Basics of Noise and Its Measurements
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Lecture – 04
The Decibel Scale

Welcome to Basics of Noise and its Measurements. In the last module, we were discussing the Nature of Sound, how it behaves as a wave, and how it follows all the rules of the wave like I can hear the regular wave. What we are going to discuss today about is, the unit of sound and in that context we will introduce the decibel scale. But before I talk about this term called the Decibel Scale, I wanted to provide a context.

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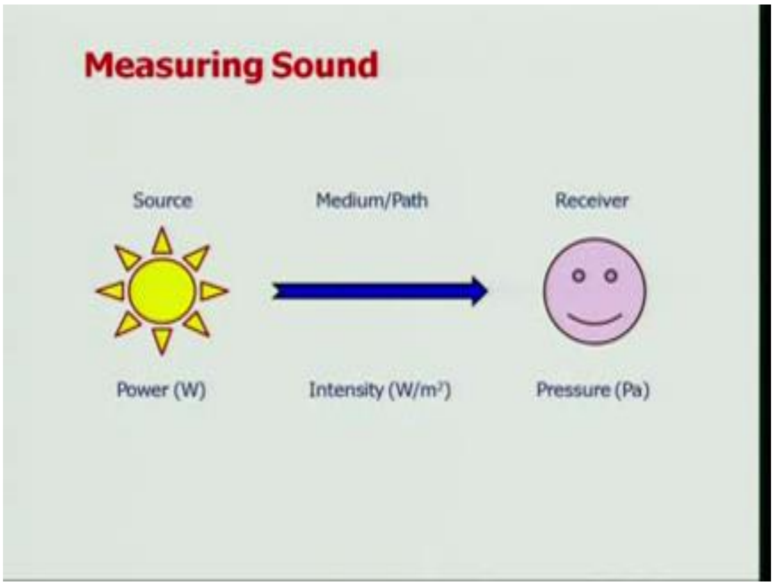

First we will look at this picture. So, what the picture shows is that there is a source which is emitting sound. In this case as I am talking, for instance, I am talking so my throat is emitting sound and this sound travels from point A to point B. In this case, it is moving from my mouth to the microphone, so that is point A that is point B. So it is actually propagating in medium. So that is the second thing. You have a source, and you have a medium and then finally there is a sensor. Let say I am talking in a room and there is a student sitting in my class and that student is listening, so his ears or her ears are acting as sensors. So, that is the third point in the system, the receiver or the sensor. The sensor could be a human being, it could be a micro phone, it could be measuring equipment or whatever.

So you have a source, you have a medium and you have a receiver. When we are talking about sound it could be in one of these contexts that when we are trying to measure sound, we may be interested in understanding how many watts of sound energy is being emitted by the source, in this case my throat. If our interest lies in that, that how many watts of energy are being emitted then what we are trying to do measure is, what is the power of that source from an acoustical strength point?

The other interest could be that as sound is traveling from point A to point B, part of it is getting absorbed; part of it is getting transferred. So, we may be interested in knowing how much sound is getting passed through a particular cross sectional area in terms of; how much power is flowing per unit cross sectional area. That brings in the notion of intensity which is this one. So here, the units would be for the intensity would be watts per square meter.

Then, the third point of interest could be that when sound hits my ear drums or a microphone, it hits it as a pressure wave. So, what my ear drum senses or a microphone senses is the pressure. At the receiver end, I may be interested in measuring the pressure fluctuation caused due to propagation of sound. In that particular case, we may be interested in measuring sound in terms of pascals. We can measure sound in terms of watts, we can measure sound in terms of intensity that is watts per square meter, or we can also measure sound in terms of pressure fluctuations and that is pascals.

So, these are the three broad concepts in which we measure sound. We can measure it as watts, we can measure it as intensity, we can measure it as pascals. So, the next thing I wanted to introduce you is the importance of a logarithmic scale whenever we are talking about sound.

