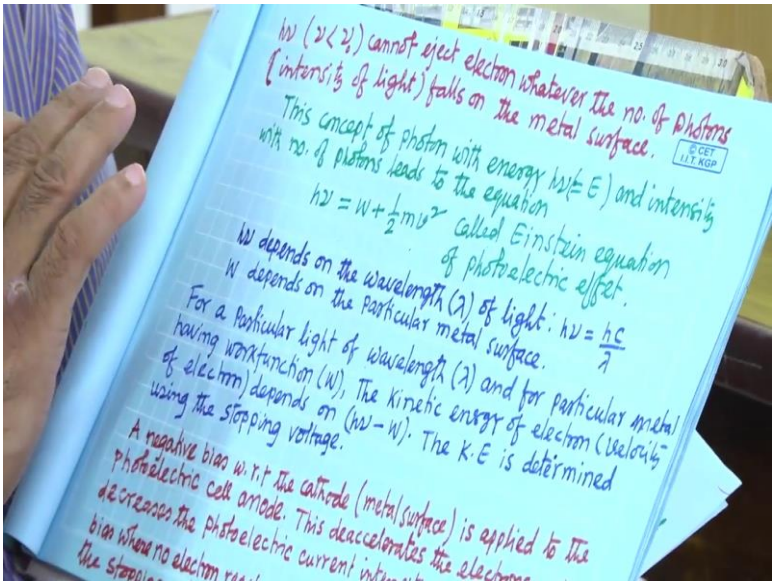

photon of lower energy say h nu, where nu is less than nu 0, cannot eject electron whatever the number of photons falls on the metal surface, this electrons they absorb one photon, when they will absorb this one electron that is the electron is getting one energy h nu, if that energy h nu is less than work function, it cannot come out. it does not matter how many photons are falling on that. that is why h nu is c by lambda so; that means, electron will come out from the surface or not, it depends on the wave length of the light or higher wavelength, lower frequency, you will not get electrons ejected from the surface of metal and there will be no anode current.

if higher wavelength; lower wavelength, higher frequency. energy h nu will be higher than the h nu 0 or higher than the W work function. then each electron will absorb this one photon it will get h nu energy which is higher than the work function. it will come out, it will overcome that work function, barrier, surface barrier and it will come out and it will have some additional energy. that energy will act as a kinetic energy,

this concept of photon with energy h nu and intensity with number of photons leads to the equation h nu the energy of the photon equal to work function plus half m v square, this is the kinetic energy of the electron, ejected electron, this called the Einstein equation of photoelectric effect, using this equation which was nicely explain the experimental fact, which was not possible to explain using the wave concept of light. h

nu depends on the wavelength of light; of course, and W depends on the particular metal surface,

for a particular light of wavelength lambda and for particular metal having work function W, the kinetic energy of photon or it is velocity of electron will depend on this h nu minus W, . the kinetic energy is determined using the stopping voltage, whatever the kinetic energy of the electron, so with this kinetic energy electron will move towards the anode and it will reach to the towards the anode. without giving any voltage; without giving any voltage to anode we may get anode current due to the kinetic energy of the electron.

Now, if we apply. what is that kinetic energy, if you want to measure? what we can do; in anode we can apply negative voltage, then this electron will be deaccelerated it will feel repulsion, see it will be deaccelerated. if you increase the negative voltage of the anode with respect to the cathode; cathode means, metal surface with respect to the cathode surface,

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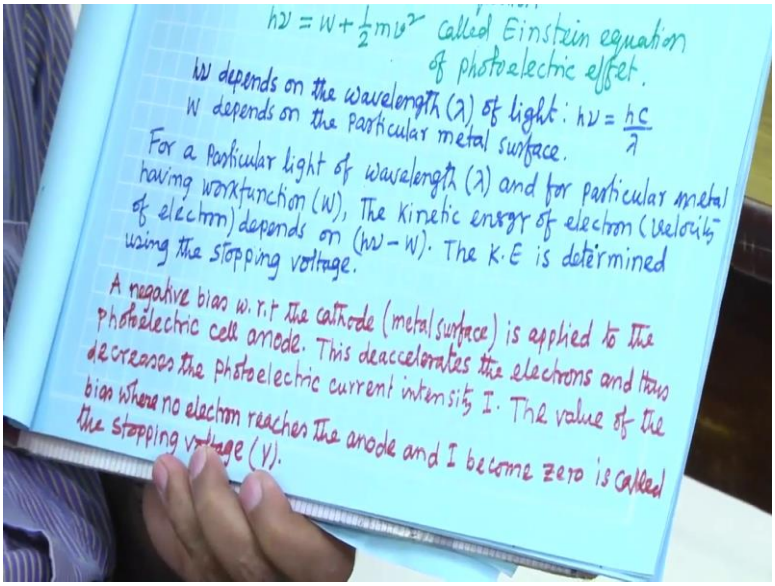

If you increase the negative voltage of anode, so what will happen; on time will come where no electron will be able to reach to the plate. the plate current will be zero. the voltage at which the plate current becoming zero, so it is a, so that we take as a stopping voltage and corresponding potential energy is e v

opposite energy that is e v, so that energy will be equal to the kinetic energy of the electron. a negative bias with respect to cathode is applied to the photoelectric cell anode. This deaccelerates the electrons and thus decreases the photoelectric current intensity I. the value of the bias where no electron reaches the anode and I become zero is called the stopping voltage V.

