Nature and Properties of Materials

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Lecture 33

Optical Properties

Today, we are going to talk about the optical properties of materials. So far we have covered all the mechanical properties of materials. However, there are many cases where the optical property becomes important along with the mechanical property. Let us say we are designing an oven for a very high temperature and we want to carry out some experiments that means what is happening inside the oven for example, the polymer is changing its glass transition temperature and you want to visualize that how it is happening.

Now, in all such cases you actually need to send light from outside, which should go penetrate this particular oven casing and it has to go inside and get reflected back from which you get the information. So in this case that part of the oven which is has to be transparent with respect to light has to also be oven like that means high temperature proof, so it is a special mechanical material where both temperature and optical property will be important.

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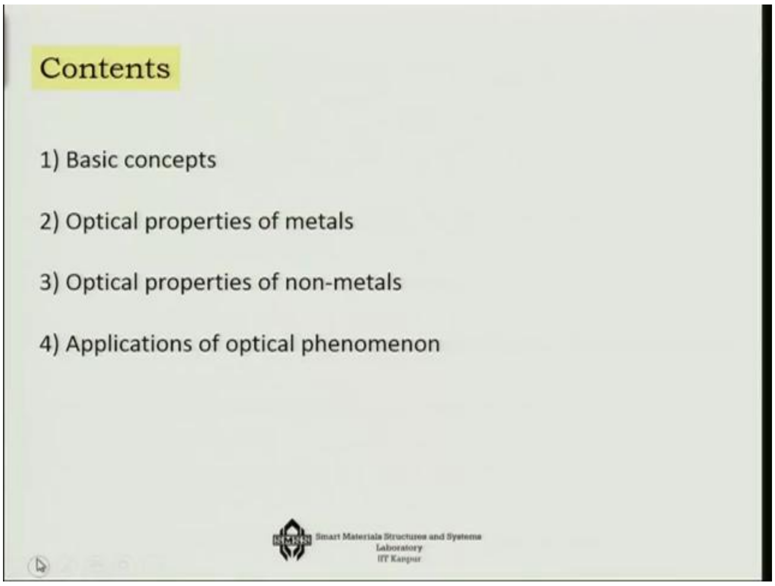

Contents

1) Basic concepts
2) Optical properties of metals
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4) Applications of optical phenomenon

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Again there are other materials other cases where it is optical property which is to be matched with magnetic property or optical property which is to be matched with of the dynamic properties, et cetera. So thus property becomes important in many of the applications. So what we are going to first while initiating the discussion today and later on we will take it further, we are going to 1st talk about the basic concepts related to the optical property, so we are going to talk about the basic concepts, then the optical properties of metal first let us discuss, then the optical properties of nonmetals and then some applications of the optical phenomena, so these are the 4 things that we are going to tackle.

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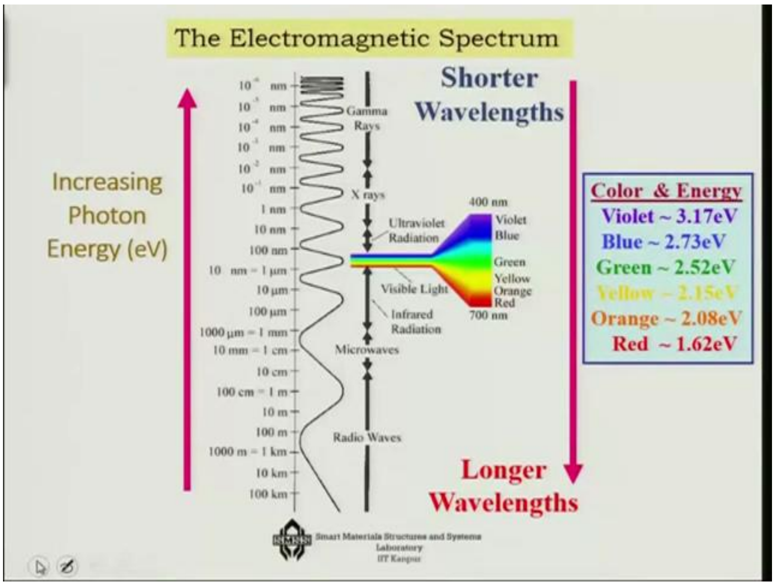

The Electromagnetic Spectrum

Color & Energy

Violet ~ 3.17eV
Blue ~ 2.73eV
Green ~ 2.52eV
Yellow ~ 2.15eV
Orange ~ 2.08eV
Red ~ 1.62eV

Now the 1st important thing is that, when we are talking about the optical property, we are talking about the electromagnetic spectrum. In that electromagnetic spectrum of the wavelength, we have shorter wavelengths at one extreme which is like the gamma rays and longer wavelength at the other extreme which are like the radio waves, so as the wavelength increases the lambda okay, we are starting from the gamma rays, which goes somewhere up to 10 raise to the power minis 4 nanometre or so, one nanometre is 10 to the power - 9 meter, so you can imagine that how small that wavelength is.

Then there is x-ray there and then from x-ray, when the wavelength further increases then we come somewhere in between we have the ultraviolet radiations and then we have the entire visible part of the visible light. In that visible light, where exactly our eyes are also very sensitive it starts from 400 nano meter of wavelength and it ends at 700 nano meter of wavelength. So at the very low wavelength and high energy end, we start with Violet, then there is indigo, then there is blue, green, yellow, orange, red, red is around 700, so that is what is the spectrum of the optical part which we generally call as the visible light.

Then once that wavelength further increase we come to the infrared radiation types and that goes somewhere up to millimeter level. If the wavelength is even more, then we come to microwave and if it increases further in the from the meter level to kilometer level, then we come to the radio waves. Interesting thing is that this picture we have discussed from shorter wavelengths to longer wavelengths, but in terms of energy it is just the reverse. What it means is that those which are having their shorter wavelengths like the gamma rays, you can see that they have the highest energy in terms of electron force.

And then gradually as you the wavelength increases, the energy actually reduces and the radio waves would have the lowest amount of energy. For example, if you consider it in the visible spectrum itself, red has energy of about 1.62 electronic volts, orange 2.08, yellow 2.15 electron volt, green 2.52 electron volt, blue 2.73 electron volt, it is increasing gradually and violet is 3.17 electron volt. Another interesting thing you might have noted that this energy is really not, it is distinct there is no doubt in it, but it is not very evenly spaced that is very interesting that you can see here however, the colours are very-very distinct.

