



SPECTROSCOPY

Presented By

**Dr. T. VARAPRASAD.M.Sc.,M.Ed.,M.Phil.,P.hD
LECTURER IN CHEMISTRY
HEAD OF THE DEPARTMENT
DEPARTMENT OF CHEMISTRY
P.R.GOVERNMENT COLLEGE(A),KAKINADA**

Synopsis

- What is Spectroscopy?
- Interaction of EMR with Matter
- Classification of Spectroscopy
- UV-Visible Spectroscopy
- ✓ Principle
- ✓ Types of Electronic Transitions
- ✓ Beer-Lamberts Law
- ✓ Instrumentation
- ✓ Applications
- ✓ Wood-Word Fieser Rules
- ✓ Question Bank

What is spectroscopy?

Spectrum + Scopies

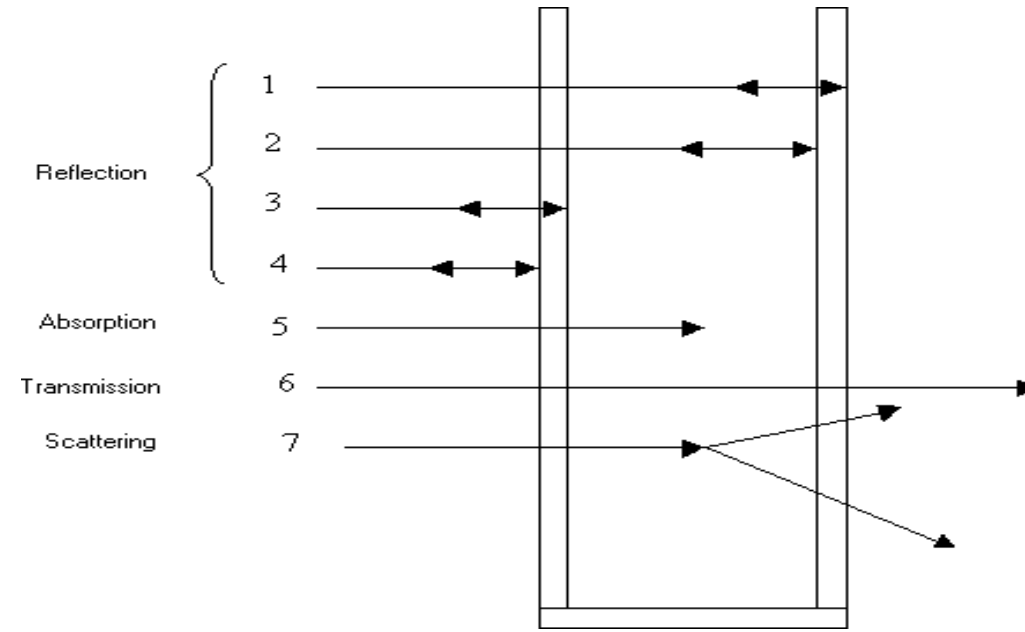
“When a beam of light is allowed to pass through a prism or grating, it will dispersed into seven colors from red to violet and the set of colors or band produced is called spectrum” + Examination

“Spectroscopy is the branch of the science dealt with the study of interaction of **Electro Magnetic Radiation (EMR)** with matter”

So the spectroscopy means examination of spectrum.

From the type of radiation, which is absorbed, we can get idea about the nature (type) of the compound and From the amount of the radiation which is absorbed, we can get idea about the concentration (amount) of the substance. So the spectroscopy is used for qualitative and quantitative analysis.

Interaction of EMR with matter



When a beam of light is passed through a transparent cell containing a solution of an absorbing substance, reduction of the intensity of the light may occur.

This is due to

- 1) Reflection at the inner and outer surfaces of the cell
- 2) Scattered by the particles present in the solution
- 3) Absorption of the light by the molecules in the solution

Classification of Spectroscopy:

1) Absorption Spectroscopy: the type and amount of the radiation, which is absorbed depend upon the structure of the molecules and the numbers of molecules interacting with the radiation. The study of these dependencies is called absorption spectroscopy. (UV, IR, NMR, X-Ray, ESR)

2) Emission spectroscopy: if sufficient energy gets impinged upon a sample, the outer electrons in the species will be raised from their stable ground state to higher energy level (unstable in nature). These excited species rapidly emits a photon and return to their ground stable energy level. The type and amount of radiation, which is emitted, is studied, this type of spectroscopy is called emission spectroscopy. (AES, MES, Fluorimetry)

3) Scattering spectroscopy: if the incoming radiation strikes with the solid particles suspended in the solution, the light transmitted at an angle other than 180° from the incident light. This spectroscopy is called scattering spectroscopy. (turbidimetry, nephelometry)

More Complex Electronic Processes

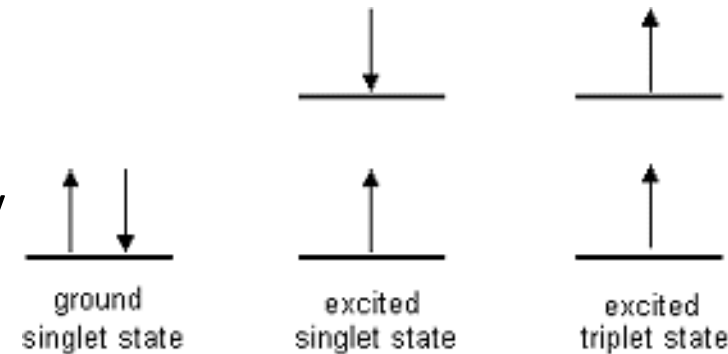
- **Fluorescence:**

absorption of radiation to an excited state, followed by emission of radiation to a lower state of the same multiplicity

- **Phosphorescence:** absorption of radiation to an excited state, followed by emission of radiation to a lower state of different multiplicity

- **Singlet state:** spins are paired, no net angular momentum (and no net magnetic field)

- **Triplet state:** spins are unpaired, net angular momentum (and net magnetic field)



What is EMR?

-EMR is a form of energy that is transmitted through space at an enormous velocity

- It can travel in space with the same speed as that of light. As the name implies an EMR is an alternating electrical and associated magnetic force field in space (It contains electrical and magnetic components)

-The two components oscillate in planes perpendicular to each other and perpendicular to the direction of propagation of the radiation.

-EMR consist of a stream of discrete packets (particles) of pure energy, which is called photons or quanta.