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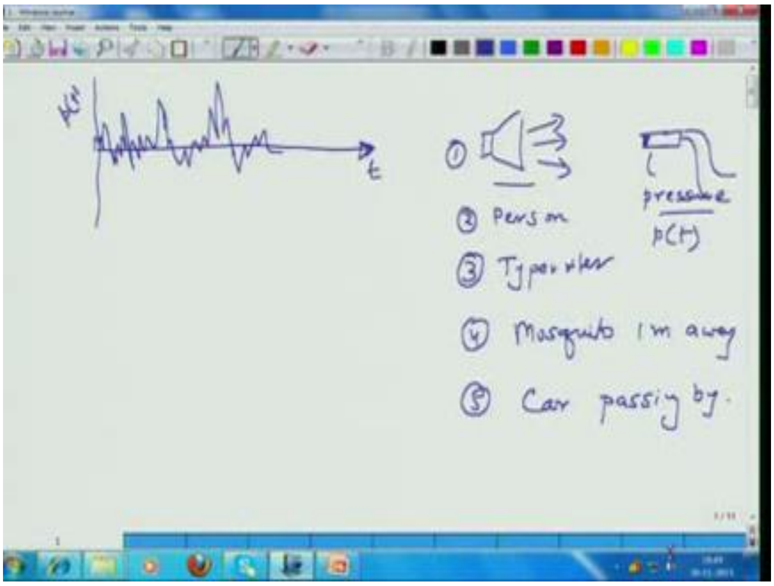

So, for that let us look at this picture. So, consider this. Suppose, I am plotting sound, suppose there is a speaker so it is emitting sound. Then I have a microphone here, and this microphone is measuring pressure fluctuation, and it measures pressure as a function of time. So, I am plotting p as a function of time and it may be measuring this and suppose, this is instead of speaker, so case 1 was a speaker, case 2 was a person who is talking at a normal amplitude level, case 3 could be a type writer, case 4 could be let say a mosquito 1 meter away, case 5 could be a car passing by.

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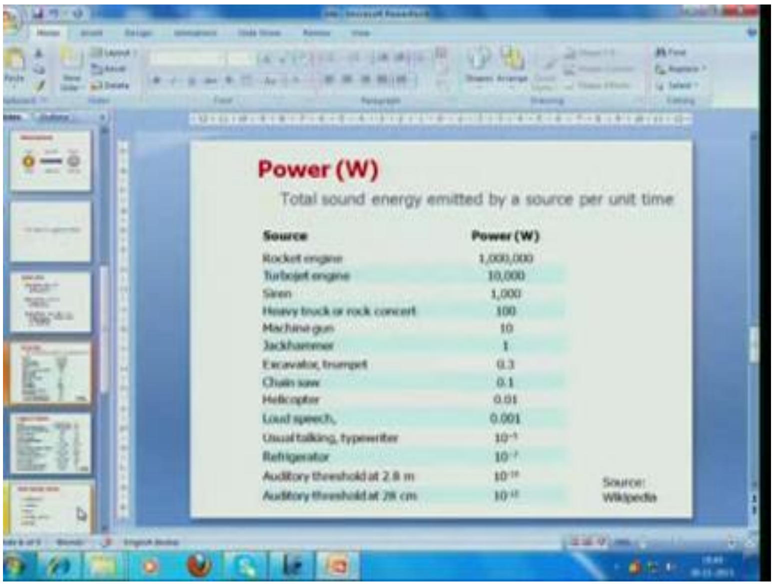

In one of the earlier classes, we had seen that the pressures which were generated by all these people, for mosquito it would be something in this range 20 micro pascals.

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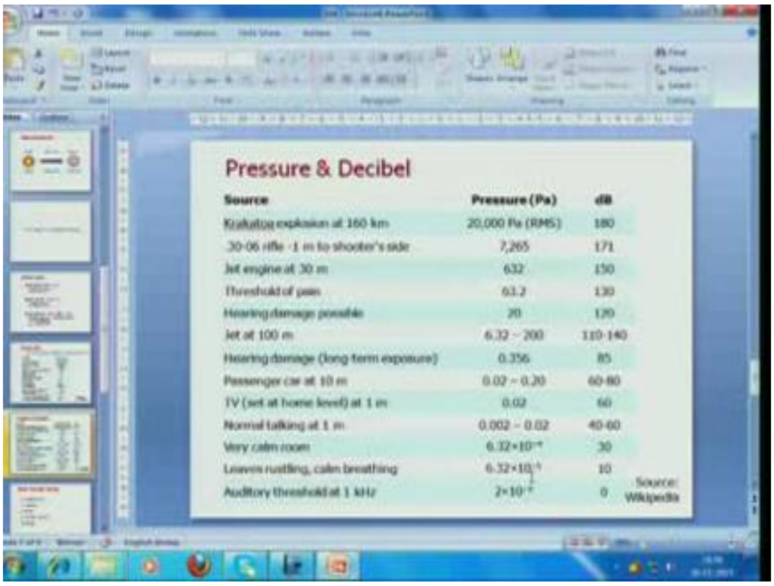