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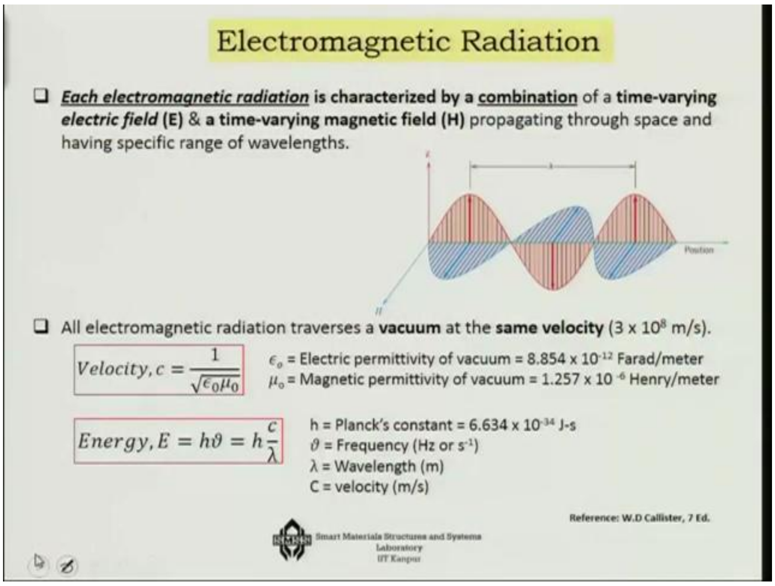

Electromagnetic Radiation

- ☐ ***Each electromagnetic radiation*** **is characterized by a** **combination** of a **time-varying** ***electric field*** (E) & **a time-varying magnetic field (H)** propagating through space and having specific range of wavelengths.

- ☐ All electromagnetic radiation traverses a **vacuum** at the **same velocity** (3 x 10^8 m/s).

$$\boxed{Velocity, c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}}$$

ϵ_o = Electric permittivity of vacuum = 8.854 x 10^{-12} Farad/meter
μ_o = Magnetic permittivity of vacuum = 1.257 x 10^{-6} Henry/meter

$$\boxed{Energy, E = h\vartheta = h\frac{c}{\lambda}}$$

h = Planck's constant = 6.634 x 10^{-34} J-s
ϑ = Frequency (Hz or s^{-1})
λ = Wavelength (m)
C = velocity (m/s)

Reference: W.D Callister, 7 Ed.

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Now, we are talking about the electromagnetic radiation. Now in the electromagnetic radiation from the functional point of view it is actually a combination of 2 time varying waves one of the electric field wave and another is a time varying magnetic field. So if you denote one in this manner as it is here okay as the time varying electric field suppose, then the other one is the time varying magnetic field, so it is just transverse to the 2. So these 2 waves, that is why he say that for electromagnetic wave these 2 fields, the electric field and magnetic field they are just always coexistent with each other.

And the speed of the electromagnetic radiation at vacuum for both of them is close to 3 into 10 to the power 8 meter per second. The velocity at any particular medium in fact is inversely proportional to the square root of Epsilon 0 and Mu 0, where Epsilon 0 is the electric field permittivity of vacuum and Mu 0 is the magnetic permittivity of vacuum, so this is interesting. What it means is that if suppose you consider a particular medium in which you have high electric permittivity, but low magnetic permittivity but it is the product that would matter and that would be the velocity of the electromagnetic wave in that particular medium.

In vacuum, Epsilon 0 is 8.854 into 10 to the power - 12 farad per meter and magnetic permittivity is 1.257 to 10 to the power - 6 Henry per meter. So in one case the unit is farad per meter for the electric field and for the magnetic field it is Henry per meter, we have to keep these points in our mind. And how do we calculate the energy? Well, that is E equals to h Mu, where h is the Planck’s constant right, which is known to you and Mu is the frequency.

That means as I already told you that for example, the frequency of each of these cases of these light wavelengths is known to you violet, blue, green or these things we know the wavelength, you also can then find out the frequency and as the frequency, you can actually find out what is the energy content corresponding to this. In fact, the wavelength and the frequency as you can see simply related by this relationship that Mu equals to C over Lambda.

In other words, if I know Lambda and I know the velocity in a medium then I know what is going to be the frequency, so I should be able to find out that what is the energy for a particular wavelength okay, wavelength we usually measure in meter and velocity in meter per second. So these are the very basic fundamental things that we have to keep in our mind corresponding to the electromagnetic waves.

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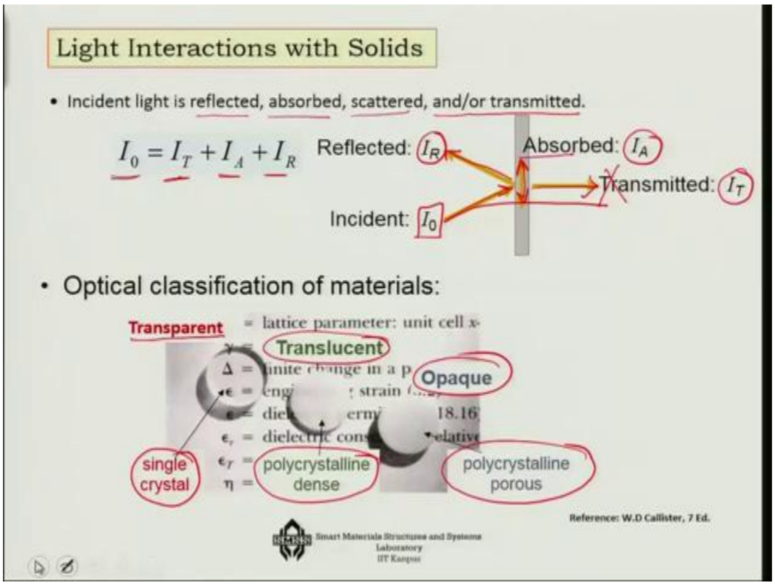

Light Interactions with Solids

- Incident light is reflected, absorbed, scattered, and/or transmitted.

$$I_0 = I_T + I_A + I_R$$

- Optical classification of materials:

Next is that light as an electromagnetic wave, when it falls on a solid what happens to it? Well, the incident light when it falls on a solid, it can either be reflected or it can be absorbed scattered and/or transmitted. So we can write that I 0 incident light is going to have at least 3 parts I T, I A and I R. That means this is my incident light I 0, some part of the light may get reflected that is I R, some part of the lightning may get absorbed inside, it may not absorb for a very long time you will see that sometimes it absorbs and then retains it. And some part of it may get actually transmit, so that is what is our I T part. Absorbed is I A and reflected is I R, whereas the incident is I 0.