-The energy of photon is proportional to the frequency

$E = hu$ where E = Energy of photons, h = plank's constant (6.624×10^{-27} erg. Sec) and u =frequency of radiation in cycles/second

-Wavelength (λ): it is the distance between two successive maxima on an electromagnetic wave. (m, cm, mm, μm , nm, and A^0)

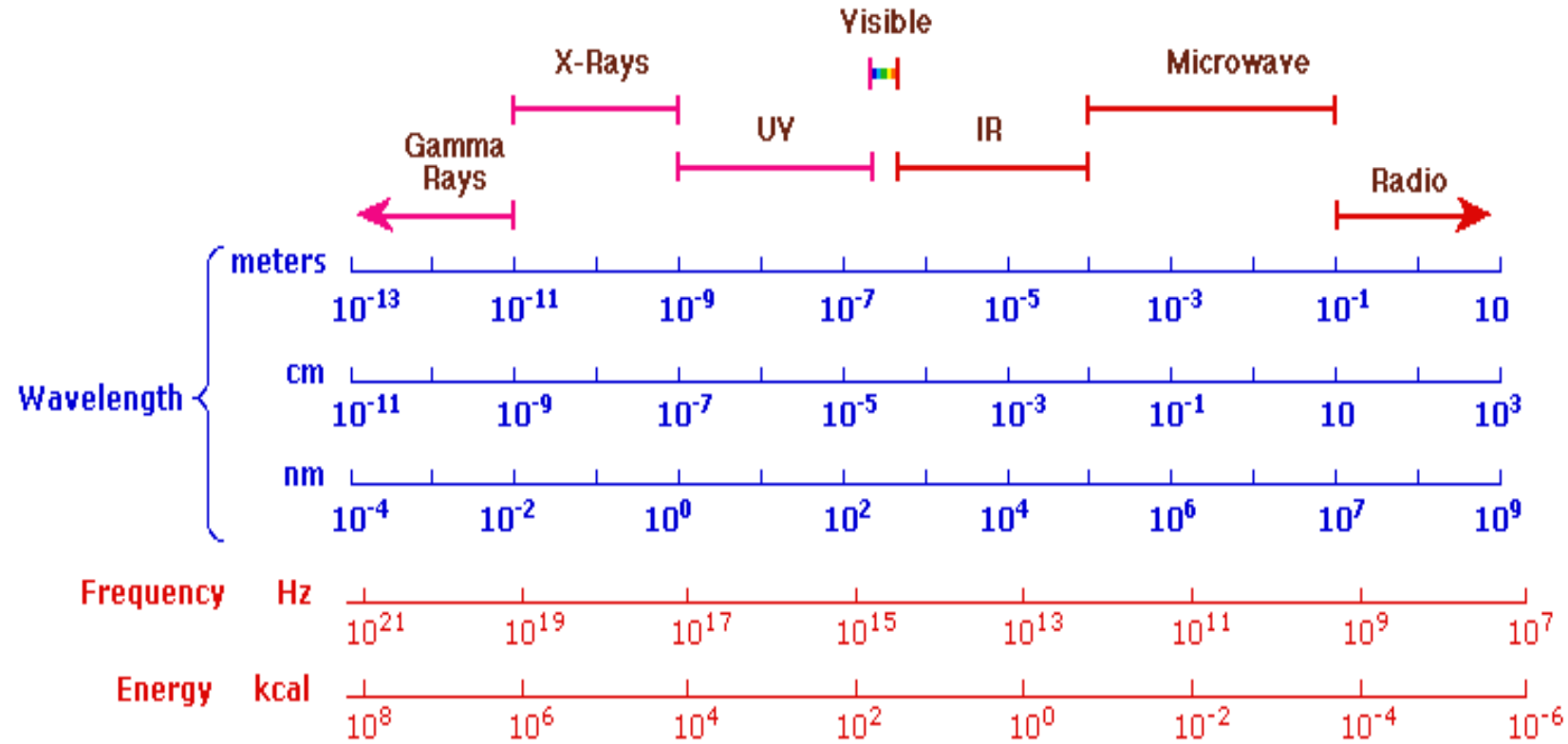
-Frequency (ν): is the numbers of waves passing through a given point in unit time. (T^{-1} , sec^{-1} , cycles/second, hertz, fresnel)

-Wave numbers ($\tilde{\nu}$): is the numbers of waves per centimeter in vacuum. (cm^{-1})

-Velocity (V): is the product of wavelength and frequency ($\lambda \times \nu = V$) (cm/sec, m/sec)

Classification of EMR: EMR is arbitrarily classified into different regions according to wavelength.