I am going to write it down 20 micropascals. Then, if I am talking normally then it could be 0.002 to 0.02 pascals, if there is a TV or a speaker then it could be 0.02 pascals, if there is a car moving 10 millimeters away then it could be 0.02 to 0.2 pascals and so on and so forth. So, I will just write down these numbers.

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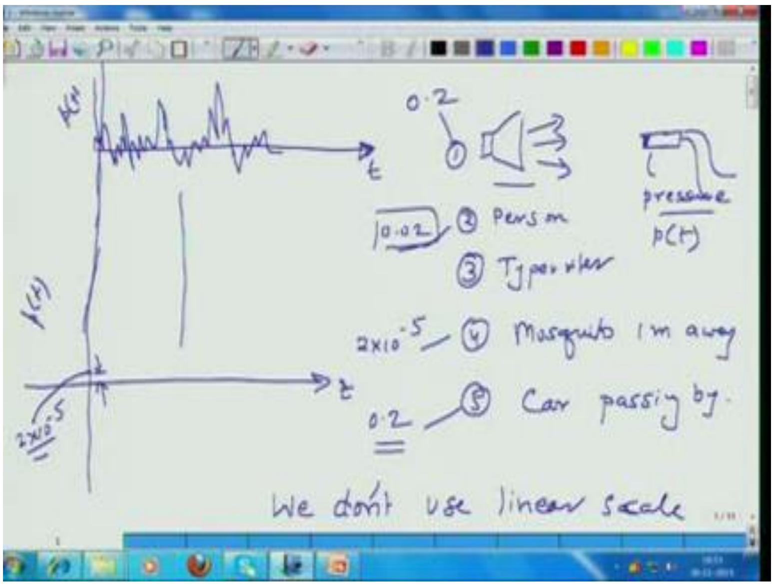

In case of a person it could be typical pressure level would be 0.02 pascals, in case of a mosquito it will be 2 into 10 to the power of minus 5 pascals, if it is a type writer or something like that or let us look at about TV then it would be something in the range of 0.2 pascals, if it is a car then it would be again something like 0.2 pascals. These are some broad numbers. But the point what I am trying to make is, that if I have to plot all these values on the same y axis. This is my time, let say this is my mosquito so this is 2 into 10 to the power of minus 5 pascals, this is my pressure. Then if I have to plot the next number, let say this is a person who is talking and that is 0.02. If I have to plot 0.02 this distance corresponds to 2 into 10 to the power of minus 5 pascals or 20 micropascals, then if I have to plot a value of 0.02 it will lie way outside the screen may be it will be a 10 meter long scale or 1 meter long screen and then that is how I will get to the 0.02 level.

If I have to plot this value of 0.2 and also 20 micropascals on the same y scale, then the scale maybe tens of meters long. If I have to plot a pressure level of 20 micropascals and also let say 60 micropascals, because sound can go as high as that also then may be my y axis or the vertical axis may be as high as 1 kilometer. So, the point what I am trying to make is that because we have to cover a very large number an extremely large range of pressures on the same graph, an extremely large range and this range stands over several orders of magnitudes, so physically it becomes not possible or impractical to plot everything using a linear scale. So, we do not use a linear scale to a plot pressures because at least context to sound, because it can make things impractical or we have to have very large width of the paper. That is one reason. So, y axis I cannot plot because on a linear scale because the paper size becomes extremely long.

