Experimental Physics - II

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

Lecture – 03
Summary of Experimental Physics - I (Contd.)

In last class I was discussing about the pendulum. Let us see what the applications of these pendulums are in our day to day life.

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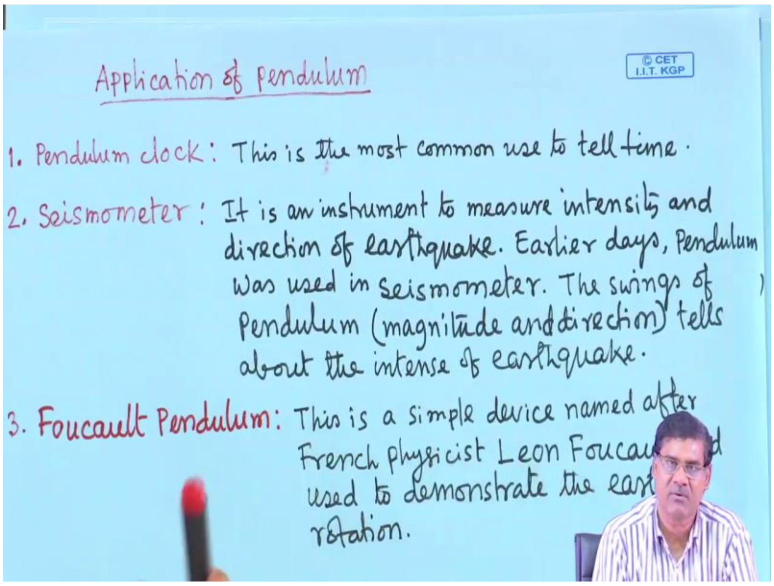

I was showing you that this pendulum clock in earlier days was the only clock which was used to know the time. So, this was very important and now-a-days also; you can tell, it can give very accurate timing. I think all of you have seen this pendulum clock. It is something like wall watch; just nowadays it is seen very less in number, but I think, in some houses, it is still there.

This is one application of pendulum; second application is seismometer. What it is? It is an instrument to measure intensity and direction of earthquake. In earlier days pendulum was used in seismometer; the swings of pendulum means magnitude and direction, which tells about the intense of earthquake. In earlier days, basically pendulum was used to sense the earthquake, ok.

It is designed in such a way that if because of earthquake; earthquake is nothing, but some waves, some oscillations; some waves in earth, it will move; so when it will move this pendulum, it will start to oscillate. So, the direction of these oscillation and magnitude of the oscillation, it will depend on the strength, at that moment, of the earth ok.

So, that moment of the earth or vibration of the earth that is nothing, but we tell the earthquake. Because of these earthquake or intensity of this earthquake, depending on the intensity of this earthquake, the magnitude and direction of the pendulum will tell us about the danger part, about the intensity of the danger of the earthquake; so that is called basically seismometer.

So, earlier this seismometer was used and now it is modified; earlier this was seismometer, now also it is called seismometer, but in different way it is used. Earlier days in seismometer, pendulum was used. And that was the only instrument which was used to indicate the earthquake. To learn, to know about the earthquake, that was the seismometer where pendulum was used. Then another application is Foucault pendulum. Foucault pendulum is a simple device named after the French physicist Leon Foucault.

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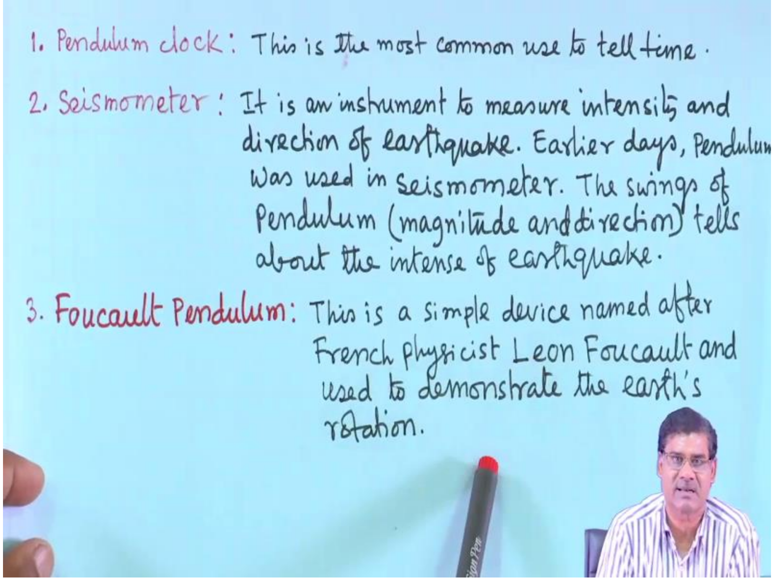