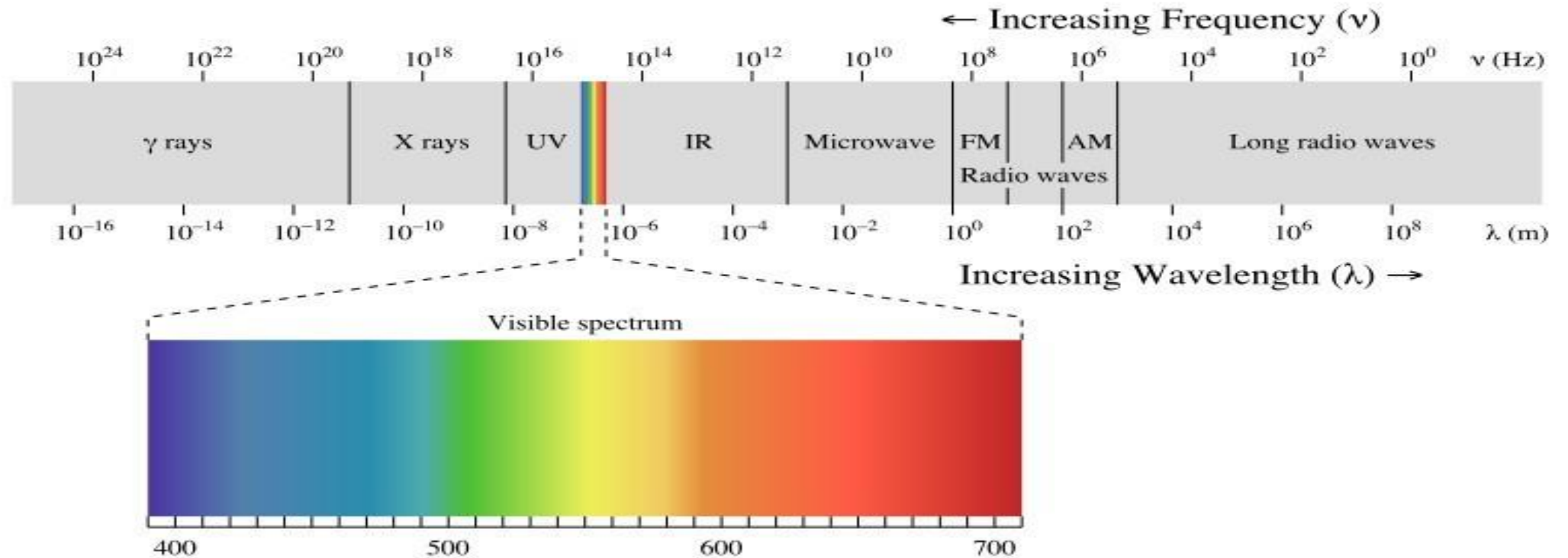
The Electromagnetic Spectrum



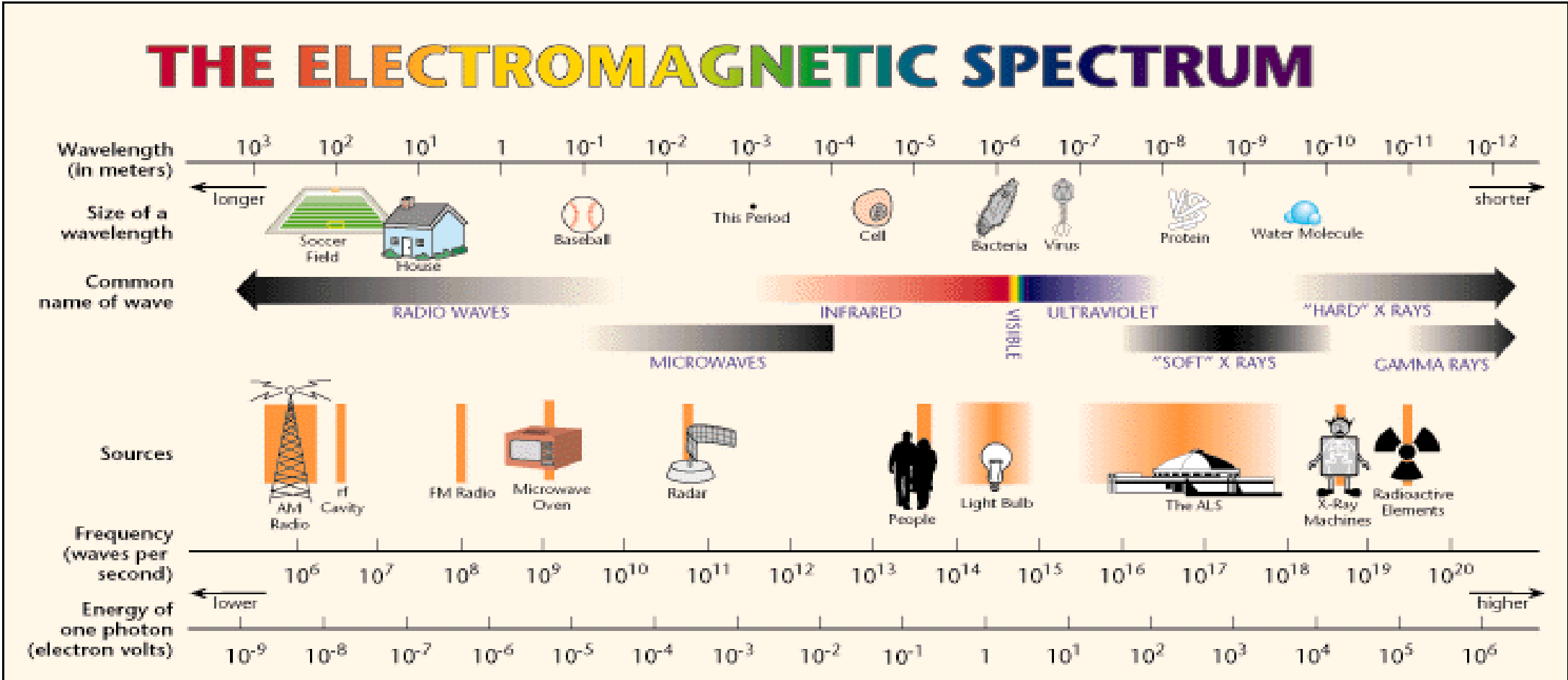
Spectroscopy: A technique of producing, detecting and analyzing spectra of electromagnetic radiation

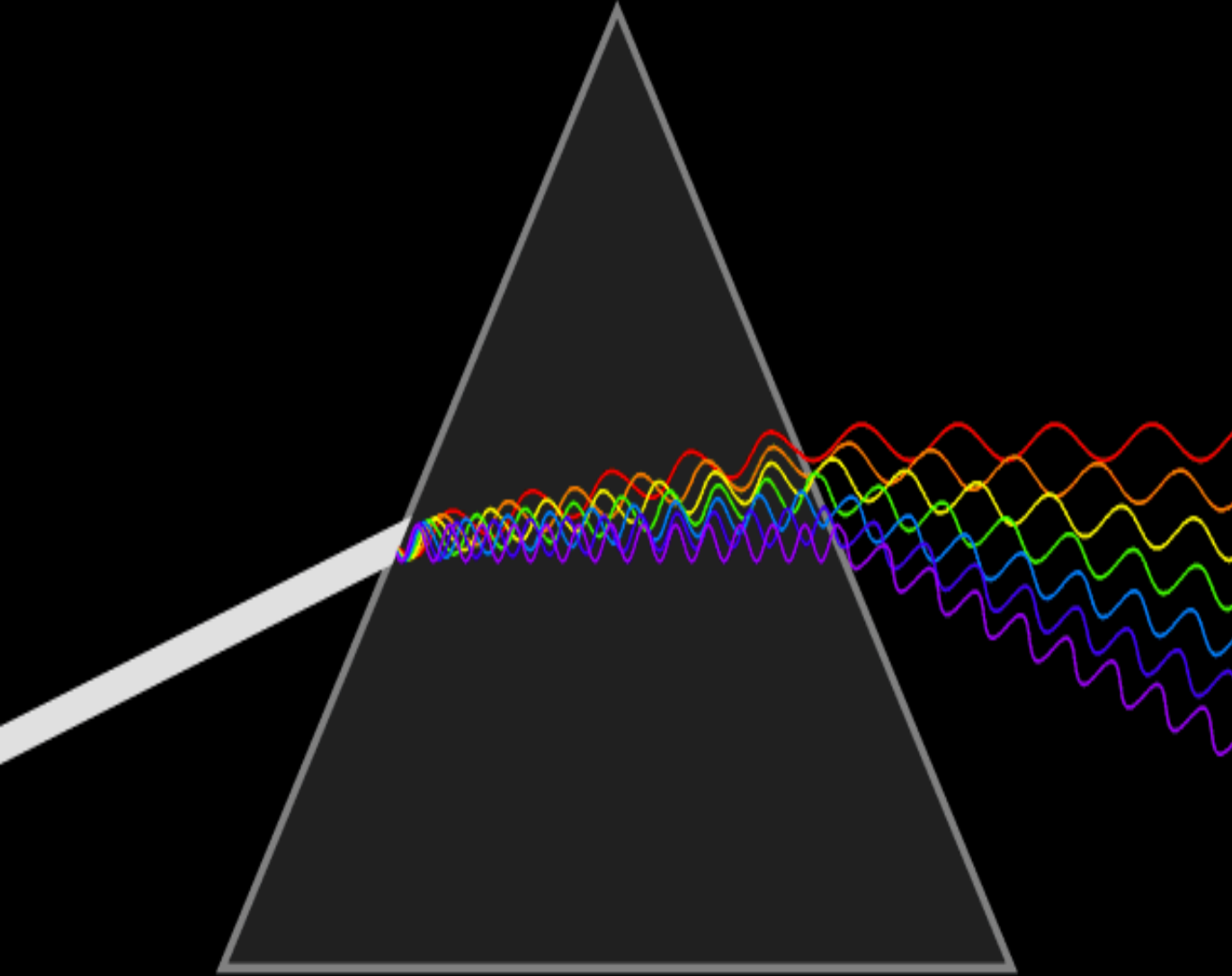
Self-propagating waves in vacuum or in matter whose spectrum will have a range of wavelength from 10^{-3}m to 10^3m