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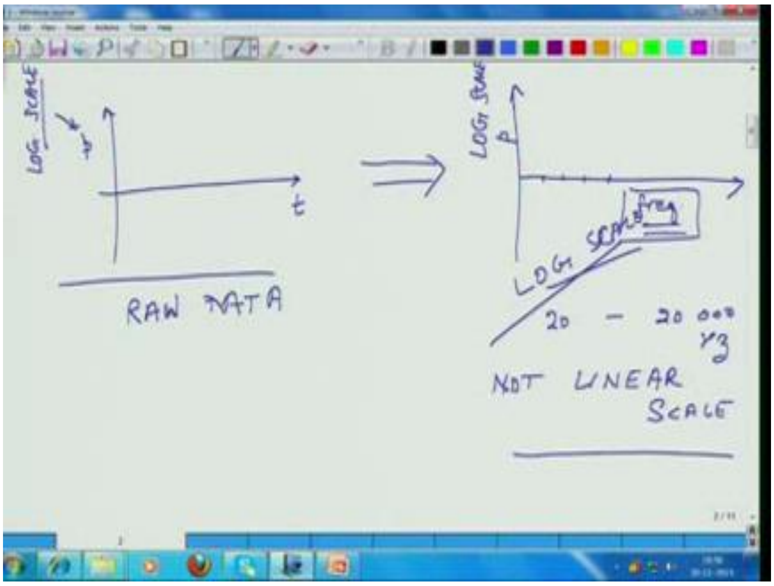

Now, let us look at frequencies. A lot of times when we make plots for sound our plots are of this nature, our x axis is time and our y axis is pressure, and I said that this is not practical if I have to do in a linear scale. So, I plot pressure in a logarithmic scale. Now this is typically our raw data. When I take a microphone I do measurement, what I essentially measure is pressure as a function of line. But a lot of times what I do is I transform this raw data into a different type of plot. So again, I am plotting pressure on a log scale, so here I am plotting pressure but instead of time I plot frequency. The frequency can range from typical hearing range is 20 hertz to 20000 hertz. So, it is 20 hertz to 20 kilo hertz that is the typical audible frequency range.

Again, if I have to plot all these 20 hertz, 40 hertz, 60 hertz, 80 hertz and if I have to go up to 20000, I have to make my x axis extremely long. This is the first reason why we also do not plot frequency typically we do not plot it on linear scale. Especially, if we have to cover the entire audio is spectrum which is 20 to 20 kilo hertz. If I am just interested in let say 1000 to 2000 hertz I am with linear scale, but if I am interested in a very large band width let say 20 to 20 kilo hertz or 20 to 1000 hertz then it becomes impractical to have a linear scale.

In that case again, whenever we use frequency on the y axis then we again use a log scale. So, this is the first reason why we use a log scale for plotting graphs or frequencies in context of frequency as well as in context of pressures There is another range reason which will relates to our perception and that is what I am going to talk about next. So, for that I will conduct small listening experiment, before I do this listening experiment just wanted to preface it with couple of comments. So, it turns out that our ears are sensitive to small fluctuations in frequency at low frequencies and when I increase the frequency significantly, and if I use the same magnitude of fluctuations in frequency at mean values higher mean values of frequencies then their our ears are not that sensitive.

In another words, suppose I play a tone of 400 hertz and I play it my ear listens to it, then I play tone which is 500 hertz, so 500 hertz is 100 hertz more than 400 my ear will be able to distinguish between a 400 hertz and a 500 hertz tone. Now, I do a similar experiment, but instead of 400 hertz I play a 4000 hertz tone. So my ear listens to it, and again I play another tone which is 4100 hertz tone. I have just increased the frequency by 100 more hertz. We will play these tones and what you will perceive is, I think that the difference between 4000 and 4100 will be perceived as much lesser compared to between 400 and 500.

Then we will do the same experiment at 10000 and 10100 hertz. There the difference will be you won't be able to probably appreciate the difference at all. So what that means is that our ears are sensitive to frequencies on a proportionally scale or on a logarithmic scale. With that preface I wanted to play these tones.