Now, we always say that there are these 3 types of materials, one is the transparent material, so when we are talking about transparency, it means that most of the light is actually transmitted through the system like a single crystal. Sometimes we say that it is translucent, well translucent means some part of the light is actually absorbed and some part of the light is getting transmitted that is like the polycrystalline dense.

And sometimes we say that it is opaque and when we say that it is opaque, what it means is that this does not occur okay, so the light is absorbed and maybe partly reflected back like polycrystalline porous materials. So, thus different materials can have this type of different optical property based on whether it allow the light through pass through it, it absorbs the light or it reflects the light. Let us 1st discuss on the metals that is the optical properties of the metals.

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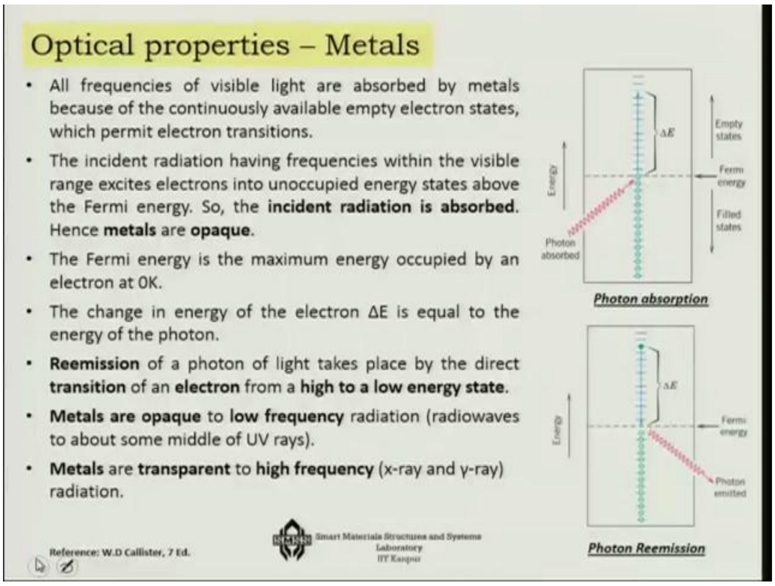

Optical properties – Metals

- All frequencies of visible light are absorbed by metals because of the continuously available empty electron states, which permit electron transitions.
- The incident radiation having frequencies within the visible range excites electrons into unoccupied energy states above the Fermi energy. So, the **incident radiation is absorbed**. Hence **metals** are **opaque**.
- The Fermi energy is the maximum energy occupied by an electron at 0K.
- The change in energy of the electron ΔE is equal to the energy of the photon.
- **Reemission** of a photon of light takes place by the direct **transition** of an **electron** from a **high to a low energy state**.
- **Metals are opaque** to **low frequency** radiation (radiowaves to about some middle of UV rays).
- **Metals** are **transparent** to **high frequency** (x-ray and γ-ray) radiation.

Reference: W.D Callister, 7 Ed.

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Now, all frequencies of visible light are absorbed by metals because it has continuously available empty electron states, which permit the electron transition. I already told you that metal has always as if a cloud of electrons, it has never like a lack of any electron. So, if you take a metallic piece and shine light on it so the photon are going to get absorbed by the electrons at the low-energy state of which it has an infinite supply let us say. So and then, as the gate they are absorbing the energy, some of them jumps towards the higher energy state.

So there is a Fermi energy level and there are some filled states and there are some empty states in the metal, so as the photons get absorbed they go from field state, they jump towards the empty state, which are of energy states. So the incident radiation having frequencies within the visible range excites electrons into unoccupied energy states like these states okay above the Fermi energy level, so the incident radiation is absorbed and hence, metals are opaque because it is not allowing any light to pass through it because it uses the entire light to excite its own source of electrons and that is why it is opaque.

Now, the Fermi energy is the maximum energy occupied by an electron at 0 degree Kelvin that is the way it is actually defined. The change in the energy of the electron delta E is equal to the energy of the photon because this is the energy that it is absorbing, so the change in delta E is actually the amount of energy that is coming to the photon. What happens if it does not stay in that position? After it gets the energy, then it reemits reemission of a photon of light takes place by the direct transition of an electron from a high to a low-energy state. So it first gets excited, go to the higher energy state and then it reemits the photon okay, it does not hold that energy with it.

Metals are opaque to low-frequency radiation for example, radio waves to about some middle of UV rays, but they are transparent to high frequency radiations. So high frequency radiation that these source of photon they do not absorb that, so actually high-frequency waves can actually get passed through it. But if it is of a lower frequency, then this situation always happens that it absorbs it, the photon goes to the high energy state and then the photon emits this energy at a time scale. In fact, later on we will tell you what happens when it emits this energy back.

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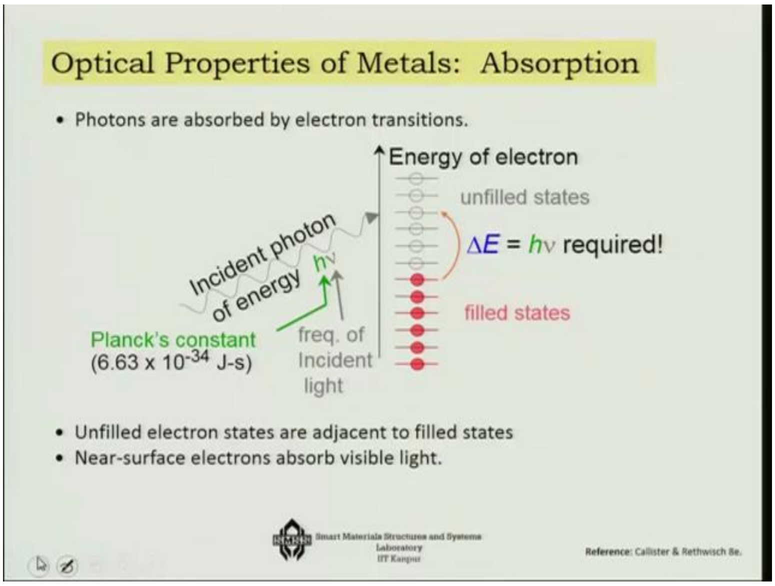

Optical Properties of Metals: Absorption

- Photons are absorbed by electron transitions.

- Unfilled electron states are adjacent to filled states
- Near-surface electrons absorb visible light.

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Reference: Callister & Rethwisch 8e.

So here the same thing we are telling that incident photon energy let us say H Mu, H is the Planck’s constant okay and Mu is the frequency of the incident light. And from the field state, the Fermi energy level, the Delta E energy is given the H Mu is coming as the source of the Delta E, and then it is jumping from here to the high energy state. Unfilled electrons states are adjacent to the field states, so it just does that and near surface electrons absorb the visible light in the case of the metals.