Can be classified into several types depending on the wavelength of the wave



Where in the spectrum are these transitions?

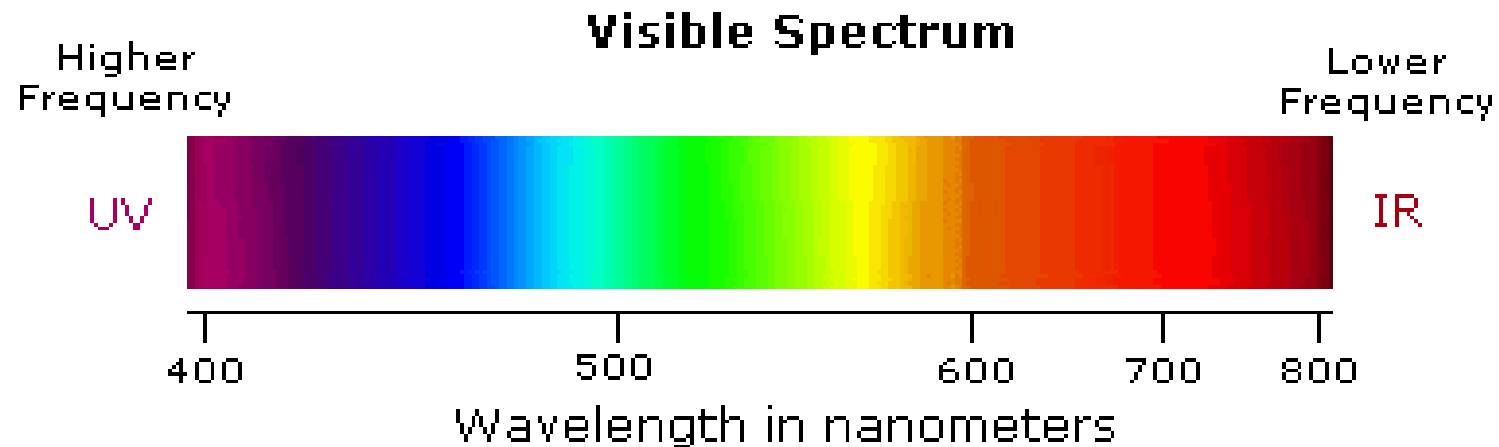
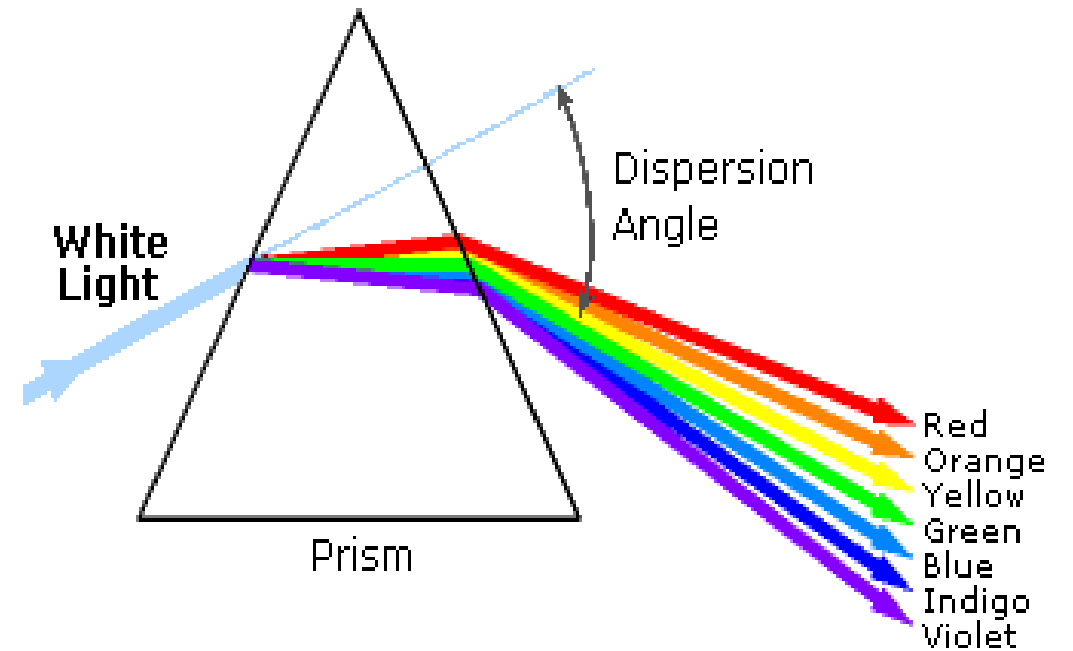