And it is used to demonstrate the earth rotation; this is very interesting instrument; these are the very interesting devices, simple devices. Basically Leon Foucault he demonstrated that this pendulum can be used to demonstrate the earth rotation, ok. There are two motions of the earth, you know, one is orbital motion and another is spinning motion; spinning motion of the earth.

This is about to sense the spinning motion of the earth, the pendulum was used and that basically called Foucault pendulum. So, Foucault pendulum basically these; these are simple pendulum, these are simple pendulum. Now this pendulum is oscillating, this pendulum is oscillating; right, the simple pendulum, this pendulum is oscillating, this pendulum is oscillating.

So, it is oscillating; it is oscillating in this plane, it is oscillating in this plane, right; this is the plane it is osculating in this plane. Now, if you come after some time, say after 12 hours if you come; then we will see this pendulum is oscillating this way; it is oscillating this way. If you come even after 12 hours, more than 12 hours, then you will see it is oscillating in this plane. So, after 24 hours you will see again, it is oscillating in this plane.

So, it is oscillating; so this plane of oscillation, it is changing; it is changing with time; it is changing with time, it is changing with time; so then it will come back after 24 hours. And that was basically this with pendulum, some pen was attached and it is the plotting of the oscillation and from there one can see this, how this direction of the oscillation is changing with time.

After 24 hours, it will complete a rotation; it complete a rotation. So, that is what the spinning motion of the earth; so that is spinning motion of the earth which was demonstrated by the Leon Foucault using the pendulum. So, that is why this is called Foucault pendulum. These are very interesting and important application of pendulum. There are many other applications. Just I have chosen few of them.

So, whatever experiment we have done in lab in experimental physics-I, during experiment physics-I, these are simple experiments, but it has enormous importance in application. So it is not that only just we are practicing some instruments, how to handle the instruments, how to do the experiment; we are not only learning that one. One can apply this knowledge for different application, right.

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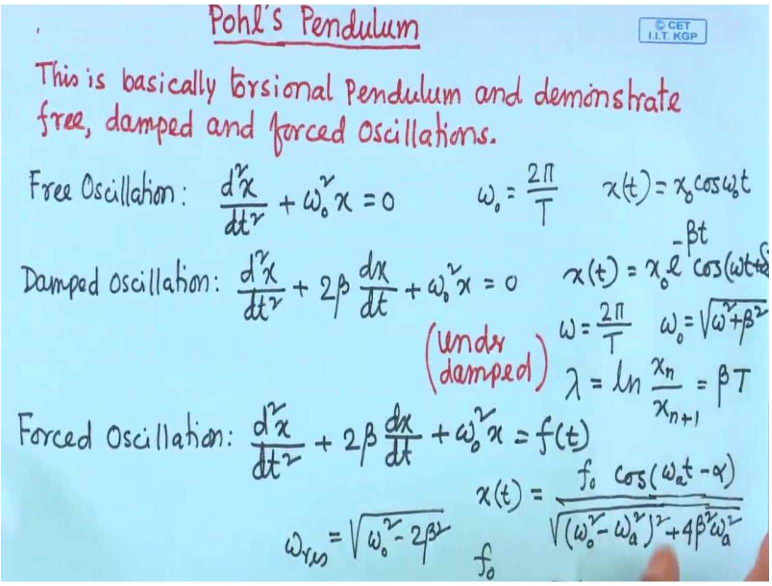

As $F = -Kx$; so, $d^2x/dt^2 + \omega^2 x = 0$; where $\omega^2 = K/m$, right and $\omega = 2\pi/T$. So, you are getting the $T^2 = (4\pi^2/K)m$

The next pendulum, we have used that is basically Pohl's pendulum. We have demonstrated this experiment; this is very nice experiment, because this is the pendulum which can demonstrate free oscillation, damped oscillation as well as forced oscillation, right.