So, this is the 400 hertz tone and this is the 500 hertz tone, so it is clearly different. And the difference between these two tones is of 100 hertz and the base frequency is 400 hertz. Now I play a 4000 hertz tone and this is 4100, so it is sounds slightly different 4000 and 4100. Here, the difference is still 100, but that 100 hertz difference does not play a much big role in terms of changing the perception. Now, I will play the 10000 hertz and this is a 10100 hertz tone and for these you will not sense any difference. A fairly minimal difference, if your ears are really sharp.

So, what this small experiment shows is that our ears listen or can identify frequencies and resolve frequencies on a logarithmic scale or on a proportional scale. That is the physical reason, why we use a log scale for frequency. For a similar reason we also use a log scale to depict pressure besides the reason of practicality that our ears are also sensitive to changes in pressure on a log scale not on a linear scale, because again I mean we have evolved in a way that we can sense very large changes in pressure in terms of order of magnitudes.

For both these reasons, for reasons of practicality that because the paper size will become very large and also because of reasons related to perception that our ears are more or less tuned to changes in frequencies and changes in pressures on a logarithmic scale we use a log scale to plot pressures. So, with that I am going to introduce this decibel scale.

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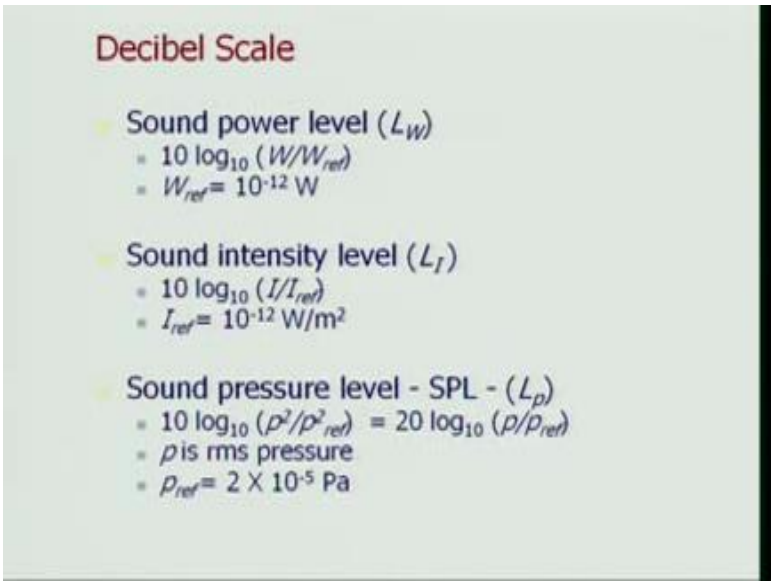

And I am going to introduce this decibel scale for all the three variables which I had talked about. Sound power level and it is designated as L W, and it is defined as the decibels for if I have to measure power are defined as 10 log 10 of the value of watts which is being emitted by the source divided by reference power and the value of reference power for ear is assume to be 1 pico watt. So that is how many decibels if I have to calculate sound power level. Then, if I have sound intensity level; SIL or L I, this is L I is industry standard terminology then it is defined as 10 log 10 I decided by a reference value of intensity and the reference value of intensity is again 1 pico watts per square meters.

So, that sound power level and that sound intensity level then finally, I have sound pressure level. And sound pressure level is defined which is turned as L P, is defined as not 20 log but 20 log or actually 10 log of squares of pressure divided by square of reference pressure and if I take the square out then it becomes 20 log 10 P over P ref. Here, P is the rms pressure; it is the rms pressure root mean square value of the pressure.

So typically, when I talk pressure is fluctuating up and down all over the place so whatever sample I have of sound I have to break it up into individual points as a function of time and then I take the squares of each of these values, take the average of these squares and then take the square root and through that I get the rms value of the pressure, and then put that in this particular relation 20 log 10 P over P ref and I get the sound pressure level.

Please remember that these reference values for wattage, intensity and pressures they are applicable if the medium is air. If the medium is water then these reference values change. But for air the values for wattage are 1 pico watts, for intensity 1 pico watts per square meters, and for pressure it is 20 micro pascals. So that is the thing.

