Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) for Pollution Monitoring

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Lecture – 07
Nature of electromagnetic radiation

Greetings to you; we are going to discuss third module, that is interaction of electromagnetic radiation with matter. Earlier, we had discussed, we have in the model 1, we had an introduction and then in module 2. We studied about the atomic structure. Now, as you know most of the spectroscopic techniques use, electromagnetic radiation and the electromagnetic radiation is a very important concept, because it interacts with the matter to give you a variety of wavelength. So, we have a continuing with this thing.

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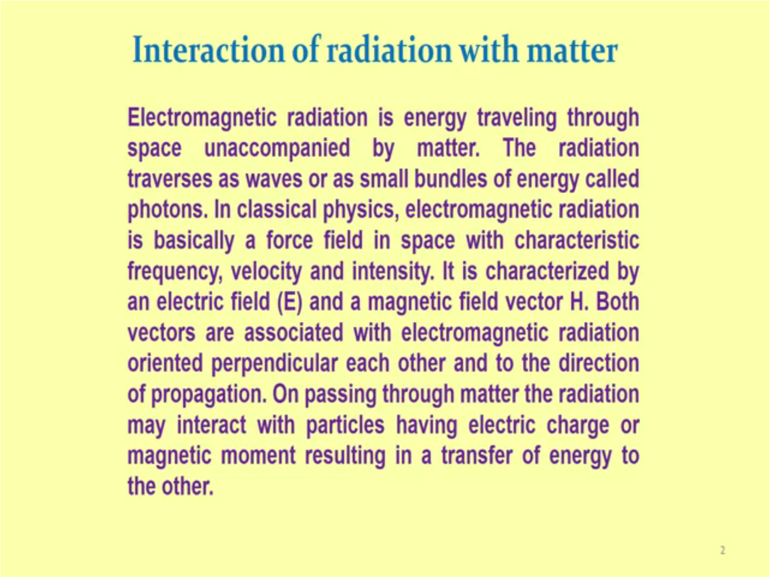

Interaction of radiation with matter

Electromagnetic radiation is energy traveling through space unaccompanied by matter. The radiation traverses as waves or as small bundles of energy called photons. In classical physics, electromagnetic radiation is basically a force field in space with characteristic frequency, velocity and intensity. It is characterized by an electric field (E) and a magnetic field vector H. Both vectors are associated with electromagnetic radiation oriented perpendicular each other and to the direction of propagation. On passing through matter the radiation may interact with particles having electric charge or magnetic moment resulting in a transfer of energy to the other.

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So, basically what do we want to discuss today is about the nature of electromagnetic radiation. So, what is electromagnetic radiation, it is the energy traveling through space unaccompanied by the matter; that means, there will be radiations, but not with the matter the radiation usually travels, traverses as waves or a small bundles of energy called as photons. In classical physics electromagnetic radiation is basically a force field in space with characteristics frequency, velocity and intensity. It is characterized by an electric field and a magnetic field that is the both of them are vectors.

So both these vectors are associated with all electromagnetic radiation and they are oriented perpendicular to each other and to the direction of propagation. So, on passing through the matter, the radiation may interact with the particles having electric charge or magnetic moment, resulting in a transfer of energy to the other.

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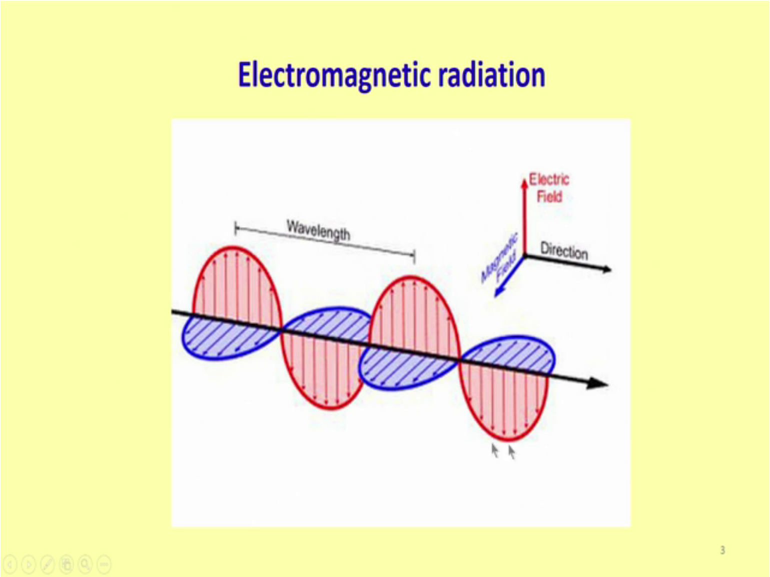

Electromagnetic radiation

Now, if I tell you so much about the theory, probably you might get confused a little bit, but this is what we mean, electromagnetic radiation is a force field, it is energy moving in one direction, there is an electric field marked with red and there is a magnetic field marked with blue and this is known as wavelength. So, all electromagnetic radiation is characterized by two components; one is electric field, another is magnetic field.

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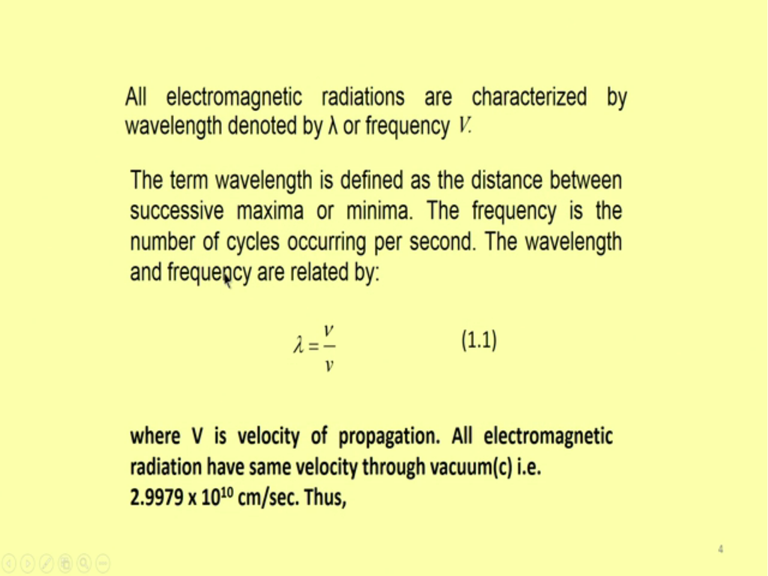

All electromagnetic radiations are characterized by wavelength denoted by λ or frequency V.

The term wavelength is defined as the distance between successive maxima or minima. The frequency is the number of cycles occurring per second. The wavelength and frequency are related by:

$$\lambda = \frac{\nu}{v} \qquad (1.1)$$

where V is velocity of propagation. All electromagnetic radiation have same velocity through vacuum(c) i.e. 2.9979 x 10^{10} cm/sec. Thus,

So, all electromagnetic radiations are there for characterized by wavelength, denoted by lambda or frequency. So, what do we mean by wavelength, it is defined as the distance between successive maxima or minima. The frequency is the number of cycles occurring per second, the wavelength and frequency are related by lambda is equal to v by MU, where V is the velocity of the propagation and all electromagnetic radiations have the same velocity through vacuum that is the number is known 2.9979 into 10 raise to 10 centimeters per second.

You can take it for granted, that it is approximately 3 into 10 raise to 10. For easy remembrance 3 into 10 raise to 10. So, most of the electromagnetic radiation traverses and it goes like this. This is the wavelength between two crush and this also can be wavelength. So, this is what we shall understand.