The oscillations: free oscillation, damped oscillation and forced oscillation; these are the standard differential form for these oscillation: $d^2x/dt^2 + \omega_0^2 x = 0$. So, omega 0 basically natural frequency; so $\omega_0 = 2\pi/T$ and solution of this differential equation is basically, it is x; x is a function of t; it is $x(t) = x_0\cos\omega_0 t$, right. That means, it will be cosine function; this oscillation is basically cosine function with the amplitude of x_0, right. With time this amplitude x_0, the equilibrium distance with time will vary, right.

So, without damping, it will continue the oscillation, it will continue the oscillation with the same amplitude; the amplitude will not decrease with time, right. Now damped oscillation: in this equation one damped term is included. Damping is basically proportional to the velocity; this beta is damping constant. So, $d^2x/dt^2 + 2\beta dx/dt + \omega_0^2 x = 0$; so one can write only β, but we prefer to write 2β, because we get some simplified form of the relation. So, $d^2x/dt^2 + 2\beta dx/dt + \omega_0^2 x = 0$; this is the equation, differential equation of damped oscillation.

Now, depending on the value of ω_0 and β, there are three kinds of oscillations: under under damped oscillation, critical oscillation or over damped oscillation right. Here I have written the solution for under damped condition. x is a function of t and then $x(t) = x_0e^{-\beta t} \cos(\omega t + \delta)$; this δ is basically this initial phase, ok.

Second is the cos function; it is the cos function and now amplitude is modified, ok; now amplitude is $x_0e^{-\beta t}$; that means, amplitude will decay exponentially, decay with time, right. That is the damping motion, where in this case, it is not ω_0; it is ω . So, ω is related with the ω_0 and β. This is the relation: $\omega_0 = \sqrt{(\omega^2 + \beta^2)}$; that means, $\omega = \sqrt{(\omega_0^2 - \beta^2)}$; So, ω is slightly less than the ω_0 and this damping we express in terms of logarithmic decrement. This is basically lambda; it is defined by this lambda equal to $\ln(x_n/x_{n+1})$; means logarithmic of; log of, natural log, of course, successive displacement x_n ; the n^{th} displacement and divided by $(n+1)^{th}$ displacement; this equal to βT; so this logarithmic decrement is related with the damping constant β and the time period T.

So one can find out the damped constant β and T; then one can find out the lambda, λ; from there one can calculate the β. So, if you find out the time period T, one can find out the ω. When you find out the ω; ω and β both are known to you. So, you can get the ω_0 also.

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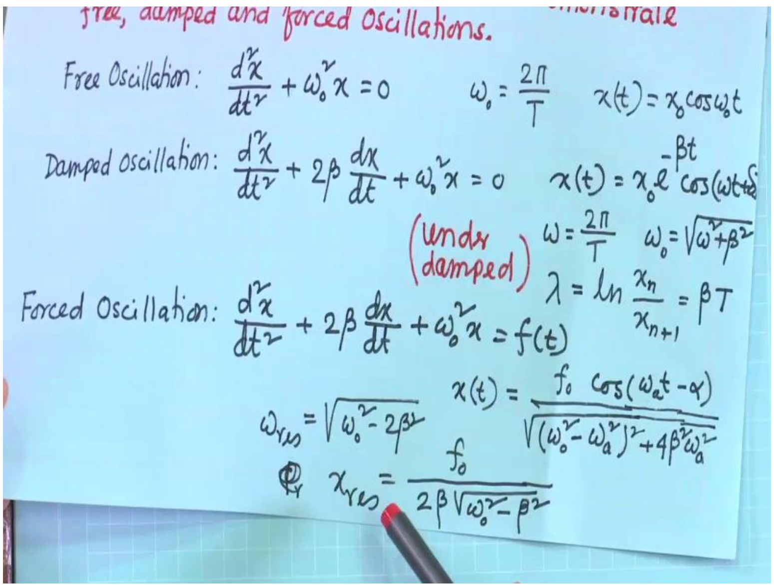

Then forced oscillation under damping condition; this is not 0 now, externally some periodic force is applied; so this is f(t). Original force capital F(t)/m; we have written force per unit mass and that is small f function of t. And it is displacement function, x is a function of t that is basically one can write $f(t) = f_0 \cos(\omega_a t - \alpha)/\sqrt{((\omega_0^2 - \omega_a^2)^2 + 4\beta^2\omega_a^2)}$. What is ω_a is the applied force, periodic force is applied; that is basically frequency of that force, which is ω_a.