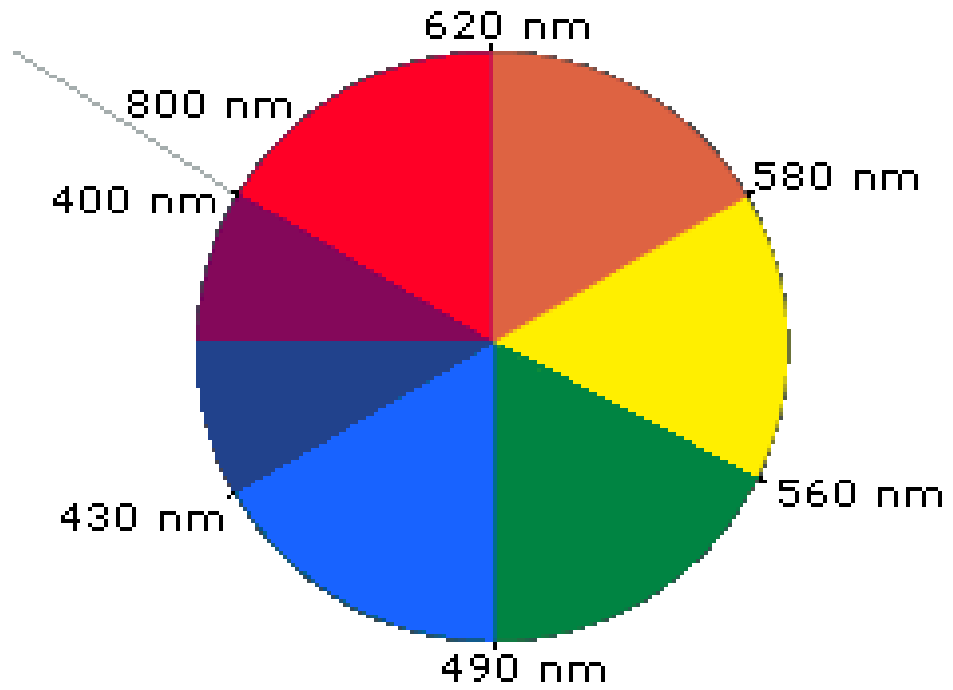
UV-Visible Spectroscopy

UV-Visible Spectroscopy

- ♠ The wavelength range of UV radiation is from 200nm – 400nm.
- ♠ The wavelength range of Visible radiation is from 400nm – 800nm



- Violet: 400 - 420 nm
- Indigo: 420 - 440 nm
- Blue: 440 - 490 nm
- Green: 490 - 570 nm
- Yellow: 570 - 585 nm
- Orange: 585 - 620 nm
- Red: 620 - 780 nm



Energy associated with the molecules:

1)The molecule as a whole may move this is called translation and the energy associated with this movement is called translational energy. (E_{trans})

2)The part of the molecules, that is atom or groups of atoms, may move with respect to each other. This motion is called vibration and the associated energy is called vibrational energy. (E_{vib})

3)The molecule may rotate about an axis. And such rotation is characterized by the rotational energy. (E_{rot})

4)Besides these modes of movements, the molecule possesses an electronic configuration and the energy associated with this configuration is called electronic energy. (E_{ele})

$E_{\text{total}} = E_{\text{trans}} + E_{\text{vib}} + E_{\text{rot}} + E_{\text{ele}}$.

Theoretical principles

If a molecule is allowed to interact with the EMR of a proper frequency, the energy of the molecule is raised from one level to a higher one; we say that absorption of radiation takes place. In order for absorption to occur, the energy difference between the two energy level must be equal to the energy of the photon absorbed $E_2 - E_1 = h\nu$ where E_1 is energy of lower level and E_2 is the energy of upper level

- This energy jump from one level to another is called transition
- The graph of the light absorption against the frequency is called absorption spectra.
- Visible and Ultraviolet light provides enough energy for electronic transition there for called electronic spectra.

The range is from 10^{-3}m to 10^3m

This range will be associated with range of energy

$$E = hc / \lambda ,$$

$$c = \sim 300,000,000 \text{ m s}^{-1}$$

$$h = 6.626 \times 10^{-34} \text{ J s (Planck's Constant)}$$

High Wave length

Short Energy

Low wave length

High Energy

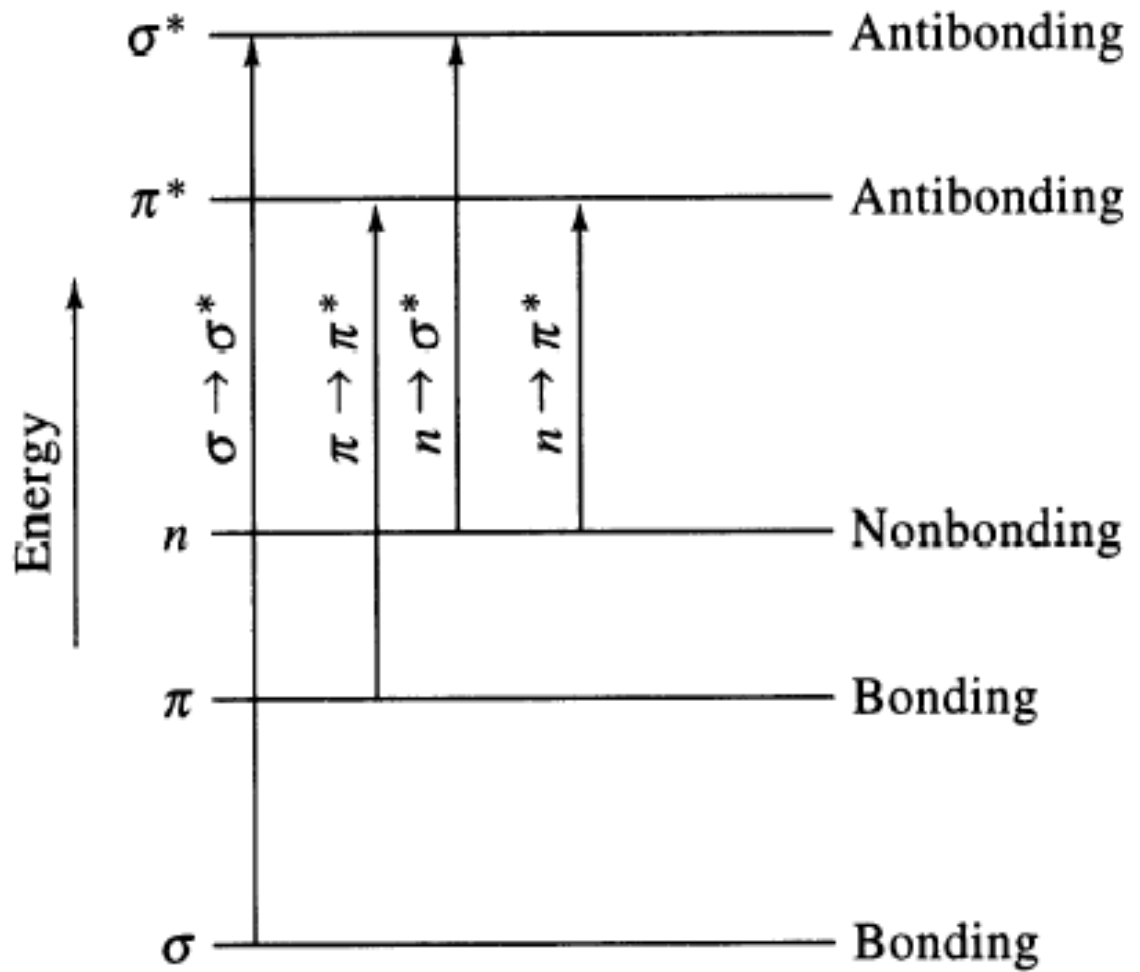
Types of transitions:

1) $\sigma \rightarrow \sigma^*$: A transition of electrons from a bonding sigma orbital to the higher energy antibonding orbitals. (eg. Alkane). Sigma bonds are, in general, very strong, therefore they require high energy for the transitions and this transition requires very short wavelength (near about 150 nm)

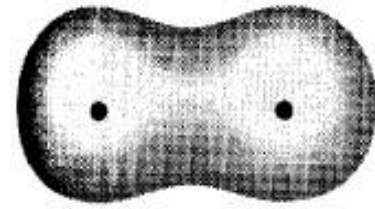
2) $n \rightarrow \sigma^*$: This transition involves saturated compounds with one hetero atom with unshared pair of electrons (n electrons). Corresponding band appears at 180-200 nm.

3) $\pi \rightarrow \pi^*$: This transition is available in compounds with unsaturation (eg. Alkene). Corresponding band appears at 170-190 nm.

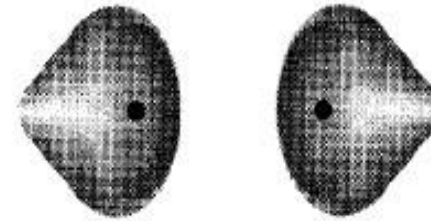
4) $n \rightarrow \pi^*$: This type of transitions are shown by the unsaturated molecules containing one or more hetero atoms. (O, N, S)



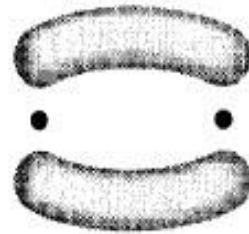
Sigma and Pi orbitals



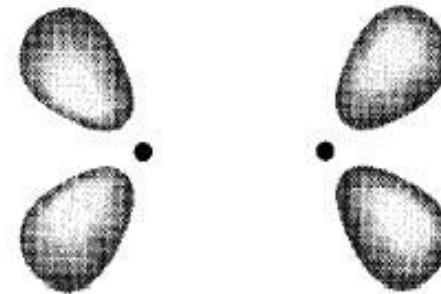
(a) σ orbital



(c) σ^* orbital



(b) π orbital



(d) π^* orbital

Chromophore	Example	Excitation	λ_{\max} , nm	ϵ	Solvent
C=C	Ethene	$\pi \rightarrow \pi^*$	171	15,000	hexane
C \equiv C	1-Hexyne	$\pi \rightarrow \pi^*$	180	10,000	hexane
C=O	Ethanal	$n \rightarrow \pi^*$	290	15	hexane
		$\pi \rightarrow \pi^*$	180	10,000	hexane
N=O	Nitromethane	$n \rightarrow \pi^*$	275	17	ethanol
		$\pi \rightarrow \pi^*$	200	5,000	ethanol
C-X	Methyl bromide	$n \rightarrow \sigma^*$	205	200	hexane
	Methyl Iodide	$n \rightarrow \sigma^*$	255	360	hexane

Solvents for UV (showing high energy cutoffs)

Water	205	THF	220
$\text{CH}_3\text{C}\equiv\text{N}$	210	CH_2Cl_2	235
C_6H_{12}	210	CHCl_3	245
Ether	210	CCl_4	265
EtOH	210	benzene	280
Hexane	210	Acetone	300
MeOH	210	Various buffers for HPLC, check before using.	
Dioxane	220		

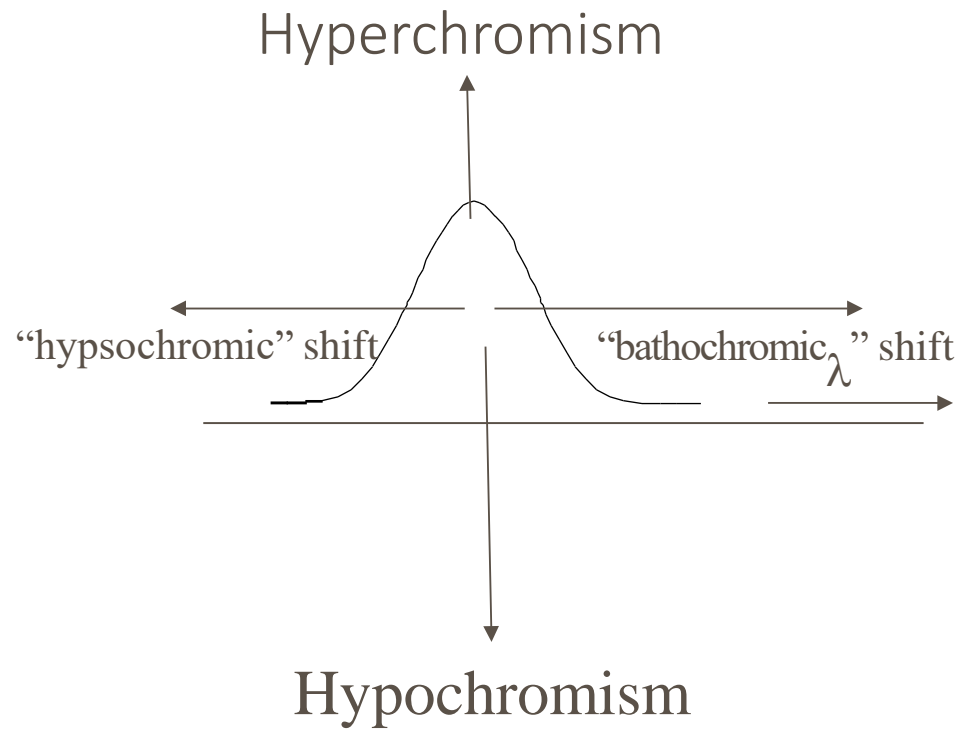
Some important terms:

1) Chromophore: It is a group of molecules, which is responsible for the absorption of light by molecules. It is conjugated dienes. It is minimum structural requirements for the absorption of radiation in UV range. E.g., $-\text{NO}_2$, $-\text{N}=\text{N}$, $-\text{C}=\text{C}-\text{C}=\text{C}-$

2) Auxochrome: It is a saturated group containing unshared electrons which when attached to a Chromophore changes both intensity as well as the wavelength of the absorption maxima. e.g. OH, NH₂, Cl etc.