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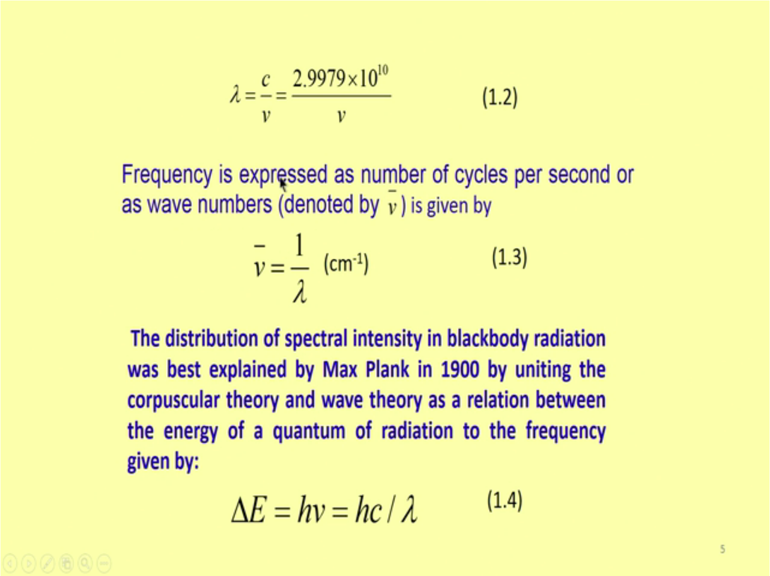

$$\lambda = \frac{c}{v} = \frac{2.9979\times10^{10}}{v} \qquad (1.2)$$

Frequency is expressed as number of cycles per second or as wave numbers (denoted by $\bar{v}$) is given by

$$\bar{v} = \frac{1}{\lambda} \; (\mathrm{cm}^{-1}) \qquad (1.3)$$

The distribution of spectral intensity in blackbody radiation was best explained by Max Plank in 1900 by uniting the corpuscular theory and wave theory as a relation between the energy of a quantum of radiation to the frequency given by:

$$\Delta E = hv = hc/\lambda \qquad (1.4)$$

We can do a little bit more numbers. For example, lambda gives nothing, but velocity of light divided by frequency. So, that is 2.9979 into 10 raise to 10 frequency is expressed as the number of cycles per second or as wave numbers. So, wave number is denoted by mu bar and that is given by mu bar is equal to 1 over lambda that is, unit should be in centimeters inverse, the distribution of spectral intensity in the black body radiation was best explained by max plank in 1900 by uniting the corpuscular theory and wave theory as a relation between the energy of a quantum of radiation to the frequency given by delta E is equal to h mu or h c by lambda.

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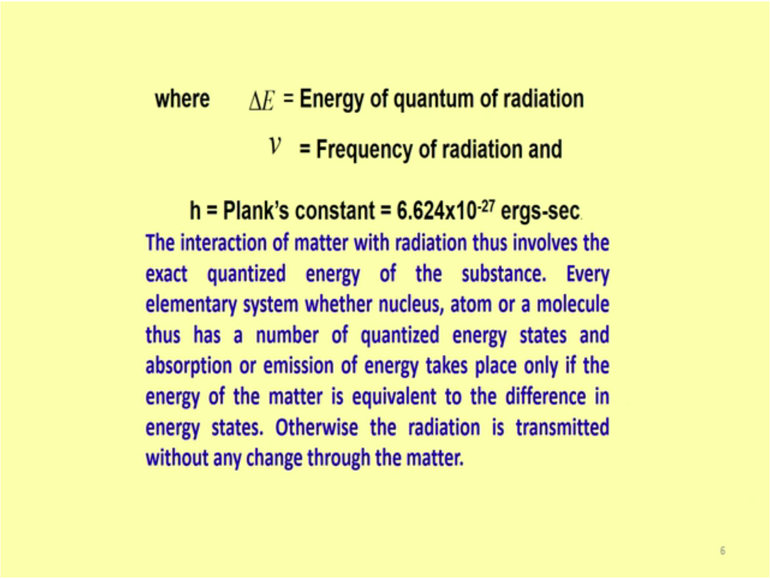

where ΔE = Energy of quantum of radiation

v = Frequency of radiation and

h = Plank's constant = 6.624×10^{-27} ergs-sec

The interaction of matter with radiation thus involves the exact quantized energy of the substance. Every elementary system whether nucleus, atom or a molecule thus has a number of quantized energy states and absorption or emission of energy takes place only if the energy of the matter is equivalent to the difference in energy states. Otherwise the radiation is transmitted without any change through the matter.

So, in this equation delta E is the energy of quantum of radiation and mu is the frequency of radiation, h is known as planks constant that is 6.624 into 10 raise to minus 27 ergs second. The interaction of matter with radiation does involve exact quantized energy of the substance. So, there is no continuum energy transfer in that. So, every elementary system whether nucleus atom or a molecule does as a number of quantized energy states and absorption or emission of energy takes place, only if the energy of the matter is equivalent to the difference between the energy states. So, otherwise the radiation is transmitted without any change through the matter. So, this is a very important concept; that means, if you want to change in the matter, you have to supply exact amount of energy characterized by the matter.

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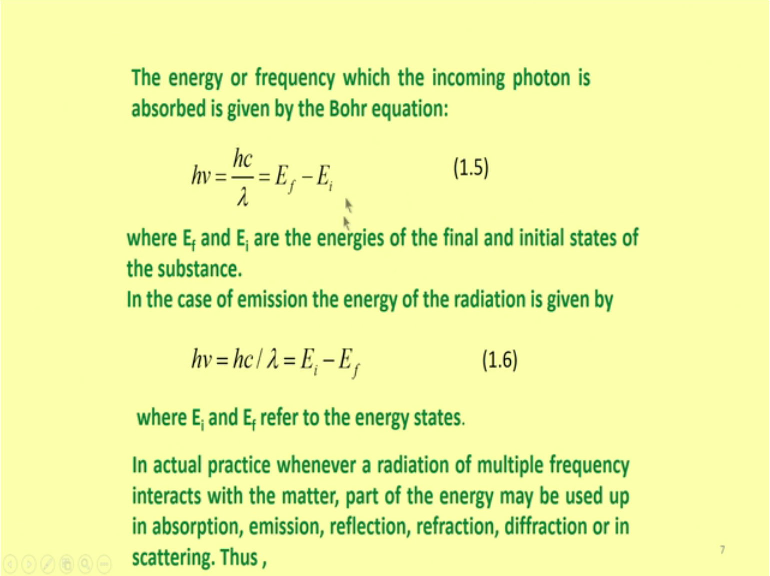

The energy or frequency which the incoming photon is absorbed is given by the Bohr equation:

$$h\nu = \frac{hc}{\lambda} = E_f - E_i \qquad (1.5)$$

where E_f and E_i are the energies of the final and initial states of the substance.
In the case of emission the energy of the radiation is given by

$$h\nu = hc/\lambda = E_i - E_f \qquad (1.6)$$

where E_i and E_f refer to the energy states.

In actual practice whenever a radiation of multiple frequency interacts with the matter, part of the energy may be used up in absorption, emission, reflection, refraction, diffraction or in scattering. Thus ,

So, the energy of frequency which the incoming photon is observed; is given by the Bohr equation, that is h mu is equal to h c by lambda, that is expressed as energy of the final state and energy of the initial state of the substance. So, in the case of emission the energy of the radiation is given by h mu is equal to h c by lambda, that is e i minus e f. So, here we are talking about the absorption, here we are talking about equation 1.0 pi refers to absorption, 1.6 refers to emission. So, in actual practice whenever a radiation of multiple frequencies interacts with the matter part of the energy, may be used up in absorption, emission, reflection, refraction, diffraction or in scattering. So, many possibilities are there, whenever there is interaction of the electromagnetic radiation.

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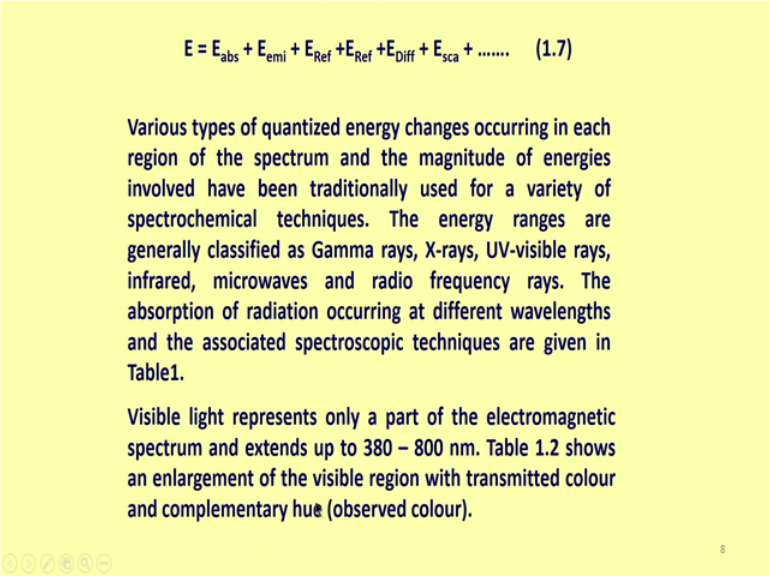

$$E = E_{abs} + E_{emi} + E_{Ref} + E_{Ref} + E_{Diff} + E_{sca} + ... \quad (1.7)$$

Various types of quantized energy changes occurring in each region of the spectrum and the magnitude of energies involved have been traditionally used for a variety of spectrochemical techniques. The energy ranges are generally classified as Gamma rays, X-rays, UV-visible rays, infrared, microwaves and radio frequency rays. The absorption of radiation occurring at different wavelengths and the associated spectroscopic techniques are given in Table1.