Here in case of forced oscillation, interesting phenomena one can see; this is the resonanc. If you change the frequency of the applied force, at a particular frequency you will get huge, very large oscillation amplitude of the oscillation. So, that we tell, it is the resonance and what will be the amplitude of the resonance at resonance condition what would be the amplitude.

That will be the amplitude and what is that frequency at which frequency resonance will come; this relation is this, ok. Here whatever this free oscillation, damped oscillation, forced oscillation whatever we have discussed, here all these oscillations you can demonstrate in a single pendulum; that is basically called Pohl's pendulum, right.

You have seen this pendulum in our laboratory. There is a metal ring, metal disc kind of things. So, a metal disc that is equivalent to pendulum. This metal disc is connected with a spring; if you just rotate this disc, this spring will apply the restoring force and then it will try to take it back.

This disc will oscillate due to a spring force from the spring. Now you can find out the time period, then ω etcetera. Now this disc it is put between two pole pieces of electromagnet that is what you have seen. When you put in a magnetic field; when you put a metal in a magnetic field and then this metal disc is rotating; that means, it is there will be change the magnetic flux linked with this disc.

Then, there will be current; there will be induced current in the disc, metal disc, ok. There will be local current loop in the metal disc; this current is called eddy current. And due to this eddy current, there will be magnetic field; it will generate magnetic field; it will generate magnetic field in such a way, it will oppose; it will oppose the motion of the disc in the original magnetic field. So, the direction of the eddy current will be such that it will oppose the motion of the disc.

That means, it is damping the motion of the disc. So, this damping is coming due to the eddy current, right. So, it is called electromagnetic damping; so that arrangement is there in Pohl's pendulum. You can choose different magnetic field and repeat the experiment; so damping constant will be different. Under this damping condition one can again study the oscillation; one can study the oscillation and we have shown that if you measure the amplitude with time and plot it, then we have seen that this amplitude decay, exponential decay with time; that is what we have seen.

Also there is an arrangement for applying external force; periodic force in that setup. There is an option to change the frequency of the applied force; changing the frequency of the applied force, if you measure the oscillation, the amplitude of the oscillation of the disc, then if you plot the amplitude versus the frequency, then you will see, you will get a frequency where the amplitude is maximum.

From that plotting, plotted graph you can find out the resonance frequency as well as you can find out this maximum amplitude at resonance frequency ok. So, that is the experiment we have demonstrated in the laboratory. Basically that is what the beauty of this experiment? The beauty of this experiment that this experiment is designed in such a way that all sorts of oscillation means free oscillation, damped oscillation, forced oscillation you can see, you can demonstrate in a single instrument.

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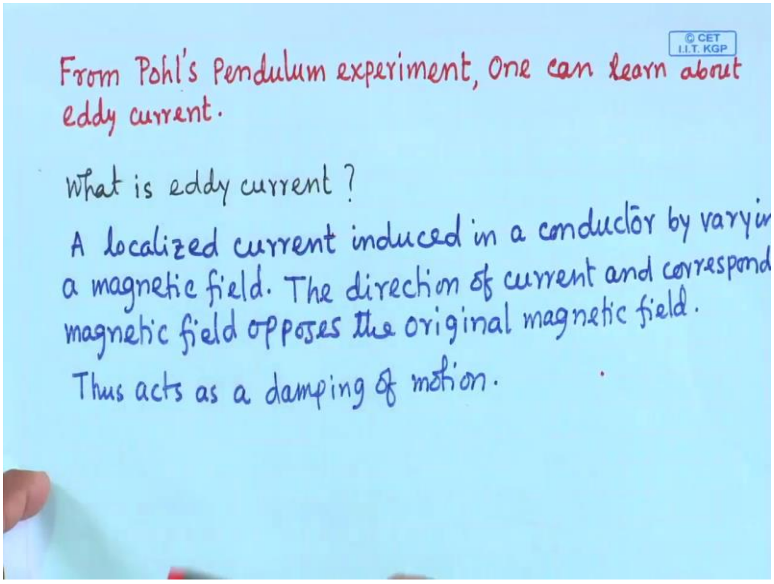

So, this is the beauty; another beauty is to learn about the eddy current; to learn about the eddy current, to visualize the effect of the eddy current, the concept of eddy current, which is generally not much familiar to students, but this is the experiment, where student can visualize the effect of the eddy current.