3) λ -max: It is a wavelength at which there is a maximum absorption or absorption intensity. It is a physical constant and characteristic of structure and so useful for identification of compounds. It is independent of concentration.

4) Bathochromic shift: The shifting of absorption to a longer wavelength due to substitution or solvent is called as bathochromic shift. It is also called as Red shift. e.g., λ_{max} of Ascorbic acid=243nm, λ_{max} of Ascorbic acid in alkali medium=299nm.



5) Hypsochromic shift (Blue shift): Shifting of λ_{\max} to lower value or left hand side due to substitution, solvent, pH etc is called as Hypsochromic shift. e.g. λ_{\max} of Phenol in basic

media=297nm, λ_{\max} of Phenol in acidic media=277nm.

6) Hyperchromism: Increase in absorption intensity (ϵ) due to solvent, pH or some other factors called hyperchromic effect.

7) Hypochromism : Decrease in absorption intensity due to substituent, solvent, pH etc. called hypochromic effect.

8) (A one percent one centimeter): Is the

absorbance of the solution having concentration 1 gm per 100 ml of the solution and 1cm path length.

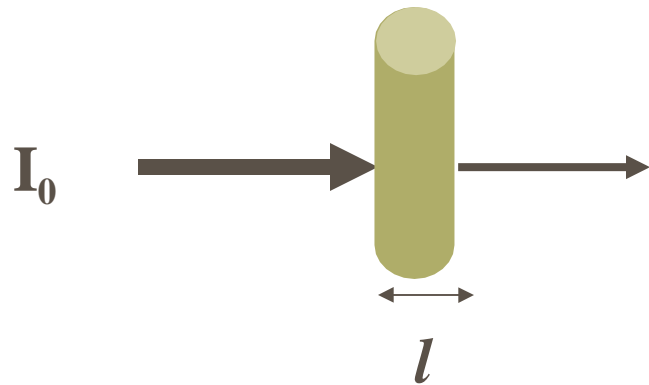
9) Molar absorptivity (ϵ): Is the absorbance of the solution having concentration gm.mol.weight/1000 ml of the solution. [$\epsilon = (A^{1\%}_{1\text{cm}} \times \text{Mol. Wt.})/10$].

BEER'S – LAMBERTS Law

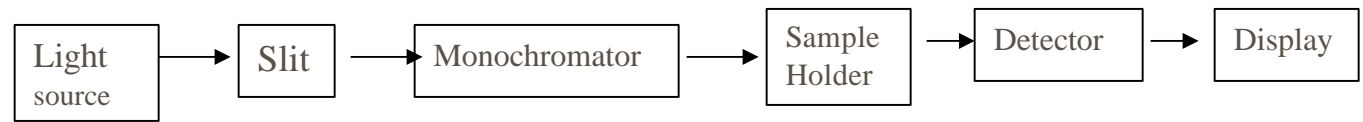
1) **Thickness of the medium**: Lambert's law: “when a beam of monochromatic light is allowed to pass through a transparent medium, the rate of decrease of intensity with the thickness of medium is directly proportional to the intensity of incident radiation”. It gives relationship between absorbance and the thickness of the medium.

2) **Concentration of absorbing solute**: Beer's law: “when a beam of monochromatic light is allowed to pass through a transparent medium, the rate of decrease of intensity with the concentration of absorbing solute is directly proportional to the intensity of incident radiation”. It gives relationship between absorbance and the concentration of the medium.

$$A = a b c \text{ (Fundamental equations of spectroscopy)}$$



INSTRUMENTATION



Transmittance, $T = I / I_0$

Absorbance, $A = -\log_{10} I / I_0$

$$= -\log_{10} T$$

$$= \log_{10} I_0 / I$$

1) **Light Source: (source of electromagnetic radiation):**

The tungsten filament lamp is a satisfactory light source for the region 350 to 2000 nm.

It consists of a tungsten filament contained in a glass envelope. The most convenient light source for UV radiation is discharge lamp.

Generally deuterium discharge lamp is used.

It is consisting of deuterium-filled silica envelope. It gives radiation from 185 to 380 nm.

2) Slit: (Radiation intensity controlling device):

Enough light must pass through the sample to elicit a measurable response from the detector.

3) Monochromator: (wavelength selecting device).

It converts polychromatic light in monochromatic light (light having one wavelength).

a) Filters:

Glass filters are pieces of colored glass, which transmit limited wavelength ranges of the spectrum. The color is produced by incorporating oxides of such metals.

b) Prisms:

When a beam of light passes through a prism, it is bent or refracted. The amount of deviation is dependent on the wavelength.

The prism is made up of quartz for use in the UV light, since glass absorbs wavelengths shorter than about 330 nm.

Glass prism are preferable for the visible region of the spectrum, as the dispersion is much greater than that obtained with quartz.

c) Grating:

Most modern UV spectrophotometer uses diffraction grating as a Monochromator. It consisting of a very large number of equispaced lines (200-2000 per mm) ruled on a glass plate.

They can be used either as transmission grating or when aluminized, as reflection grating.

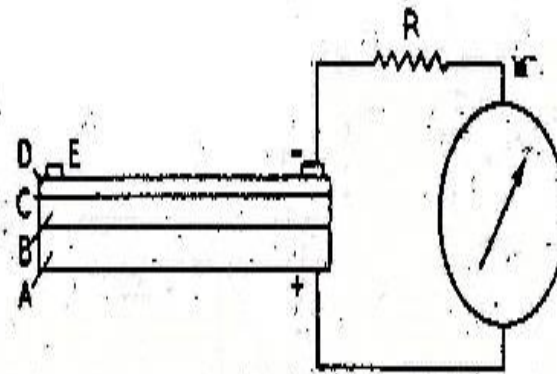
4) Sample Holder:

The sample holder is known as cuvettes. Cuvettes must be transparent to the light, so the glass cells are used in the visible region and quartz or silica cells are used in the UV region. The cells used in the UV spectrophotometers are usually 1 cm in path length but cells are available from 0.1 cm to 10 cm or more.

5) Detectors (Radiation measuring device):

It is also known as photocell. They convert radiation energy in electrical energy. For the determination of substances by spectrophotometric techniques, precise determinations of the light intensities are necessary. Photoelectric detectors are most frequently used for this purpose. They must be employed in such a way that they give a response linearly proportional to the light input and they must not suffer from drift or fatigue.

a) Barrier-layer photoce^{ll}.