Visible light represents only a part of the electromagnetic spectrum and extends up to 380 – 800 nm. Table 1.2 shows an enlargement of the visible region with transmitted colour and complementary hue (observed colour).

So, I can put it in an equation, something like this energy is equal to, is the sum total of energy, absorbed energy, emitted energy, reflected energy, refracted energy, diffracted energy, scattered and so many other phenomena. So, various types of quantized energy, changes occurring in each region of the spectrum and the magnitude of energies involved have been traditionally used for a variety of spectro chemical techniques. The energy ranges are generally classified as Gamma rays, X-rays, UV-visible rays, infrared, microwaves, radio frequency. I think most of you familiar with this kind of radiations.

They are all part of the electromagnetic radiation only. So, the absorption of radiation occurring at different wavelengths and the associated spectroscopic techniques, I am giving in the table 1. And this is the absorption of the electromagnetic representation of the electromagnetic radiation.

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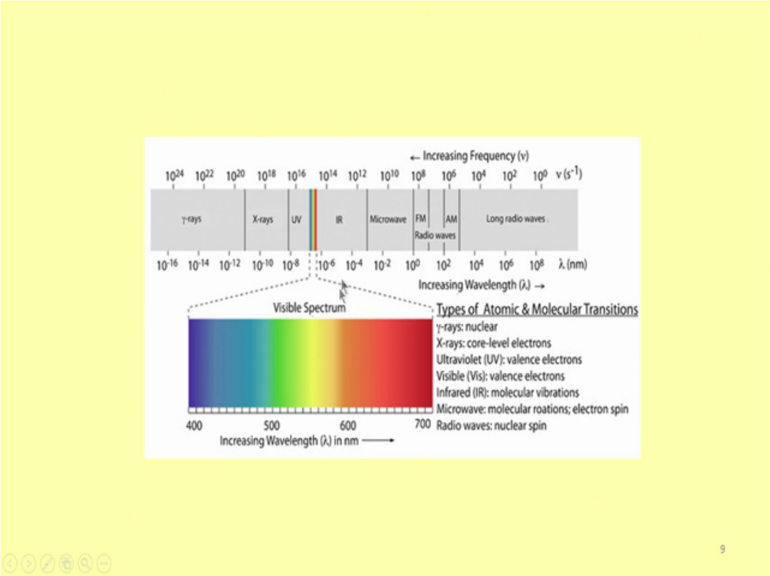

Types of Atomic & Molecular Transitions

γ-rays: nuclear

X-rays: core-level electrons

Ultraviolet (UV): valence electrons

Visible (Vis): valence electrons

Infrared (IR): molecular vibrations

Microwave: molecular roations; electron spin

Radio waves: nuclear spin

So, at one end of the spectrum, we have Gamma rays, then X- rays, Ultra Violet, Visible, Infrared, Microwave and then F M and then A M that is a radio waves and then long radiation waves are also present there and the increasing the top portion. I am showing you the increasing frequency.

So, Gamma rays have the shortest and having maximum number of frequency and the Wavelength also would be very less. So, almost 10 to the power of minus 16 Armstrong’s, etcetera and you can see that in Gamma rays, an analytical technique based on nuclear interactions can be used, these are a such, radiations are typically used in nuclear establishments for measurement of radiation and things like that and X- rays are core level electrons, Ultra Violet rays corresponds to valence electrons and then visible range also refers to valence electrons, infrared refers to molecular vibrations, microwave and molecular rotations, may electron spin, electron, radio waves, etcetera.

So, with each radiation an analytical technique is available, which can be used as a spectroscopic basis. So, you can also see that the visible range is only a very small portion of the total electromagnetic radiation, isn’t it. So, here we see from one end 400 to 700 nanometers. So, violet, ultra violet, vigor that is rainbow colors you would be seeing all over the invisible range.

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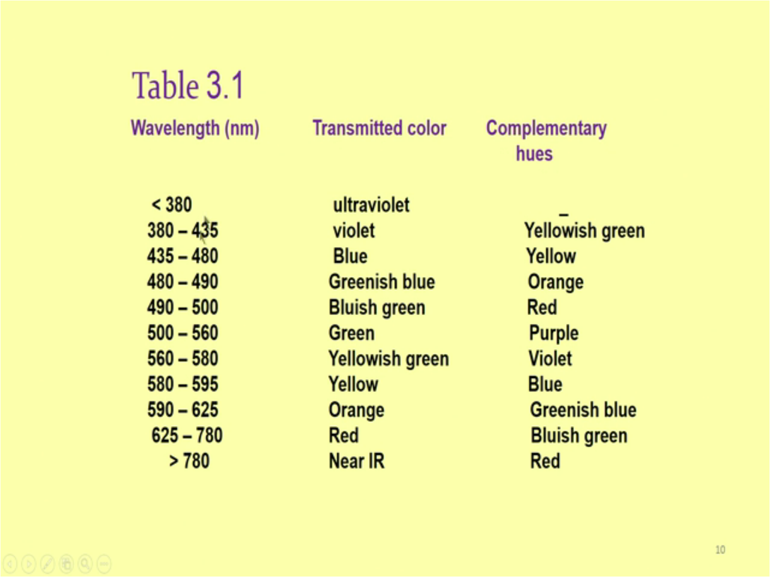

Table 3.1

Wavelength (nm)	Transmitted color	Complementary hues
< 380	ultraviolet	–
380 – 435	violet	Yellowish green
435 – 480	Blue	Yellow
480 – 490	Greenish blue	Orange
490 – 500	Bluish green	Red
500 – 560	Green	Purple
560 – 580	Yellowish green	Violet
580 – 595	Yellow	Blue
590 – 625	Orange	Greenish blue
625 – 780	Red	Bluish green
> 780	Near IR	Red

Now, even among the visible range, what you see actually is a complementary view rather than the transmitted color. Suppose, I have taken ultra violet you do not see any color at all, but between 380 and 435, what is transmitted is violet, but complementary view is what you see in the solution that is yellowish green. Similarly, 435 to 480, it is blue transmitted color and yellow is the complementary view. Similarly, 484 to 490 greenish blue and orange 490 to 500 that is red and 500 to 560, if it absorbs, you would see a purple color and then 560 to 580, you will be seeing violet.

580 to 595 is blue color, 590 to 625 is greenish blue and beyond that is bluish green and above 780, it is near infrared that is red color, only you will be seeing. So, it must be noted that there are no sharp difference in color, at any wave length; they all lot of merge themselves. You know in reddish, blue, green, blue, greenish blue like that, but they rather merge into one another in a diffused manner. They are no sharp differences that above 380. You will see only one color above 390. You will see only one color, nothing like that. This process is a specific phenomena related to the characteristic molecular structure.

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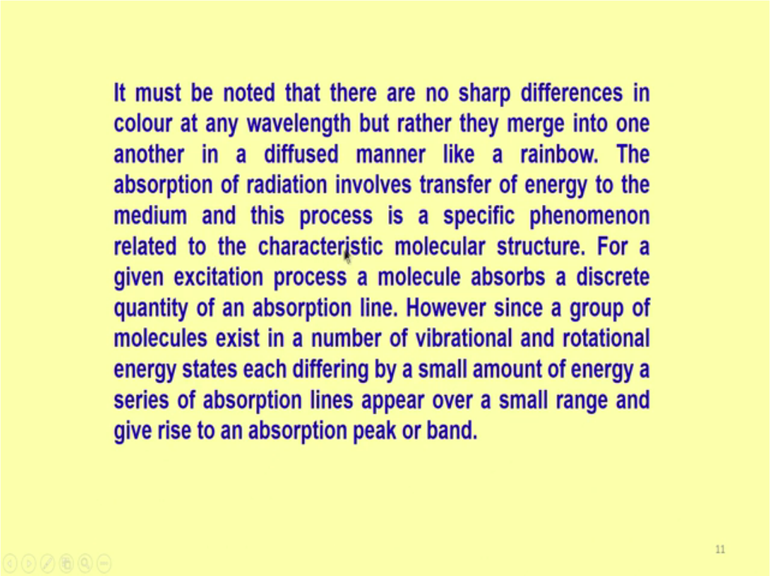

It must be noted that there are no sharp differences in colour at any wavelength but rather they merge into one another in a diffused manner like a rainbow. The absorption of radiation involves transfer of energy to the medium and this process is a specific phenomenon related to the characteristic molecular structure. For a given excitation process a molecule absorbs a discrete quantity of an absorption line. However since a group of molecules exist in a number of vibrational and rotational energy states each differing by a small amount of energy a series of absorption lines appear over a small range and give rise to an absorption peak or band.