So, what is eddy current that already I have mentioned. The eddy current is basically a localized current induced in a conductor by varying a magnetic field, right. So, the direction of current and the corresponding magnetic field opposes the original magnetic field; thus acts as a damping of motion. So, this is the definition of the eddy current and this definition, according to this definition, that arrangement is done in this pendulum, in Pohl's pendulum to produce the damping in the motion. This is the very nice experiment where one can see the effect of the eddy current.

Next pendulum which we have discussed and demonstrated in experimental physics one, that is basically coupled pendulum.

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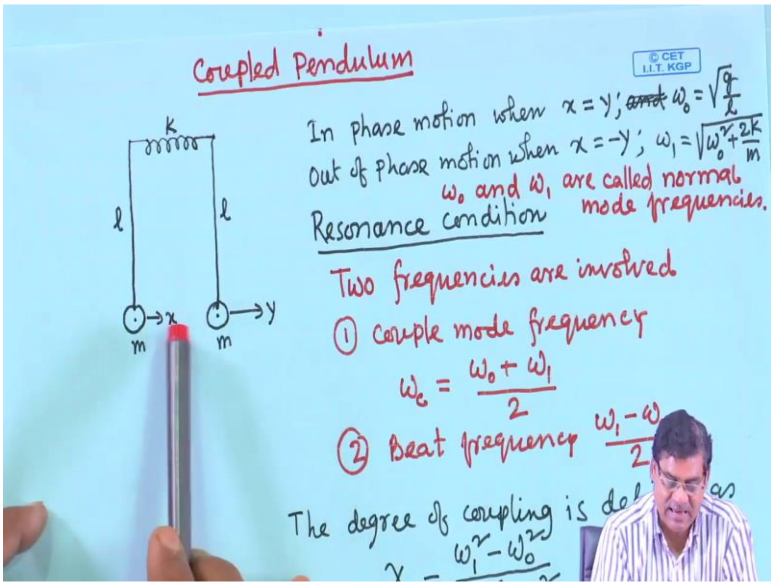

This is another very nice experiment that we have demonstrated, is coupled pendulum. Two pendulum, exactly equal pendulum: length is same l and the mass of this bob is same; both bob mass is m. Now, this two pendulum is coupled with a spring and this spring constant is k. In this condition, individual simple this two simple pendulums are coupled with a spring having constant spring constant k; when it oscillates what will be seen, that is the things you, one can study.

This displacement of this bob, this mass say this x and displacement of this; other one it is say y. This will get coupled equation; now you have to decouple it, etcetera, etcetera; that we have discussed. What we have seen or what will be seen, will get three types of motion. One is in phase motion, when x = y, means, when this one is displaced by a, x = a.

Other one is also displaced by around y equal to a; that means, x equal to y equal to a. Both are displaced in the same direction and leave it. Then they will oscillate; it is like a simple oscillation, like a simple pendulum. And this frequency is of this oscillation in phase motion that is basically $\omega_0 = \sqrt{(g/l)}$. So, this frequency is as same as the frequency of the single pendulum; individual pendulum ok.

So, this is the basically, one can see, in phase motion. One can see also out of phase motion when these two are displaced in opposite direction: x = -y, means x = y = -a. So, if it is displaced this way, this other one is displaced, this by same amount in this other direction and then leave it; then they will oscillate in this way; so this called out of phase.

So, oscillate in same direction, that is the in phase and oscillation like this. This is out of phase and the frequency of this out of phase motion will be basically $\omega_1 = \sqrt{(\omega_0^2 - 2k/m)}$. k is the spring constant. This omega ω_0 and ω_1 are called the normal mode frequency; this type of motion, in phase and out of phase, is called normal mode motion; this motion is in normal mode and this frequency is called normal mode frequencies ω_0 and ω_1.