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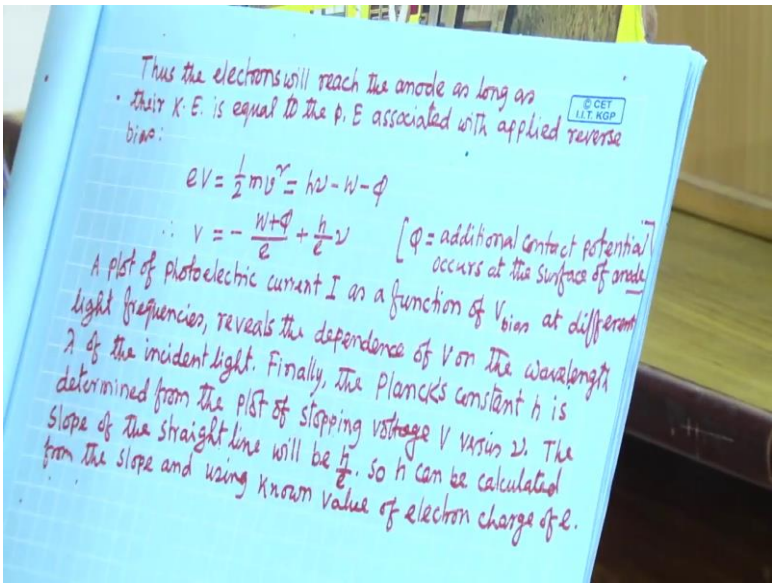

that is why, that is what I explain. thus the electrons will reach the anode as long as their kinetic energy is equal to the potential energy associated with the applied reversed bias. That is I told that e v, the potential energy e v equal to half m v square. that half m v square equal to h nu minus W, here additional minus phi I have written. this phi is additional contact potential occurs at the surface of the anode.

when; from metal surface, electron just cannot come out. there is a barrier. delta with a work function W and when that is falling on the anode surface, that electron will in contact with the anode surface. we that is there will be contact potential; means again to that electron cannot enter to the anode, cannot plated the anode surface. it has to spend some energy. it will feel some barrier their also. that is that we are telling contact potential. that we are it is a phi.

whatever the energy of this light h nu photons. the energy will be spent for the work function of the metal surface, for the contact potential of the anode surface, then the

balance rest of the energy h nu minus W minus phi will be the kinetic energy of the electron and at stopping potential V, stopping bias V, so this kinetic energy will be equal to e v.

we can find out v equal to stopping potential equal to minus W plus phi by e plus h by e nu. for a particular metal and anode, so this term is constant, h by e that also is a constant. they are independent of frequency we are considering. this here y equal to m x plus c, so this is the equation of straight line; so y means here V, stopping potential and x means here nu ok, so m will be the slope.

from this straight line, so if you plot v verses frequency; then you will get a straight line and from that straight line if you find out the slope, so that slope equal to h by e. e is supplied electronic charge ok, it is supplied 1.6 into 10 to the minus 19 coulomb, that is supplied, then you can find out from the slope and from known e, known value of e you can find out h ok, Planck's constant. this is the first part of the experiment and second part of the experiment is I think, yes.

we will for a particular wavelength and particular intensity of the light what we will do, we will increase the distance between the source and photocell ok; so light will fall on the cathode, so we will increase the distance between the cathode and the source,

when we will increase the distance then; that means, the intensity of light which is falling on the cathode of photocell. that cathode, that intensity will be lower, will decrease. that way increasing the distance of light source from the cathode, from the photocell; we will change the intensity of light on the cathode surface and for a particular wavelength of course and we will note down the change of the anode current,

how anode current in changing with the intensity of light for a same for a particular frequency or for a particular wavelength,