So, you can imagine a rainbow, where the colors, you will see all the colors, but there are no sharp differences in the color. So, for a given excitation process what happens is a molecule absorbs, a discreet quanta of energy resulting in an absorption line; however, since a group of molecules exists in a number of vibrational and rotational energy levels, each differing by small amount of energy, a series of absorption lines appear over a small range and give rise to an absorption peak or a band. So, this is how the absorption takes place.

For example, I take a substance pass the electromagnetic radiation, it absorbs. So, you will see a complementary view, but why they are so diffused, because the rotational and vibrational energy levels of the absorbing medium are not, they are closely comparable in terms of energy. So, instead of getting simple line spectra, you will get a small peak like this. So, this you should understand.

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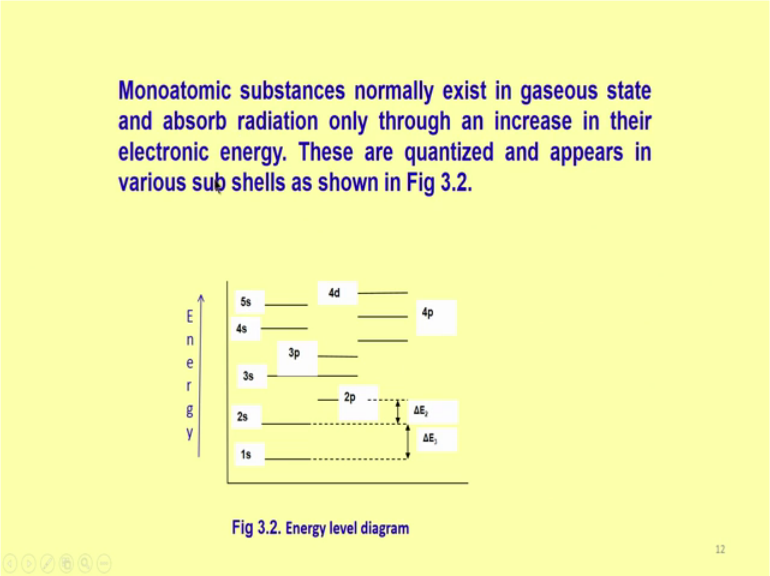

Monoatomic substances normally exist in gaseous state and absorb radiation only through an increase in their electronic energy. These are quantized and appears in various sub shells as shown in Fig 3.2.

Fig 3.2. Energy level diagram

So, if we look at mono atomic substances normally existing in gaseous state; that absorbed radiation only through an increase in their electronic energy. These are quantized again and appear in various sub shells. For example, here I am showing 1 s, 2 s, 2 p, 3 s, 3 p, 4 s, 3 d. So, like that there are different energy levels and the electrons will be moving from 1 s to 2 s, 2 s to 2 p like that there will be transition that give raise to an absorption peak.

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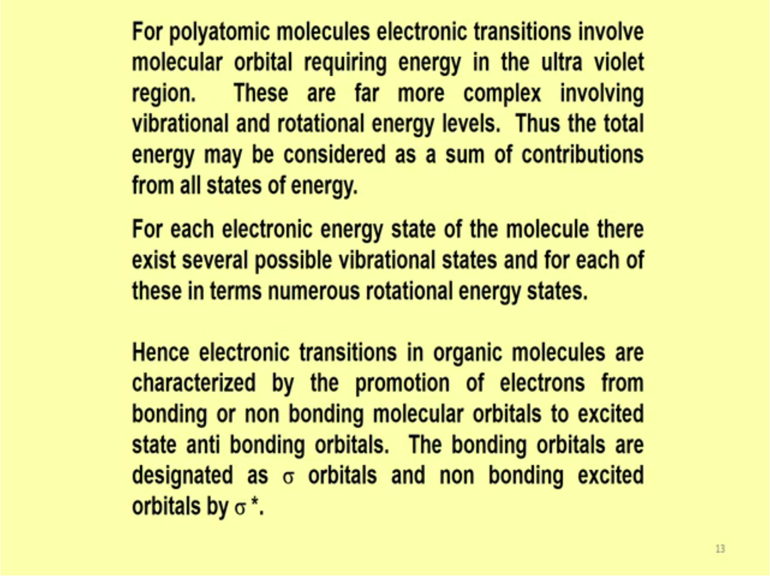

For polyatomic molecules electronic transitions involve molecular orbital requiring energy in the ultra violet region. These are far more complex involving vibrational and rotational energy levels. Thus the total energy may be considered as a sum of contributions from all states of energy.

For each electronic energy state of the molecule there exist several possible vibrational states and for each of these in terms numerous rotational energy states.

Hence electronic transitions in organic molecules are characterized by the promotion of electrons from bonding or non bonding molecular orbitals to excited state anti bonding orbitals. The bonding orbitals are designated as σ orbitals and non bonding excited orbitals by σ *.

Now, for poly atomic molecules that is, if a substance is having number of mole atoms unlike single atom like hydrogen. The electronic transition involve molecular orbitals requiring energy, in the ultra violet region these are far more complex, usually they at involve vibrational and rotational energy levels there, for the total energy may be considered as some of the contributions from all states of energy.

So, for each electronic energy state of the molecule, there exists several possible vibrational states and for each of these, in terms of numerous rotational energy level so; that means, for every electron, electronic energy level the energy is this much, but with each electronic energy level, there will be number of small steps defines as vibrational energy level. So, for each vibrational energy level, in turn there will be a number of rotational energy levels. So, if you look at the structure of an atom poly, atomic molecule, you would see that the energy levels are diffuse.

Not so sharp, so, but electronic transitions in organic molecules are characterized by promotion of electrons from bonding and or non-bonding electrons orbitals to excited state antibonding orbitals. I have not thought you about bonding and antibonding orbitals yet so, but for you to remember the bonding, orbitals are something like you can imagine a molecule like methane, carbon hydrogen c h 4 correct. So, sigma bond, it is most of you would have studied sigma bond, pi bond etcetera. So, if I take the molecule excited, the energy of the excited molecule will be slightly higher it becomes.

So, much unstable. So, what happens to the system? So, the electrons go to the next higher energy level that is known as antibonding's orbital o for each sigma bond. Let us say, there will be an antibonding sigma as star anti-bonding orbital for p orbitals, it is double bonds. There will be pi star, then there are certain number of electrons having n non-bonding electrons. For example, in alcohol the oxygen is having two pairs of electrons on oxygen and they in turn can get excited 2 pi star. So, we get transition from sigma to sigma star pi to pi star n to pi star and several other possibilities.

So, we will not go much into details of this, but except that sigma orbitals and non-bonding orbitals are designated as sigma star pi star etcetera.

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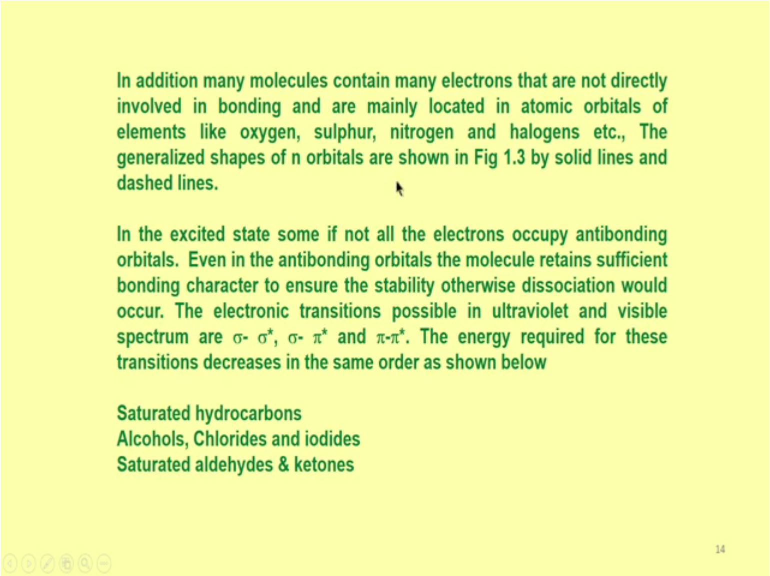

In addition many molecules contain many electrons that are not directly involved in bonding and are mainly located in atomic orbitals of elements like oxygen, sulphur, nitrogen and halogens etc., The generalized shapes of n orbitals are shown in Fig 1.3 by solid lines and dashed lines.