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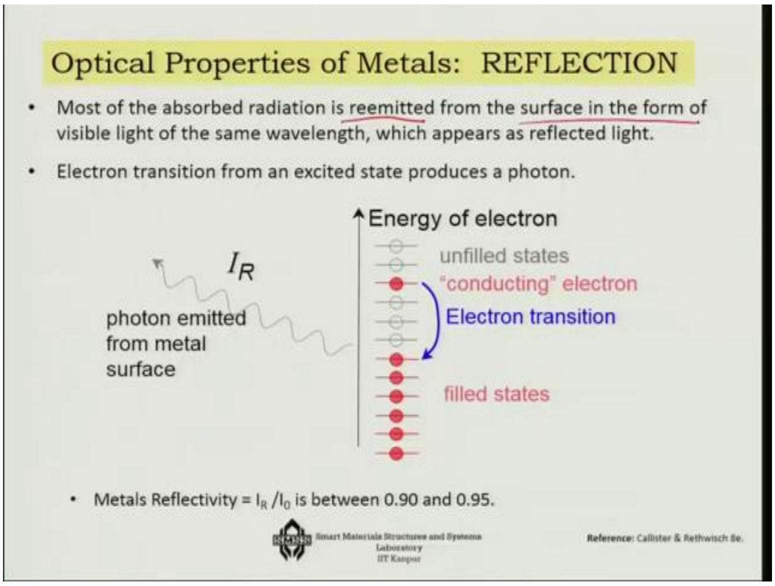

Optical Properties of Metals: REFLECTION

- Most of the absorbed radiation is reemitted from the surface in the form of visible light of the same wavelength, which appears as reflected light.
- Electron transition from an excited state produces a photon.

- Metals Reflectivity = I_R/I_0 is between 0.90 and 0.95.

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Reference: Callister & Rethwisch 8e.

Now, most of this absorbed radiation is actually reemitted from the surface in the form of visible light of the same wavelength which appears as the reflected light. So, when we see that some light is reflected, is not the same light which actually is incident on the system that is what we have to understand. That light falls on the metallic surface and then that light gets absorbed by the electron, the energy that is absorbed by this electron that it absorbs and it goes to the high energy state I told you, but it cannot be sustained at a high energy state why because minimisation of energy or maximization of entropies, they are in the nature of every system.

So as soon as it goes to the excited state, it again tries to jump back to the low-energy state in order to minimise the energy. And as a result, this photon is going to emit the energy which is approximately of the same frequency as the incident energy that is coming and then it is coming back as a reflected energy. Now, it is this reflected energy that I have actually watching, but this reflected energy is coming from the electrons of the metal that is the important thing, the source is inside the material we have to keep it in our mind.

The reflectivity of metal can be actually measured in terms of the ratio of the incident energy and the I R is the reflected energy, so the I R over I O ratio, which is generally between 0.9 to 0.95. A little bit of energy gets absorbed into the system, but generally it is of very high reflectivity 90 to 95%. In fact, before glass was discovered by people, actually mirror shiny mirror was used as mirrors okay. So you can easily imagine that people use to use for example shining copper surfaces, et cetera as their mirrors.

Of course there is a problem there that copper for example, will get oxidized pretty fast, so that is how the glass is much better because it does not get oxidized so fast. But it is because of this high reflectivity, you can easily imagine that you can see your image very nicely on the metallic surface because the light wave which will get reflected from your body and then go to the this metallic surface will actually almost 90% to 95% will come out and hence we will be able to see this and you will be able to see the image. Now we will talk about the nonmetals.

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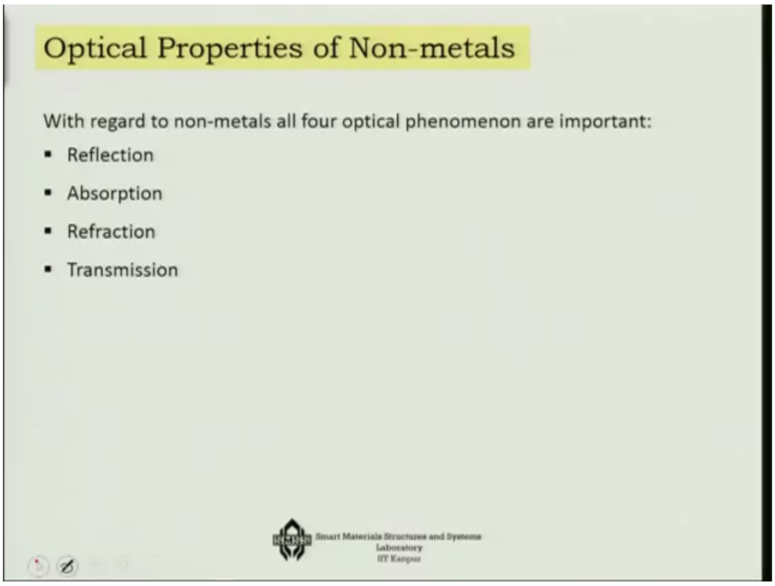

Optical Properties of Non-metals

With regard to non-metals all four optical phenomenon are important:

- Reflection
- Absorption
- Refraction
- Transmission

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So with regard to nonmetals, 4 optical phenomena are important; reflection, absorption, refraction and transmission, so let us look into them and buy one.

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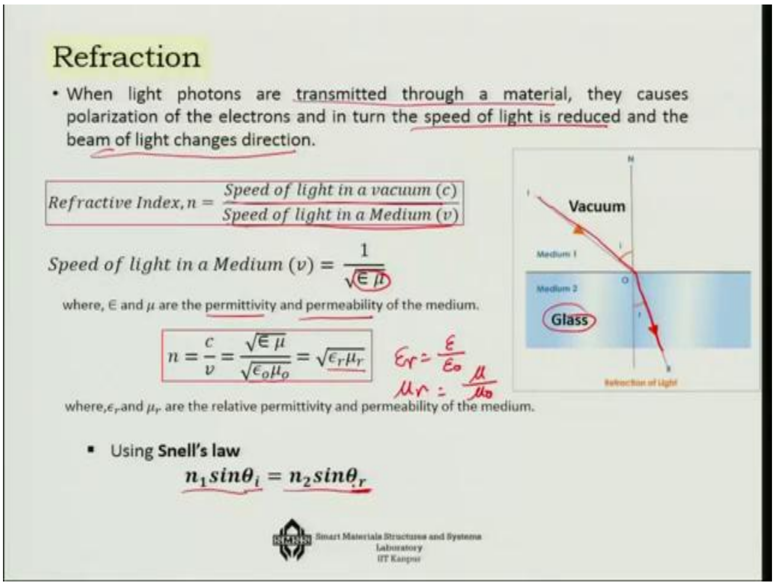