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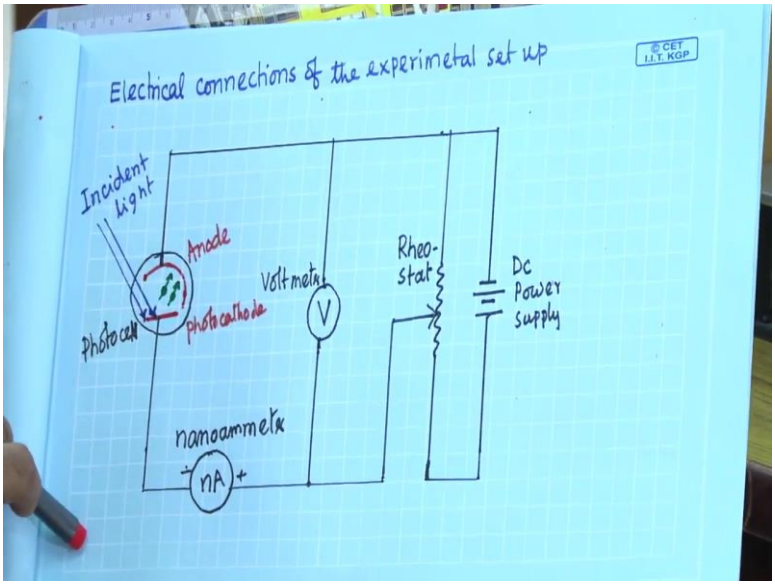

that is the second part we will do. for this experiment, the electrical circuit we will use, this is the electrical circuit. we have a is the compact one you know, we have a it is called it is the photocell, we tell is the photocell, in photocell there is a photocathode and there is a anode,

light will fall on this cathode, now electrons will emit from this photocathode and it will reach to the anode, then we will get photocurrent, we will get photocurrent and that current will measure using the nanoammeter. Now to study is, so to study the behaviour of the current photocurrent with respect to the voltage applied to the anode with respect to the cathode, whatever these we are telling negative voltage we are applying, so retarded potential we are applying, so stopping potential we are applying, how much voltage is applied, so that from this volt meter we will get, it is the parallel connection with this one,

how much voltage you are applying. we are applying from this setup. we have a DC power supply of constant voltage; say we will take here around two volt now, this is the, so these voltage will drop across these resistance. this is the rheostat . we will vary the resistance, so then voltage, so this end and this end that voltage drop across this part of the resistance will give the voltage to the, so that way this from this changing the resistance, here moving this rheostat knob, we can vary the voltage.

How much voltage we are varying power from applying, so that we will get from voltmeter. what experiment we will do, we will change for a particular wavelength of light we will choose to fall on the photocell, and we will apply initially we will apply 0 no voltage, 0 voltage, we will get maximum photo current, because here we are applying negative voltage now, voltage is 0. maximum voltage you will get, now sorry maximum current will get. maximum electrons will reach to the anode.

Now, we will increase the voltage negative voltage, negative voltage ok, negative it is attached with the anode, negative voltage and we will change this voltage, we will change this voltage and we will note down this current, The current will decrease and we will get a particular voltage where this current will be 0. that voltage is we will take as a stopping voltage, whatever the in equation we have used.

for different wavelength of light, different frequency of light we will find out the shopping voltage ok, from this measuring the photo current, this is the experiment and another experiment is actually, we will apply particular voltage, we will apply particular voltage we will choose particular wavelength, now if we increase the distance of these light source from the photocell, so intensity of light will decrease on this photocell. thus will change the intensity of light falling on the photocell and we will see how current is changing,

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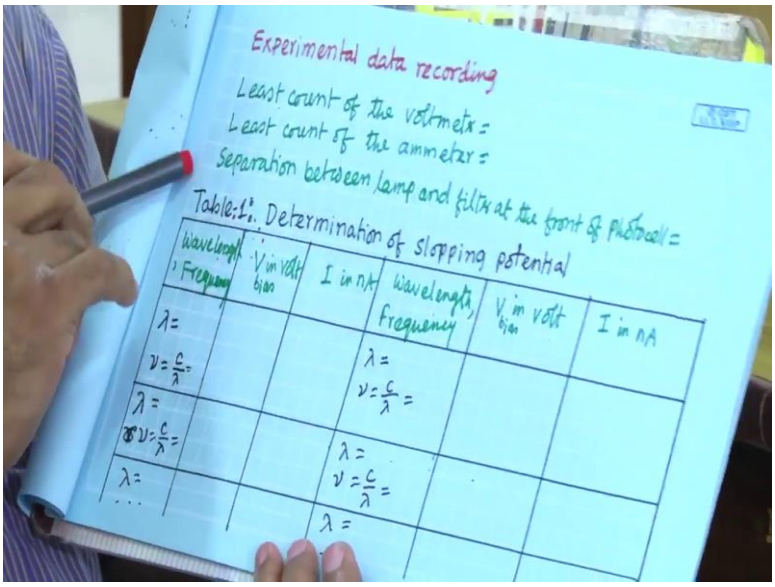

there are table for that for noting down the data, experimental data recording. least count of voltmeter, least count of ammeter, separation between the lamp and here filter, the source. We will filter because we have to get monochromatic light of different wavelength, so we will use filter. we will take that from filter monochromatic light is going. filter as if that is the source of light, monochromatic light, so at front of the photocell, we will note down this, because these are important, because this will keep the intensity constant for a particular experiment.