In the excited state some if not all the electrons occupy antibonding orbitals. Even in the antibonding orbitals the molecule retains sufficient bonding character to ensure the stability otherwise dissociation would occur. The electronic transitions possible in ultraviolet and visible spectrum are σ- σ^*, σ- π^* and π-π^*. The energy required for these transitions decreases in the same order as shown below

Saturated hydrocarbons
Alcohols, Chlorides and iodides
Saturated aldehydes & ketones

In addition many molecules contain electrons that are not directly involved in bonding. This I have already explained to you, with respect to oxygen, but there are many other elements like sulfur, nitrogen, halogens etcetera, they also have a number of non-bonding electrons and the possibility of transition is always there. So, in the excited state some if not all the electrons occupy antibonding orbitals, most of the excitation if not all the electrons, majority of them will occupy anti bonding orbitals.

So, molecule it even in the antibonding orbital, even if the molecular electron is excited, the molecule retains sufficient bonding character to ensure the stability of the molecule, otherwise dissociation will occur. So, the dissociation we do not want, we just want it to go to next higher energy level and stay there. So, the electronic transitions possible in ultra violet and visible spectrum are sigma to sigma star, sigma to pi star and pi to pi star, n to pi star etcetera, the energy required for these transitions decreases in the same order as shown below, that is sigma to sigma star, sigma to pi star and pi to pi star. So, the saturated hydro carbons have only sigma bonds.

So, the energy required would be very high to excite the electrons, alcohols, chlorides etcetera. They have non-bonding electrons saturated aldehydes and keytones, they also have non-bonding electrons present on the oxygen atoms.

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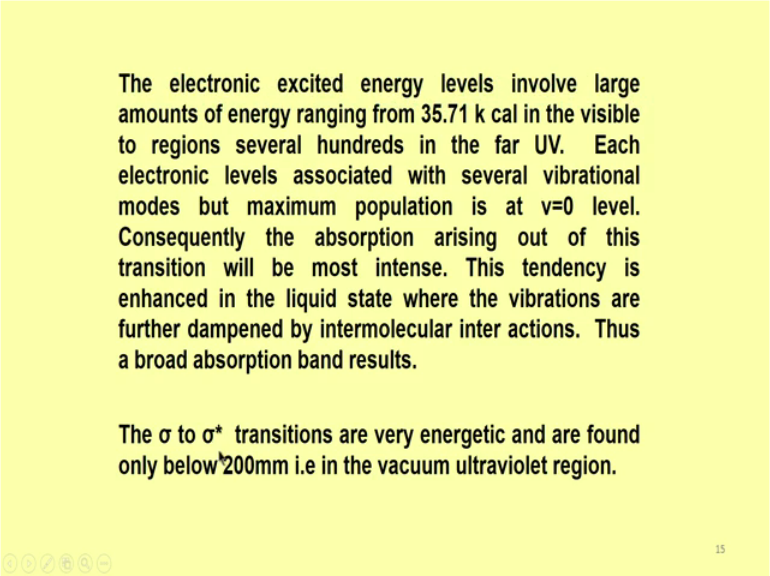

The electronic excited energy levels involve large amounts of energy ranging from 35.71 k cal in the visible to regions several hundreds in the far UV. Each electronic levels associated with several vibrational modes but maximum population is at v=0 level. Consequently the absorption arising out of this transition will be most intense. This tendency is enhanced in the liquid state where the vibrations are further dampened by intermolecular inter actions. Thus a broad absorption band results.

The σ to σ* transitions are very energetic and are found only below 200mm i.e in the vacuum ultraviolet region.

So, the electronic excited energy levels how much energy is required to supply, that is a mid-point in general. We feel that the energy ranges from 35.71 kilo Kelvin that is in the visible range to regions, several 100 kilo calories in the far ultra violet. So, each electronic level associated with several vibrational modes and maximum population is at the vibrational level 0.

So, consequently the absorption arising out of this transition will be most intense, because maximum number of electrons is there in the ground state that is vibrational energy level 0. So, a broad absorption band results. So, sigma to sigma star, transitions are very energetic and are found only below 200 nanometers that is in the vacuum ultraviolet range.

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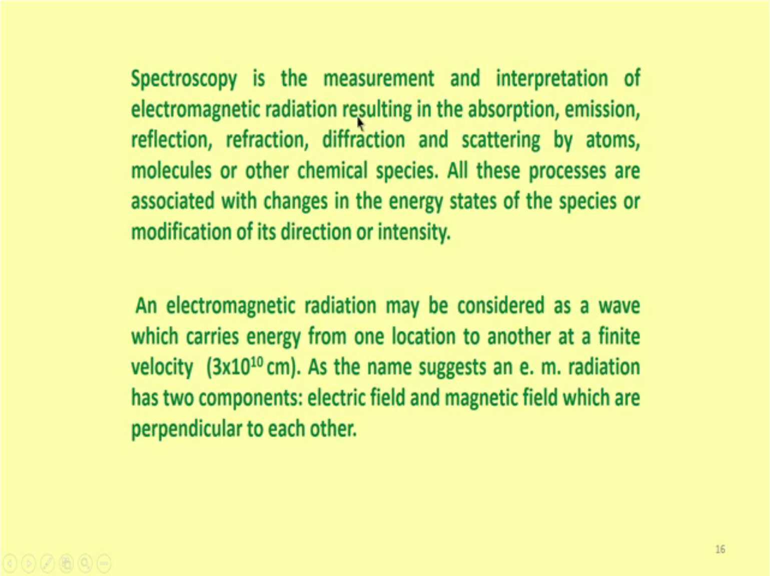

Spectroscopy is the measurement and interpretation of electromagnetic radiation resulting in the absorption, emission, reflection, refraction, diffraction and scattering by atoms, molecules or other chemical species. All these processes are associated with changes in the energy states of the species or modification of its direction or intensity.

An electromagnetic radiation may be considered as a wave which carries energy from one location to another at a finite velocity ($3x10^{10}$ cm). As the name suggests an e. m. radiation has two components: electric field and magnetic field which are perpendicular to each other.

So, Spectroscopy is the measurement and interpretation of the electromagnetic radiation resulting in the absorption, emission, reflection etcetera, this you have already covered. So, all these processes are associated with energy changes and the electromagnetic radiation may be considered as a wave, which carries energy and this way also we have seen as the name suggests electromagnetic radiation, electromagnetic. So, it has an electric field and magnetic field.

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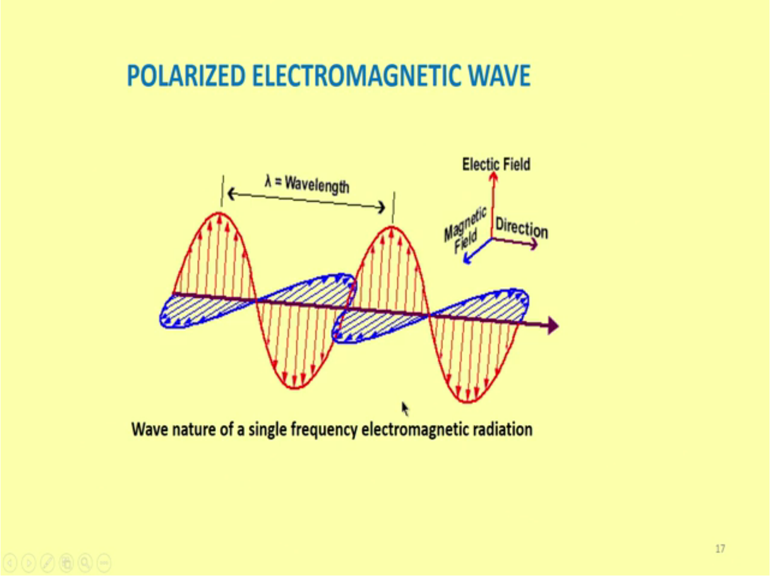

POLARIZED ELECTROMAGNETIC WAVE

Wave nature of a single frequency electromagnetic radiation

So, this is what we had already shown you earlier. So, this is polarized radiation.