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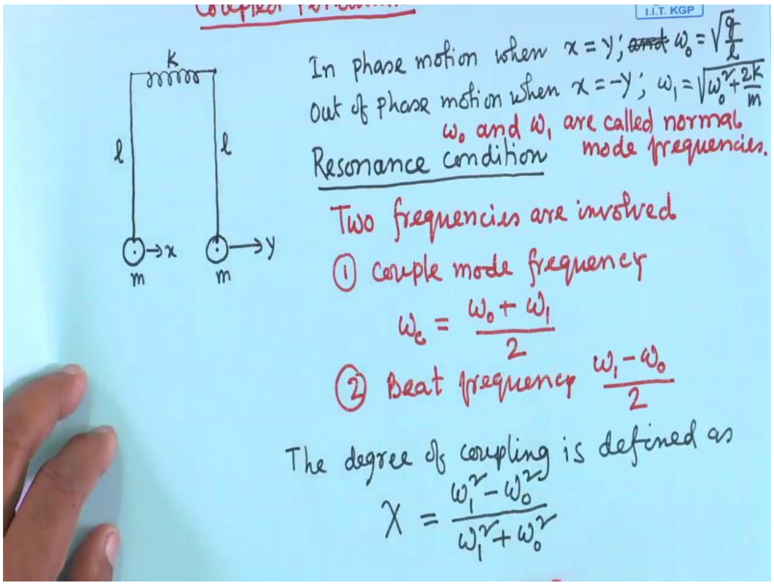

We have seen this type of motion in our laboratory, we have demonstrated. Omega one can find out measuring the time period using the clock; so one can find out the omega 0, one can find out the omega 1; one can find out ω_0 and ω_1. If you find out, if you know the spring constant, you can compare with your experimental value or one can find out the spring constant from this experiment also or if spring constant known one can find out the unknown parameter, one can find out. Anyway, here interesting things is that you can get couple motion.

So, in phase motion and out of phase motion and also third, fourth; third one is basically resonance motion you can get resonance condition you can achieve in this system; when if you displaced one of them say if you keep it here x this one here and other one if you displace by two a, say.

Earlier one individual one we have displaced by both we displace by a either in same direction or in opposite direction. So, now one keep at 0 position, 0 displacement and other one you displace by 2 a and then leave it. Then you will see the motion, so that is basically it is the couple mode you will see this; it is motion in two frequencies, its motion in two frequencies. So, one is called couple mode frequency that is omega c equal to omega 0 plus omega 1 by 2.

Another frequency you will see that is the beat frequency that is $(\omega_1 - \omega_0)/2$. So, this is the higher frequency; this is the higher frequency and this is the lower frequency called beat frequency. So, this resonance, in resonance condition, you will see these two frequencies: one is higher frequency and other one is lower frequency. And basically this beat frequency, basically it is the higher frequency. So, that is modulated with this lower frequency; this basically as if the amplitude of this higher frequency is varying with the beat frequency.

So, one can actually find out the degree of coupling in this; from this experiment if you measure the ω_0 and ω_1, from this definition of this coupling, degree of coupling is $\chi = (\omega_0^2 - \omega_1^2)/(\omega_0^2 + \omega_1^2)$. From the experiment, one will get this ω_0 and ω_1 from time period; so you have to measure time period.

Also one can find out the degree of coupling in this system. That depends mainly on this k; because here omega 1 depends on the k. Coupling comes, the degree of coupling; it will depend on mass as well as spring constant k. This is the beautiful experiment we have demonstrated in our laboratory. I just again discussed this one. So, this whatever I have discussed, mainly one has to measure the time period; if you measure the time period you can find out the frequency.

Now you will get frequency, it may be natural frequency, it may be frequency under damping condition, it may be frequency under in phase mode or out of phase mode, etcetera. In this experiment, the main task is to measure the time period; that we have seen in the laboratory. I think this is the about the oscillation, I discussed whatever the experiment we have demonstrated in last semester, in experimental physics 1. Just I summarize here. I will stop here. I will continue this summary in next class also.

Thank you very much.