Refraction

- When light photons are transmitted through a material, they causes polarization of the electrons and in turn the speed of light is reduced and the beam of light changes direction.

$$\boxed{\text{Refractive Index}, n = \frac{\text{Speed of light in a vacuum } (c)}{\text{Speed of light in a Medium } (v)}}$$

$$\text{Speed of light in a Medium } (v) = \frac{1}{\sqrt{\epsilon \mu}}$$

where, ϵ and μ are the permittivity and permeability of the medium.

$$\boxed{n = \frac{c}{v} = \frac{\sqrt{\epsilon \mu}}{\sqrt{\epsilon_o \mu_o}} = \sqrt{\epsilon_r \mu_r}} \quad \epsilon_r = \frac{\epsilon}{\epsilon_o} \quad \mu_r = \frac{\mu}{\mu_o}$$

where, ϵ_r and μ_r are the relative permittivity and permeability of the medium.

- Using **Snell's law**

$$n_1 sin\theta_i = n_2 sin\theta_r$$

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First of all we will talk about the reflection of a system. So when light photons are transmitted through a material, they actually cause polarisation of the electrons and in turn, the speed of the light is reduced and the beam of light changes its direction okay, so from the vacuum for example the light is coming to any such nonmetallic system, suppose it is coming into glass okay, so the moment it is coming inside the system, there is a polarisation and the speed of light will get change and as a result, the speed of light will get change, will not be able to progress in the same direction but it is going to get change.

Now refractive index n is nothing but the ratio of speed of light in a vacuum to the speed of light in a medium. So any medium is going to slow down if the light comes from vacuum and to a medium. Let us say sunlight is coming from space to the atmosphere of earth, it is going to get refraction because it is going to get slowed down in the medium. Now for any medium what will be the speed of light? Well, for any electromagnetic system I already told you that it is actually one over square root of Epsilon Mu, where Epsilon is the permittivity and Mu is the permeability of the medium.

So if I want to calculate n as C over V, then it is simply square root of E Mu over square root of E 0 Mu 0. In other words, it is square root of Epsilon r Mu, where Epsilon r is nothing but Epsilon over Epsilon 0 and Mu r is nothing but Mu over Mu 0. That means relative permittivity and relative permeability will come into the picture. Now also we know that the Snell’s law you must have studied earlier and that says that if my incident angle is theta I and reflected angle is theta r or refracted angle is theta r, then n 1sine theta I = n 2 sine theta r. This is an important relationship, which we will later on we will see that for optical fibre we are going to use this principle.

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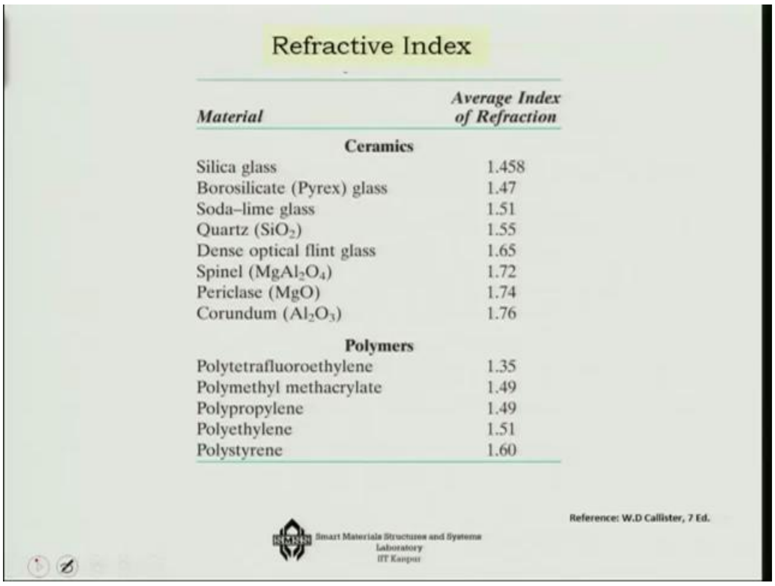

Refractive Index

Material	*Average Index of Refraction*
Ceramics	
Silica glass	1.458
Borosilicate (Pyrex) glass	1.47
Soda–lime glass	1.51
Quartz (SiO_2)	1.55
Dense optical flint glass	1.65
Spinel ($MgAl_2O_4$)	1.72
Periclase (MgO)	1.74
Corundum (Al_2O_3)	1.76
Polymers	
Polytetrafluoroethylene	1.35
Polymethyl methacrylate	1.49
Polypropylene	1.49
Polyethylene	1.51
Polystyrene	1.60

Reference: W.D Callister, 7 Ed.

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Now, the refractive index of some of the very common materials let us say silica glass ceramics, it has refractive index of 1.458, so quite a low refractive index. Then we have borosilicate glass 1.47, 1.51 like that Al2O3 is 1.76, so that is the kind of refractive index that you are finding in the ceramics. In the polymers it is even lower like 1.35 for Polytetrafluoroethylene PTFE we call it, then polyethyl methacrylate 1.49, polypropylene 1.49.

In fact some of them are somewhat similar to the glass that is why some of the polymers today are used as glasses, polyethylene 1.51, and polystyrene 1.60. So it is possible today to have optically transparent systems made from polymers as well as from ceramics. That is good because ceramics are brittle you know, but polymers are not.