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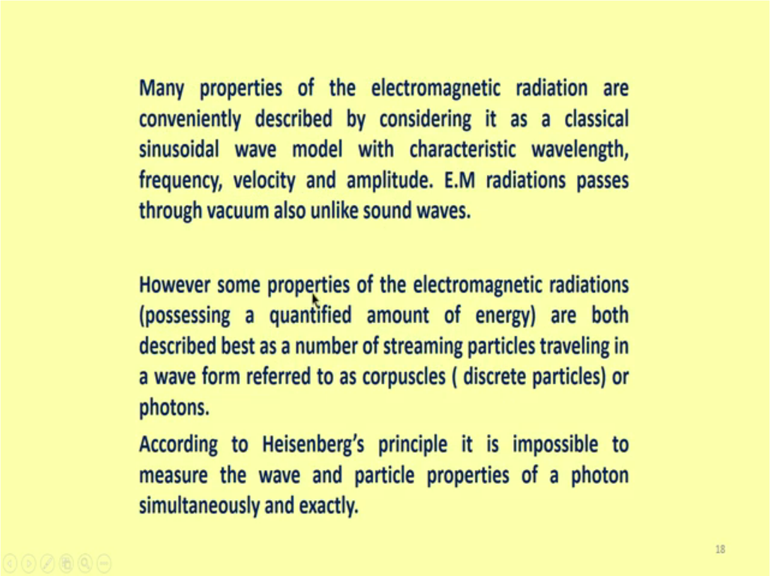

Many properties of the electromagnetic radiation are conveniently described by considering it as a classical sinusoidal wave model with characteristic wavelength, frequency, velocity and amplitude. E.M radiations passes through vacuum also unlike sound waves.

However some properties of the electromagnetic radiations (possessing a quantified amount of energy) are both described best as a number of streaming particles traveling in a wave form referred to as corpuscles (discrete particles) or photons.

According to Heisenberg's principle it is impossible to measure the wave and particle properties of a photon simultaneously and exactly.

So, many properties of the electromagnetic radiation are described by considering it as a classical sinusoidal way that is like a sin wave with characteristic wavelength, frequency, velocity and amplitude. So, electromagnetic radiation passes through vacuum unlike sound waves. So, sound waves do not travel in vacuum whereas, electromagnetic radiations travel through the vacuum; however, some of the electromagnetic radiations are both described best as a number of streaming particles that is the, you take an electromagnetic radiation, you can imagine the number of photons coming out from a given source.

So, the photons may be these are considered as particles of or bundles of energy. So, they are best described as a number of streaming particles and according to Heisenberg's principle, it is impossible to measure the wave and particle properties of a photon simultaneously. This is a very important concept with respect to spectroscopy.

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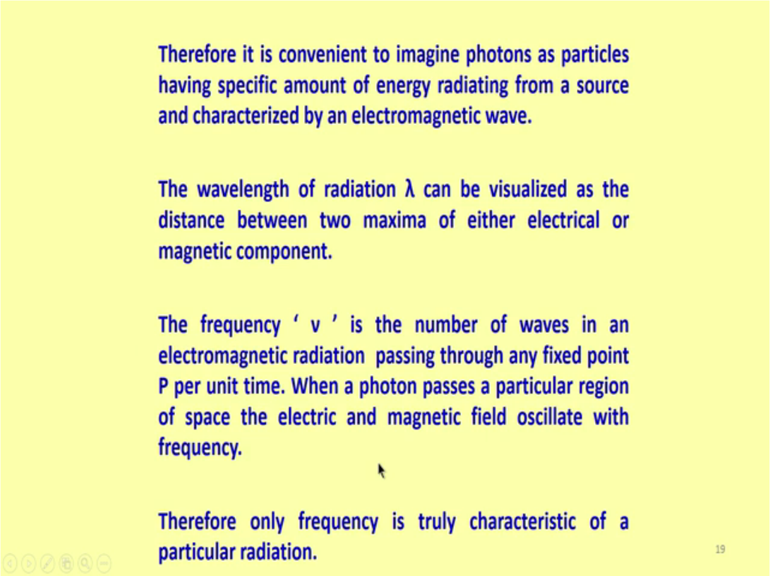

Therefore it is convenient to imagine photons as particles having specific amount of energy radiating from a source and characterized by an electromagnetic wave.

The wavelength of radiation λ can be visualized as the distance between two maxima of either electrical or magnetic component.

The frequency ' ν ' is the number of waves in an electromagnetic radiation passing through any fixed point P per unit time. When a photon passes a particular region of space the electric and magnetic field oscillate with frequency.

Therefore only frequency is truly characteristic of a particular radiation.

Therefore, it is convenient to you to imagine photons as particles having specific amount of energy radiating from source and characterized by an electromagnetic wave. So, the wavelength of radiation lambda can be visualized as the distance between two maxima of either electrical or magnetic component the frequency as we have already said it is the number of waves in electromagnetic radiation passing through a new fixed point P per unit time.

So, when a photon passes a particular region or space the electric and magnetic field oscillate with the frequency there for only frequency is truly characteristic of a particular radiation this you should understand. So, you want to describe the free the electromagnetic radiation whatever you wish to say if you say the frequency it is well defined for the electromagnetic radiation. So, how do we say mathematically then we have to say it is a sin wave. So, mathematically A is equal to A0 into sin theta.

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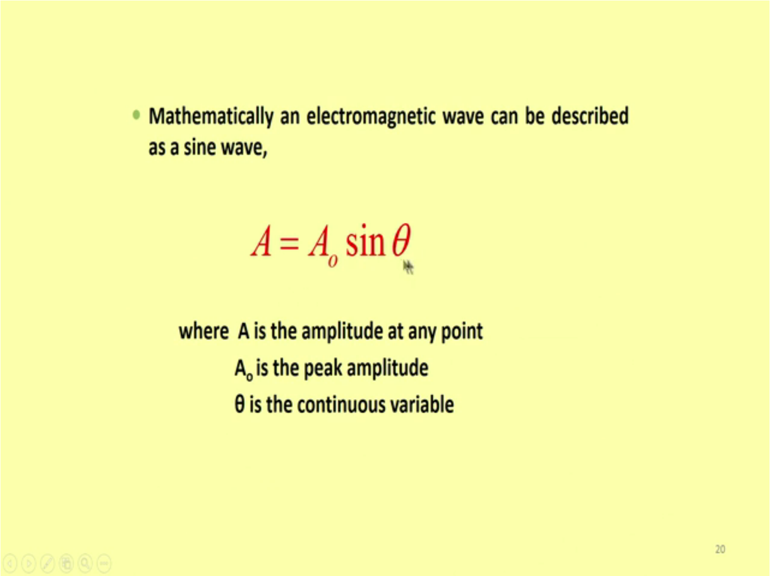

- Mathematically an electromagnetic wave can be described as a sine wave,

$$A = A_o \sin\theta$$

where A is the amplitude at any point

A_o is the peak amplitude

θ is the continuous variable

So, A is the amplitude, at any point A, 0 is the peak amplitude and theta is the continues variable. So, these are all basically physics, you would have studies in high school, in second year P U or something like that. So, I am only giving you some sort of an insight into these things, it is I am making a passing remark, just to refresh your memory.

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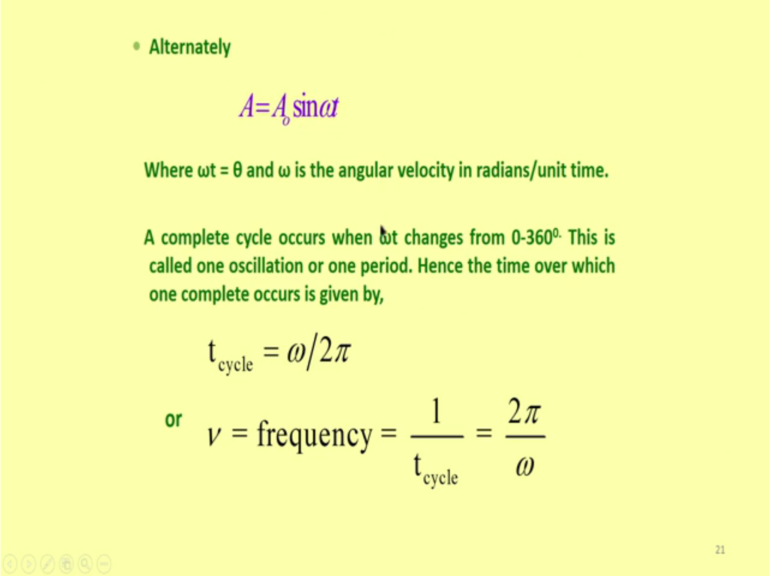

- Alternately

$$A = A_o \sin\omega t$$

Where $\omega t = \theta$ and ω is the angular velocity in radians/unit time.

A complete cycle occurs when ωt changes from $0\text{-}360^0$. This is called one oscillation or one period. Hence the time over which one complete occurs is given by,

$$t_{\text{cycle}} = \omega/2\pi$$

or

$$\nu = \text{frequency} = \frac{1}{t_{\text{cycle}}} = \frac{2\pi}{\omega}$$

So, alternately we can say A is equal to A0 into sin omega t. So, where omega t is nothing, but theta and omega is the angular velocity in radians per unit time. So, a complete cycle occurs when omega t changes from 0 to 360. That is understandable. So, after keeps on moving. So, when it starts moving after every 360 degrees, it comes back to 0 level, again 360 it will move, again 0 level it will come. So, 0 to 360 degrees is where the repetitive, repetition of the electromagnetic radiation occurs. So, the time over which one completely occur repetition is given by t cycle that is omega by 2 pi or frequency, what we do define now is; 1 over t cycles or 2 pi by omega.