And what this chart shows is the calculation of a decibels corresponding to different values of pressures. So again, for auditory threshold 20 micro pascals it corresponds to zero dB, very calm room 30 decibels corresponding to 6.32 times 10 to the power of minus 4 pascals. If I have a TV running about 0.02 pascals. So these are some approximate values. 0.02 pascals corresponding to 60 dB. If there is a passenger car it is about 60 to 80 dB and so on and so forth.

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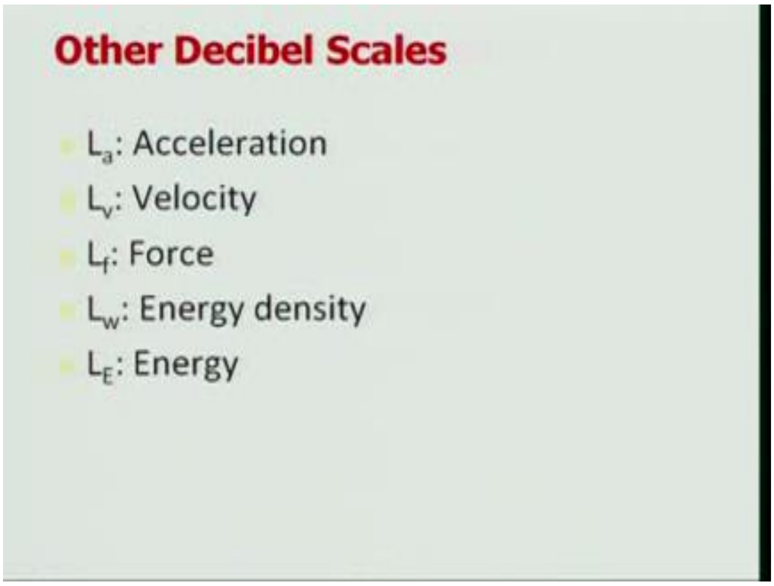

You can calculate decibels using these relations. And then lastly I wanted to share this information with you because these three terms L W, L I and L P these are very popular, but in industry there are dozens of other decibel scales and some of these are also related to acceleration L a: velocity, L v: force, L f: energy density, L w but here w is lower case not upper case, energy is L e.

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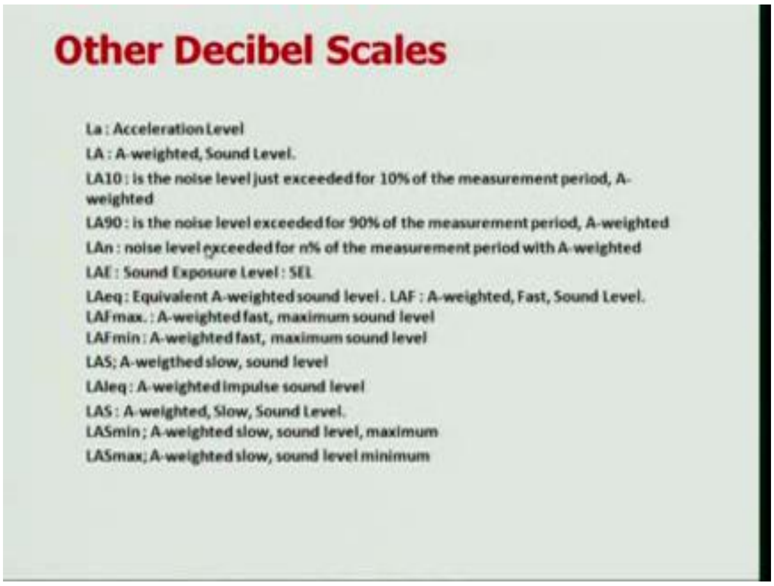

Then you have a bunch of more decibel scales, and their brief descriptions are given and there are even more maybe 2 dozen more as far as I know and may be even more than that and all of them are related to decibel scales. So, the number of decibels as scale size extremely large, but at least in context to sound these three decibel scales are more popular so definitely you should know about these. Then some other decibel scales like L A, L A 10, L A 90 these are also somewhat popular, but once you know the decibel scale concept you can easily apply that concept to understand these are the decibel scales. So, with this we conclude this particular module and I look forward you to having you in the next lecture.

Thanks.