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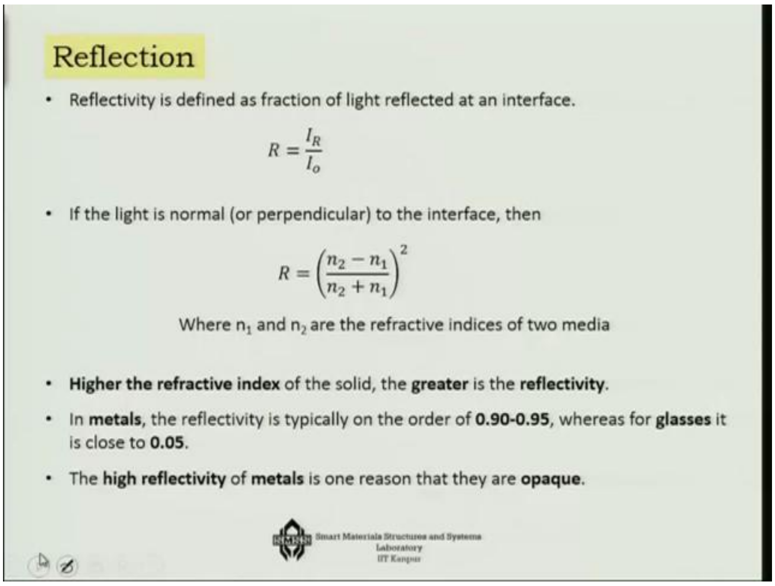

Reflection

- Reflectivity is defined as fraction of light reflected at an interface.

$$R = \frac{I_R}{I_o}$$

- If the light is normal (or perpendicular) to the interface, then

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Where n_1 and n_2 are the refractive indices of two media

- **Higher the refractive index** of the solid, the **greater** is the **reflectivity**.
- In **metals**, the reflectivity is typically on the order of **0.90-0.95**, whereas for **glasses** it is close to **0.05**.
- The **high reflectivity** of **metals** is one reason that they are **opaque**.

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Now let us come to the reflection, reflectivity is defined as the fraction of light that is reflected at an interface, so it is the ratio of I R over I 0, this we have also discussed when we have discussed about the metals. So if the light is normal or perpendicular to the interface, then the R can be actually derived to be something like n 2 - n 1 square and in to + n 1, so n 2 - n 1 by n 2 + n 1 whole square where n 1 and n 2 are the refractive indices of the 2 medium.

Higher is the refractive index of the solid, the greater is the reflectivity of the medium. So in comparison to between the 2 materials, if the um the refractive index is higher, then we can say that R is actually going to be more for this particular material. Now in metals, the reflectivity is typically I told you of the order of 0.90 to 0.95, whereas it is just the reverse for the glass, it is about 0.05 okay.

So what it means is that the value of the refractive index is very-very high in the metals and as a result, you get a very high reflectivity in metals, whereas for glasses it is just the reverse. High reflectivity of metals is also one of the reasons that they are opaque; anyway we have explained the fundamentals to you. Now let us come to the absorption part of it.

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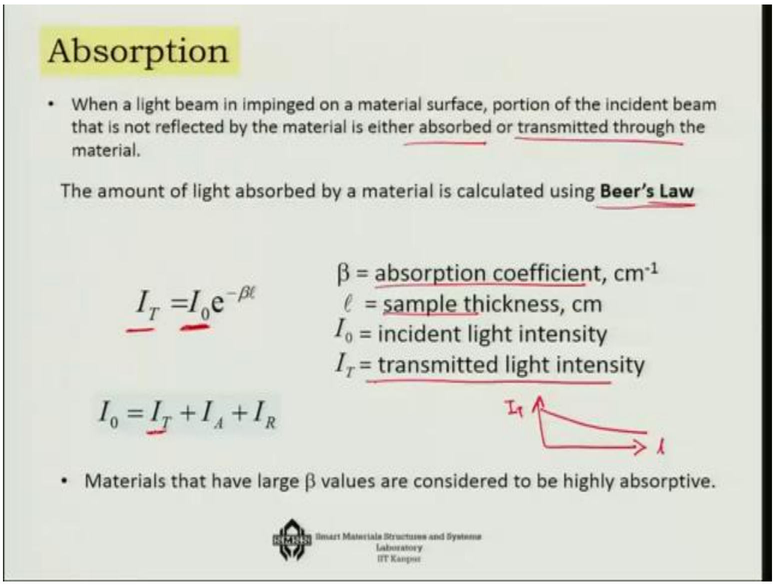

Absorption

- When a light beam in impinged on a material surface, portion of the incident beam that is not reflected by the material is either absorbed or transmitted through the material.

The amount of light absorbed by a material is calculated using **Beer's Law**

$$I_T = I_0 e^{-\beta \ell}$$

β = absorption coefficient, cm^{-1}
ℓ = sample thickness, cm
I_0 = incident light intensity
I_T = transmitted light intensity

$$I_0 = I_T + I_A + I_R$$

- Materials that have large β values are considered to be highly absorptive.

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When a light beam is impinged on a material surface, portion of the incident beam that is not reflected by the material is either absorbed or transmitted through the material. The amount of light which is absorbed by a material actually can be calculated using Beer's law. So here I T is the transmitted light intensity and I 0 is the incident light intensity. Suppose if the absorption coefficient Beta and the sample thickness L, then you can say that the transmitted light intensity is I 0 e to the - Beta L okay.

So the intensity of I T will actually with respect to the thickness as well as with respect to the absorption coefficient, it will follow an exponentially way of actually falling down okay. So with respect to length or with respect to if I consider the absorption coefficient Beta either of them it exponentially falls down, so that is about the light which is absorbed in the system that is the I T part of it okay. Now materials that have large beta values, they are considered to be highly absorptive because they are taking most of the transmitted most of the light energy into the system.

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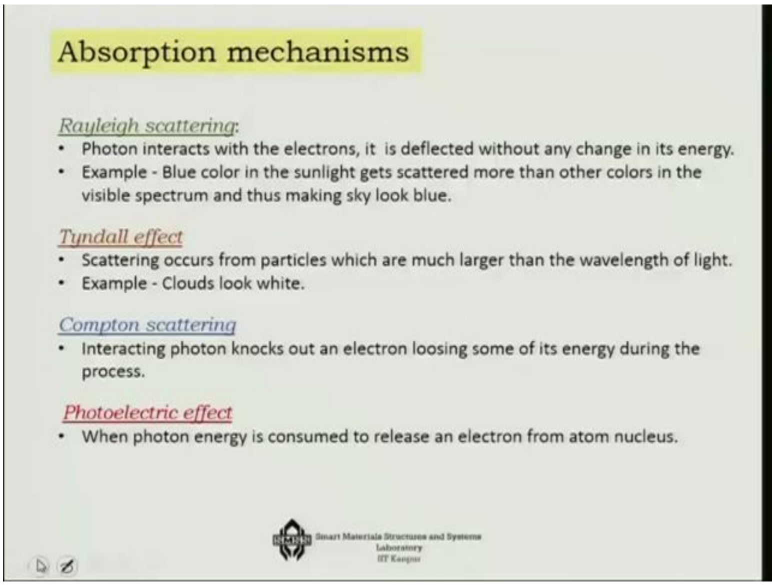

Absorption mechanisms

Rayleigh scattering:

- Photon interacts with the electrons, it is deflected without any change in its energy.
- Example - Blue color in the sunlight gets scattered more than other colors in the visible spectrum and thus making sky look blue.