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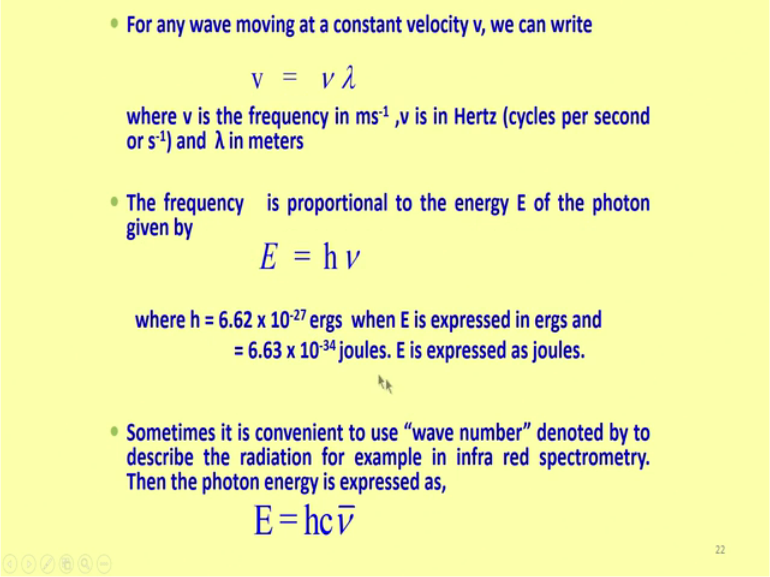

- For any wave moving at a constant velocity v, we can write

$$v = \nu \lambda$$

where v is the frequency in ms^{-1} ,v is in Hertz (cycles per second or s^{-1}) and λ in meters

- The frequency is proportional to the energy E of the photon given by

$$E = h\nu$$

where h = 6.62 x 10^{-27} ergs when E is expressed in ergs and = 6.63 x 10^{-34} joules. E is expressed as joules.

- Sometimes it is convenient to use "wave number" denoted by to describe the radiation for example in infra red spectrometry. Then the photon energy is expressed as,

$$E = hc\bar{\nu}$$

So, far any wave moving at a constant velocity V, we can write v is equal to v into lambda, where v is the frequency in milliseconds. Inverse V is in Hertz that is cycles per second and lambda is in meters, we can say meters, nanometers, whatever are the appropriate units. So, the frequency is proportional to the energy E of the photon as given by E is equal to h mu. So, sometimes it is convenient to use wave number, this also we have covered earlier and that is the wave number refers more to infrared radiation. We will study that sometime in the next course, with time permits.

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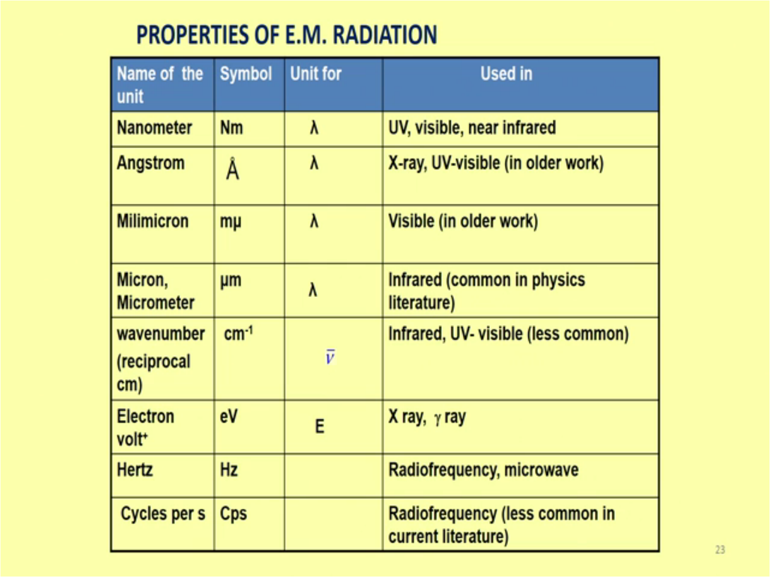

PROPERTIES OF E.M. RADIATION

Name of the unit	Symbol	Unit for	Used in
Nanometer	Nm	λ	UV, visible, near infrared
Angstrom	Å	λ	X-ray, UV-visible (in older work)
Milimicron	mμ	λ	Visible (in older work)
Micron, Micrometer	μm	λ	Infrared (common in physics literature)
wavenumber (reciprocal cm)	cm^{-1}	$\bar{\nu}$	Infrared, UV- visible (less common)
Electron volt^{+}	eV	E	X ray, γ ray
Hertz	Hz		Radiofrequency, microwave
Cycles per s	Cps		Radiofrequency (less common in current literature)

So, in general what I want to do now is; I want to give you units of electromagnetic radiation. For example, take a look at this nanometer is a unit for wavelength and it is used in U V visible, near infrared spectroscopy Armstrong's these X- ray and U V visible in older work they used to use U V visible, now a day we call it nanometers that are fair enough and mill microns again, it is in the visible range again not. So, popular now a days and microns and micrometer used in infrared wave number, again infrared and U V visible, it is less common in U V visible.

Similarly, electron volt that is for X- ray and Gamma rays, because they have lot a very high energy, it is better to define them by electrons volts. So, a Hertz radio frequency and microwave cycle per second cps is meant for radio frequency. So, these are the different kinds of units used in different spectroscopic techniques.

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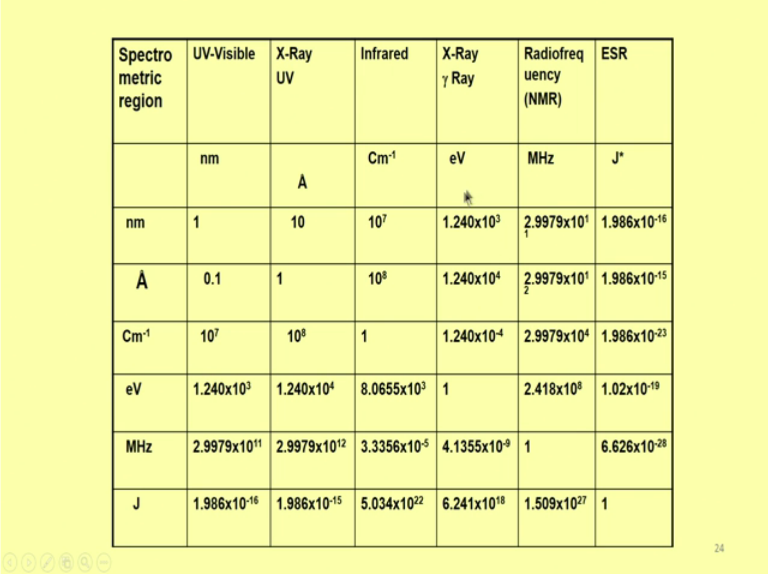

Spectro metric region	UV-Visible	X-Ray UV	Infrared	X-Ray γ Ray	Radiofrequency (NMR)	ESR
	nm	Å	Cm^{-1}	eV	MHz	J*
nm	1	10	10^{7}	1.240×10^{3}	2.9979×10^{1} 1	1.986×10^{-16}
Å	0.1	1	10^{8}	1.240×10^{4}	2.9979×10^{1} 2	1.986×10^{-15}
Cm^{-1}	10^{7}	10^{8}	1	1.240×10^{-4}	2.9979×10^{4}	1.986×10^{-23}
eV	1.240×10^{3}	1.240×10^{4}	8.0655×10^{3}	1	2.418×10^{8}	1.02×10^{-19}
MHz	2.9979×10^{11}	2.9979×10^{12}	3.3356×10^{-5}	4.1355×10^{-9}	1	6.626×10^{-28}
J	1.986×10^{-16}	1.986×10^{-15}	5.034×10^{22}	6.241×10^{18}	1.509×10^{27}	1

So, the inter connection of this is, all these wavelengths can be converted into one another and this table describes the inter convention of one unit to another of all electromagnetic radiations. You can study this and try to remember.