Now, so determination of stopping potential; as I mention, so you take different wavelength and for each wavelength you note down the change the voltage and corresponding current, and find out that which voltage the current becoming 0, that is a we will continue, we will use I think 6, 5 or 6 wavelength for this experiment and then we will plot them.

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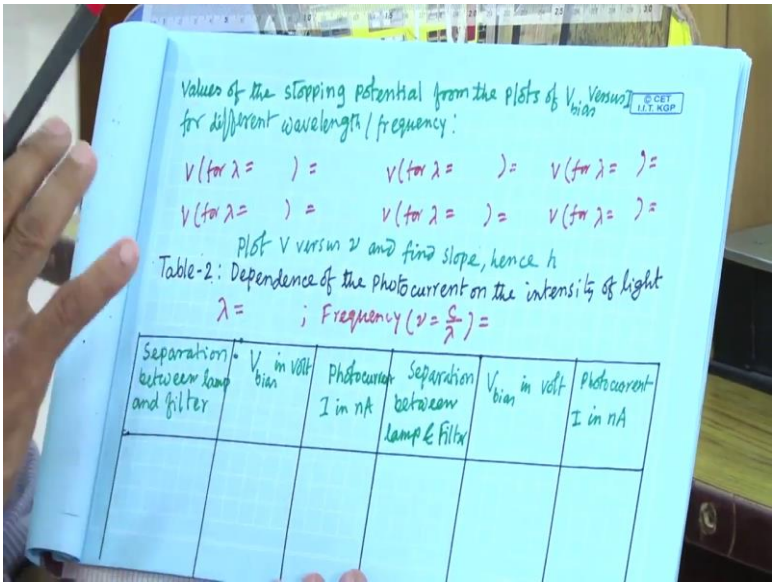

we will get stopping voltage for different wavelength, then we will plot v verses frequency nu ok; from wavelength we can calculate nu frequency and we will find out the slopes and hence h Planck constant, .

second work is dependence of the photocurrent on the intensity of light. separation between lamp and filter ok, so we will change this distance between lamp and filter intensity of light on the photo cell will decrease. bias in voltage some voltage will be

given ok, some voltage will keep fixed ok; now photocurrent will note down just changing this distance,

this way we will continue to see the how this photocurrent or ejection of the electron from the cathode surface, how it changes with the intensity of light, we will draw a graph and we can see the nature.

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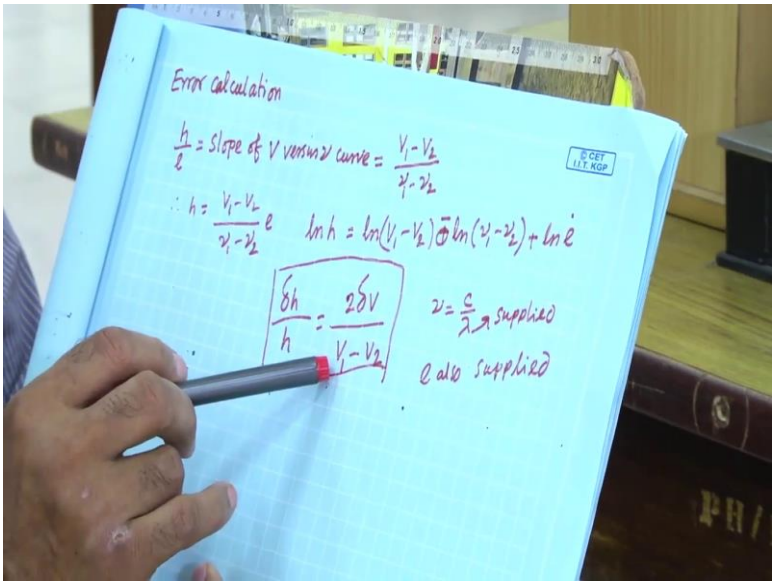

error calculation for the Planck constant, so h by e equal to slope of the V verses nu curve. slope how you will get, you will get two voltage corresponding two frequency ok, difference of frequency and difference of voltage. V 1 minus V 2 by V nu 1 minus nu 2 that is what we will take from the graph and that is the slope.

h is V 1 minus V 2 by nu 1 minus nu 2 into e. take long and then find out, because e is supplied one. no error from that e and so you will get 2 del V by V 1 minus V 2 and this also will not contribute, because we are calculating nu from the supplied lambda. we are not measuring. that is why this will be the most probable error for the measurement of h, that is the description of the experiment I made, now I will demonstrate the experiment in next class.

Thank you.