Tyndall effect

- Scattering occurs from particles which are much larger than the wavelength of light.
- Example - Clouds look white.

Compton scattering

- Interacting photon knocks out an electron loosing some of its energy during the process.

Photoelectric effect

- When photon energy is consumed to release an electron from atom nucleus.

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There are several absorption mechanisms, one is known as the Rayleigh scattering, where the photon interacts with the electrons and it is deflected without any change in its energy, so that is called the Rayleigh scattering, without any change in energy is very-very important okay, so photons simply interact with electron and gets deflected. For example, the sunlight gets deflected and the blue colour you see all over the sky, so it is like a Rayleigh scattering. There is also Tyndall effect, where scattering occurs from particles which are much larger than the wavelength of light, and colloidal suspension for that matter shows this Tyndall effect.

Compton catering where the interacting photon knocks out an electron losing some of its energy during the process. So not like Rayleigh scattering, in the Compton scattering the photon during the impact loses some of its energy and then the scattering takes place. And then the Photoelectric effect, when photon energy is consumed to release an electron from atomic nucleus, this is the famous effect for which Einstein got his Nobel Prize, so there are such various mechanisms of absorption of light Rayleigh scattering, Tyndall effect, Compton scattering and Photoelectric effect.

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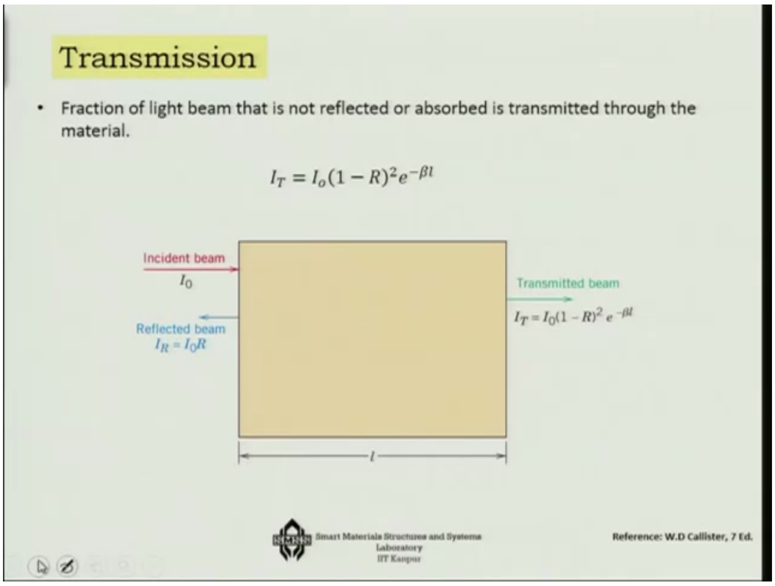

Transmission

- Fraction of light beam that is not reflected or absorbed is transmitted through the material.

$$I_T = I_o(1-R)^2 e^{-\beta l}$$

Incident beam I_0

Reflected beam $I_R = I_0 R$

Transmitted beam $I_T = I_0(1-R)^2 e^{-\beta l}$

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Reference: W.D Callister, 7 Ed.

Now, about the transmission of light I T is very similar to the refraction. Here there is a law which is very similar to Beer's law, it is I T is now I 0 into 1 - R whole square times e to the power - beta L, so that is what is the I T. So if I 0 is the intensity of the incident wave, then part of it gets reflected I R, which is I 0 times R and part of it gets transmitted, which is I 0 times 1 - R whole square times E to the power - Beta L, so this is what is when the light is transmitted from the system.

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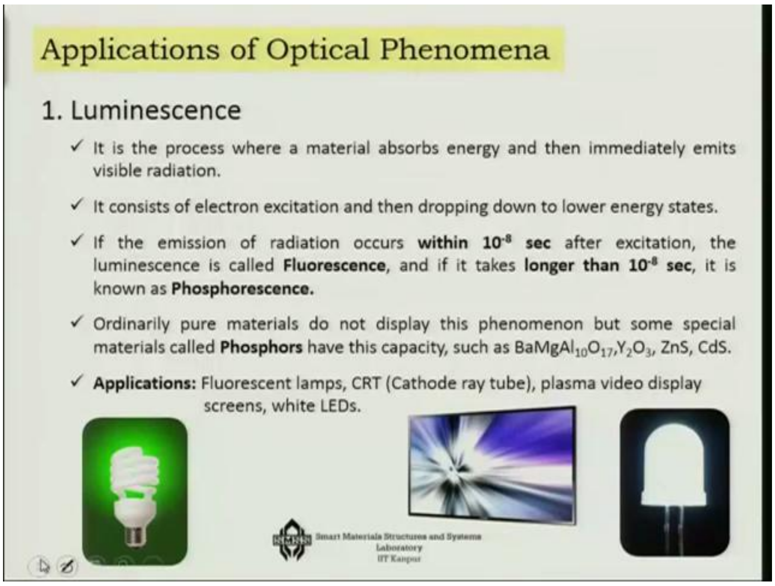

Applications of Optical Phenomena

1. Luminescence

- ✓ It is the process where a material absorbs energy and then immediately emits visible radiation.
- ✓ It consists of electron excitation and then dropping down to lower energy states.
- ✓ If the emission of radiation occurs **within 10^{-8} sec** after excitation, the luminescence is called **Fluorescence**, and if it takes **longer than 10^{-8} sec**, it is known as **Phosphorescence.**
- ✓ Ordinarily pure materials do not display this phenomenon but some special materials called **Phosphors** have this capacity, such as $BaMgAl_{10}O_{17}$, Y_2O_3, ZnS, CdS.
- ✓ **Applications:** Fluorescent lamps, CRT (Cathode ray tube), plasma video display screens, white LEDs.

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Now, I told you that materials absorb energy but I told you that when it absorbs the energy, then electrons go to a higher energy state but it cannot sustain the higher energy state because it has to come down for the minimisation of energy, so it will actually emit the energy back and it will come down to lower energy state. If this emission of radiation occurs and this entire phenomena what we will be calling as luminescence, but if this occurs within 10 raise to the power - 8 seconds after excitation, then the luminescence is called fluorescence, and if it takes longer than 10 to the power - 8 seconds, then it is called phosphorescence.

Ordinarily, pure materials not display this phenomena, but some special materials called phosphors have this capacity for example, Yttrium, ZnS, cadmium sulphide and a very complex one which contains barium, magnesium, aluminium and oxygen, etc. There are examples of many applications of this effect like fluorescent lamps, CRTs, plasma video display, white LEDs, in all of them in some way or the other exploits this fluorescence and phosphorescence of a phenomena of a optical property of a material.