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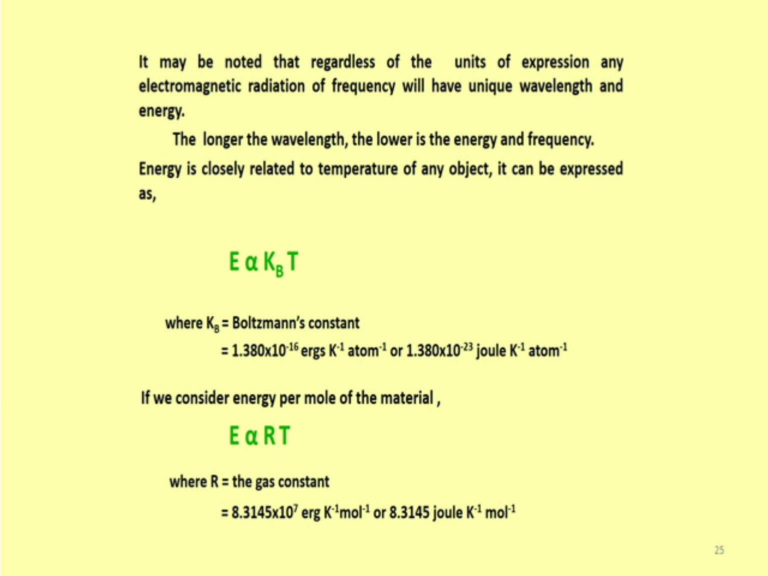

It may be noted that regardless of the units of expression any electromagnetic radiation of frequency will have unique wavelength and energy.

The longer the wavelength, the lower is the energy and frequency.

Energy is closely related to temperature of any object, it can be expressed as,

$$E \propto K_B T$$

where K_B = Boltzmann's constant

= 1.380×10^{-16} ergs K^{-1} atom^{-1} or 1.380×10^{-23} joule K^{-1} atom^{-1}

If we consider energy per mole of the material ,

$$E \propto RT$$

where R = the gas constant

= 8.3145×10^{7} erg K^{-1}mol^{-1} or 8.3145 joule K^{-1} mol^{-1}

It may be noted and that regardless of the units of expression any electromagnetic radiation or frequency will have unique wavelength and energy. So, the longer the wavelength, lower is the energy and frequency energy is closely related to the temperature of any of the object. It can be expressed as E is proportional to K B into T, where K B is the bolds man constant that corresponds to 1.380 into 10 raise to minus 16 ergs per K, per degree, per atom or 1.380 into 10 raise to minus 20, there joules per degree, per tom atmosphere. So, if we consider the energy per molecule of the material E is proportional to R T that is R is the gas, constant given by this number 8.3145 into 10 raise to 7 and you can also write the same thing in joules.

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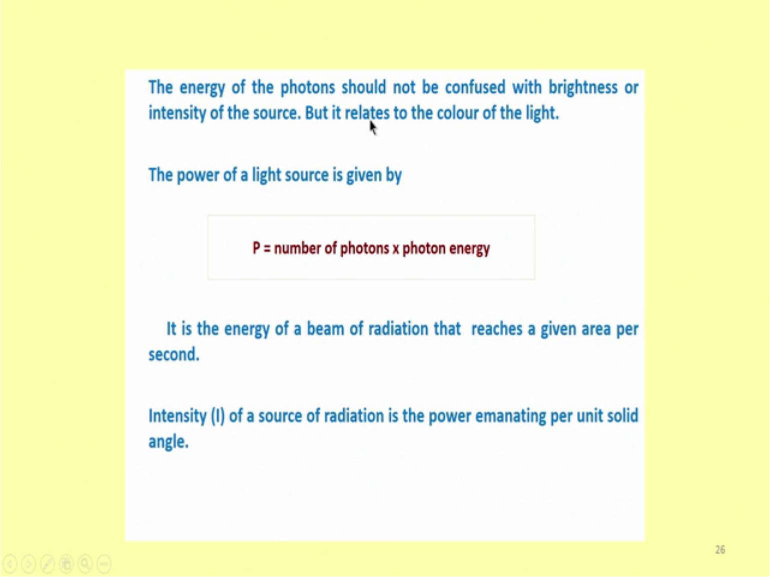

The energy of the photons should not be confused with brightness or intensity of the source. But it relates to the colour of the light.

The power of a light source is given by

P = number of photons x photon energy

It is the energy of a beam of radiation that reaches a given area per second.

Intensity (I) of a source of radiation is the power emanating per unit solid angle.

So, the energy of the photon should not be confused with the brightness. So, this is a very important concept, again is brightness intensity of this has nothing to do with the energy of the photons, but it relates to the color of the light, that is for sure. So, the power of a light source is given by P is equal to number of photons multiplied by the photonic energy. It is the energy of a beam of radiation that reaches a given area per second. So, if I give you a small light source like a torch, the energy that falls when I project it on the screen, it reaches a given area per second.

So, intensity of the source of radiation is the power emanating per unit solid angle. So, these are all basically physics concepts, you can refresh your memory later. So, this is the electromagnetic radiation.

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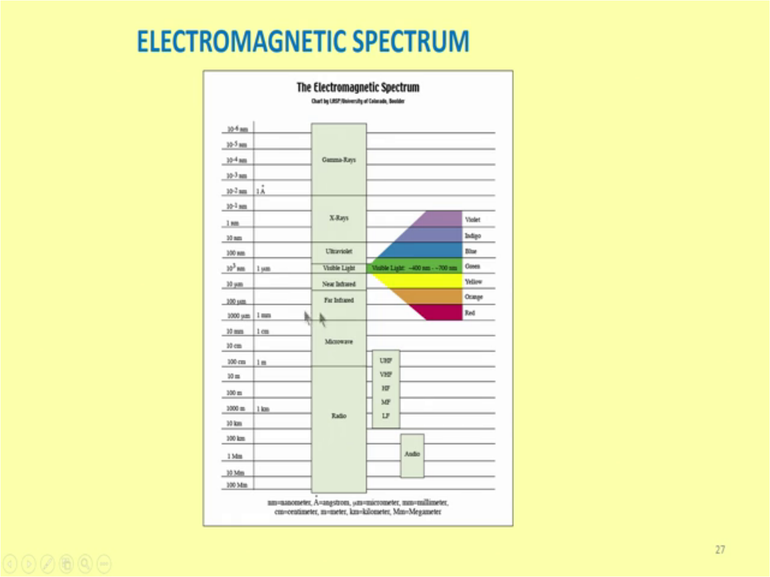

ELECTROMAGNETIC SPECTRUM

We have already seen another type of presentation in terms of frequency wavelength, etcetera and as we can see here, the color visible portion is only a small portion of this. So, remaining all are UV visible I R micro wave, radio waves etcetera.

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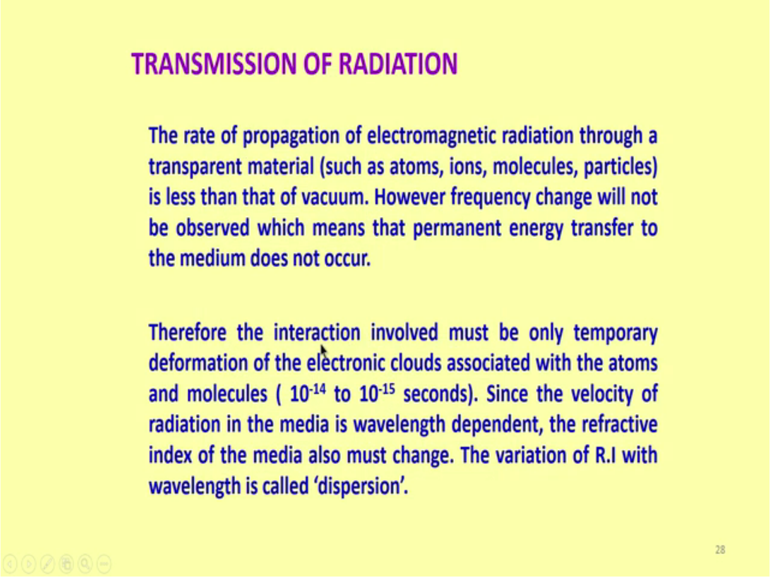

TRANSMISSION OF RADIATION

The rate of propagation of electromagnetic radiation through a transparent material (such as atoms, ions, molecules, particles) is less than that of vacuum. However frequency change will not be observed which means that permanent energy transfer to the medium does not occur.

Therefore the interaction involved must be only temporary deformation of the electronic clouds associated with the atoms and molecules (10^{-14} to 10^{-15} seconds). Since the velocity of radiation in the media is wavelength dependent, the refractive index of the media also must change. The variation of R.I with wavelength is called 'dispersion'.

So, now we will discuss about the transmission of radiation. So, the rate of propagation of electromagnetic radiation, we will spend the next half an hour studying that.