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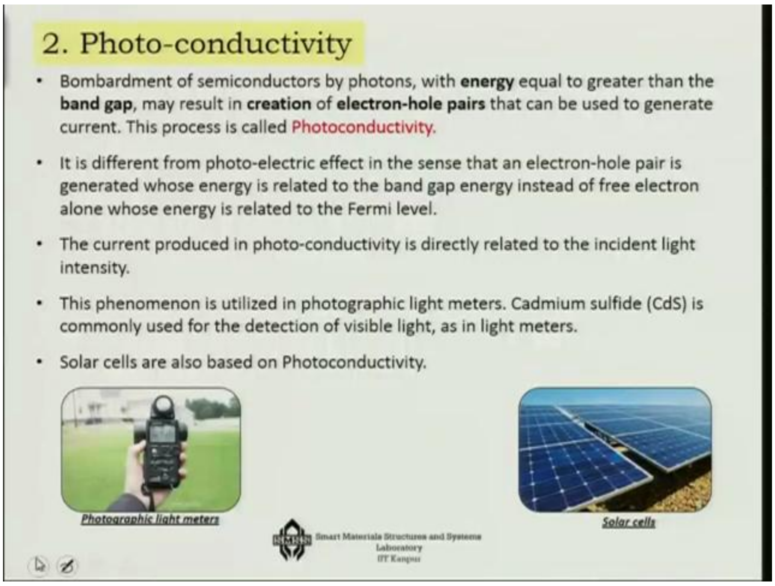

2. Photo-conductivity

- Bombardment of semiconductors by photons, with **energy** equal to greater than the **band gap**, may result in **creation** of **electron-hole pairs** that can be used to generate current. This process is called Photoconductivity.
- It is different from photo-electric effect in the sense that an electron-hole pair is generated whose energy is related to the band gap energy instead of free electron alone whose energy is related to the Fermi level.
- The current produced in photo-conductivity is directly related to the incident light intensity.
- This phenomenon is utilized in photographic light meters. Cadmium sulfide (CdS) is commonly used for the detection of visible light, as in light meters.
- Solar cells are also based on Photoconductivity.

The second interesting case is called photoconductivity which is actually important for materials like semiconductors. If you bombard the semiconductors by photons, then what happens is that the energy in this case, which is equal to the energy in that can create the electron-hole pairs that means it is greater than the band gap, they actually can use to generate a current and that is known as photoconductivity.

So it is different from the photoelectric effect because in the photoelectric effect the photon is actually absorbed by the electron itself, whereas it is the electron-hole pair which gets this energy the band gap energy and then that actually excites the flow of this electron-hole pairs and that generates a current. So this current which is produced through photoconductivity is directly related to the incident light intensity.

As a result, these light meters you see in cricket matches, etc people use, they are actually based on this photoconductivity of the incident light okay, so it is based on the electron-hole pair okay for example, cadmium sulphide is one of the very common example in light meters. And today's solar cells, they are also based on mostly the photoconductivity, so this is another very good application of the optical property. The 3rd and the most important one and towards the end of this course we will show you some of the applications to lasers is actually Light Amplification by Stimulated Emission of Radiation.

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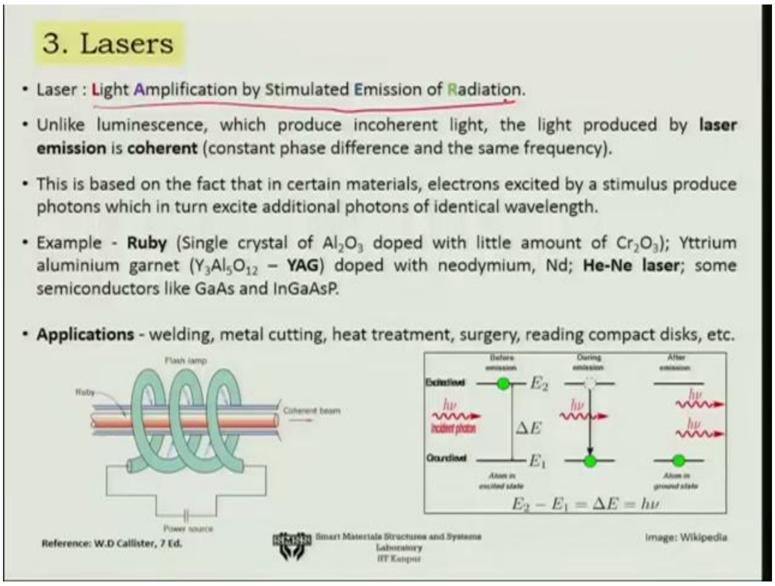

3. Lasers

- Laser : Light Amplification by Stimulated Emission of Radiation.
- Unlike luminescence, which produce incoherent light, the light produced by **laser emission** is **coherent** (constant phase difference and the same frequency).
- This is based on the fact that in certain materials, electrons excited by a stimulus produce photons which in turn excite additional photons of identical wavelength.
- Example - **Ruby** (Single crystal of Al_2O_3 doped with little amount of Cr_2O_3); Yttrium aluminium garnet ($Y_3Al_5O_{12}$ – **YAG**) doped with neodymium, Nd; **He-Ne laser**; some semiconductors like GaAs and InGaAsP.
- **Applications** - welding, metal cutting, heat treatment, surgery, reading compact disks, etc.

Reference: W.D Callister, 7 Ed.

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Image: Wikipedia

So in this case for example, if we see this particular case that you have a Ruby Crystal and then you have a flash lamp from which you are providing energy to the system, you see in the case of luminescence the energy is coming out but it is incoherent the phase relation continuously changes. Whereas, laser emission is very much coherent, constant phase difference and the same frequency will be emitted.

So when you consider this Ruby, which is a single crystal of AL2O3 doped with very little amount of chromium oxide or yttrium aluminium garnets YAG we call them or neodymium, helium neodymium lasers, this type of materials when you excite them, what happens is that you 1st get a these atoms in the excited state, the incident photon is coming and then some of the electrons are getting excited to the high-energy state.

But after that what happens is that they actually start to excite more of these electrons in the system and then this happens, this gets multiplied and then that actually becomes a source of the coherent light emission in the system, so this kind of a system at the end generates a coherent beam and that coherent beam can be used for many-many detection of physical properties of materials.

So we have seen here the various properties of we have discussed today, various optical properties of metals and nonmetals on some of the very important optical phenomena. In the next lecture you will study the optical fibres and its principles and types and various applications of optical fibre thank you.