Barrier-layer cell and circuit. A, metal base-plate; B, selenium layer; C, theoretical barrier-layer; D, transparent metal layer; E, collecting ring; R, external resistance

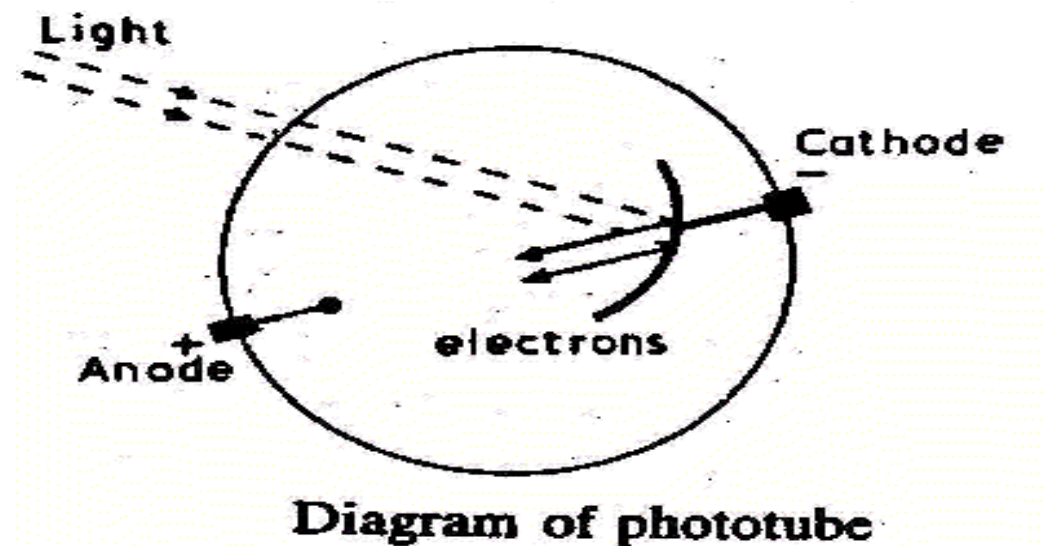
It one of the simplest detectors, which has the advantage that it requires no power supply but gives a current, which is directly proportional to the light intensity. It consists of a metallic plate, usually copper or iron, upon which is deposited a layer of selenium.

An extremely thin transparent layer of a good conducting metal, e.g. silver, platinum or copper, is formed over the selenium to act as one electrode, the metallic plate acting as the other. Light passes through the semitransparent silver layer causes release of an electron, which migrates, to the collector.

The electron accumulating on the collector resulting in a potential difference between the base and collector, which can be measured by a low resistance galvanometer circuit.

The useful working range of selenium photocell is 380-780 nm. Their lack of sensitivity compared to phototube and photo multiplier tube, restricts their use to the cheapest colorimeters and flame photometers.

b) Photo emissive tube:



It consists of an anode and a cathode sealed in an evacuated glass tube, which may have a quartz or silica window for UV measurement.

The cathode is coated with a layer of light sensitive material that emits electrons upon absorption of photons.

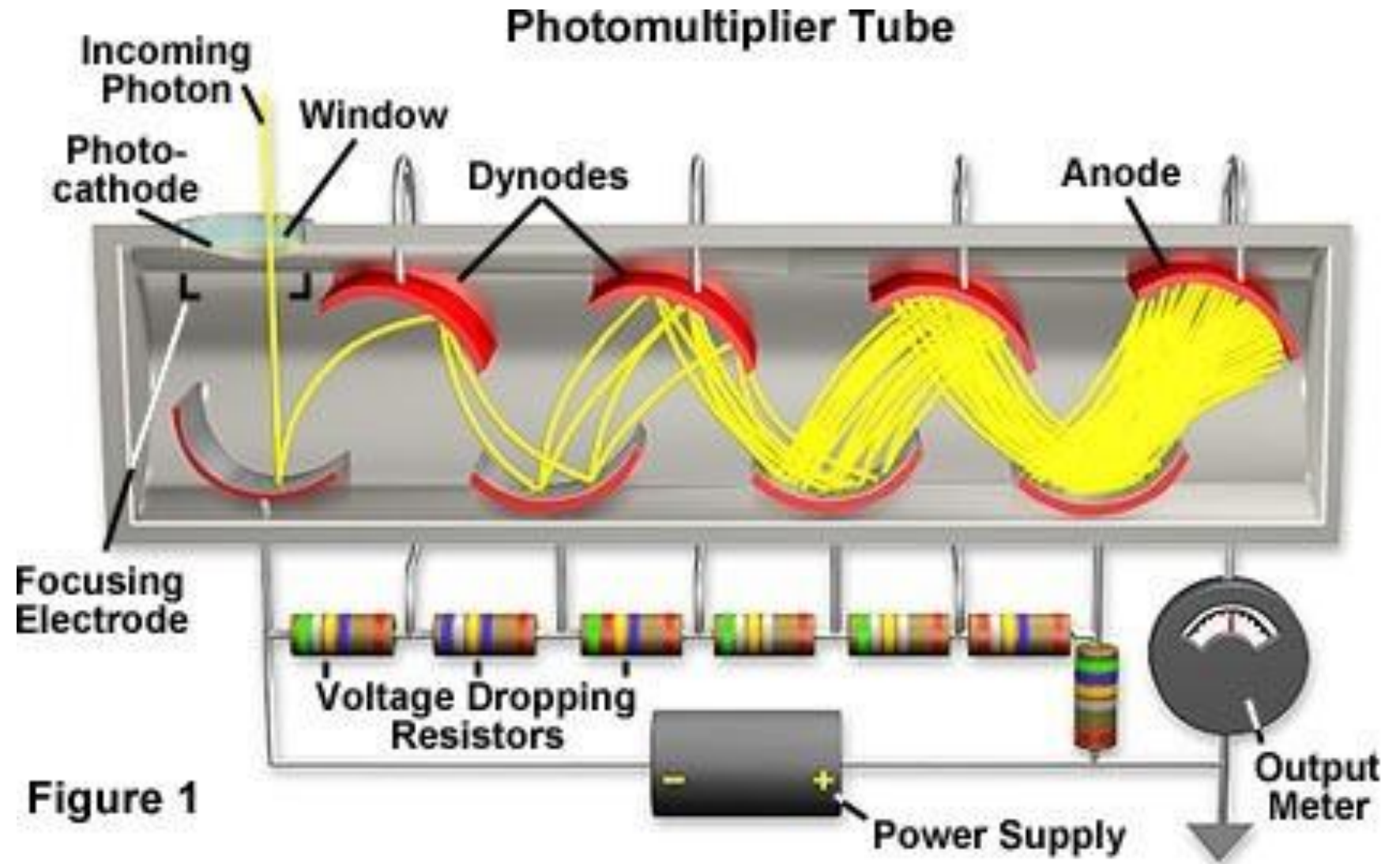
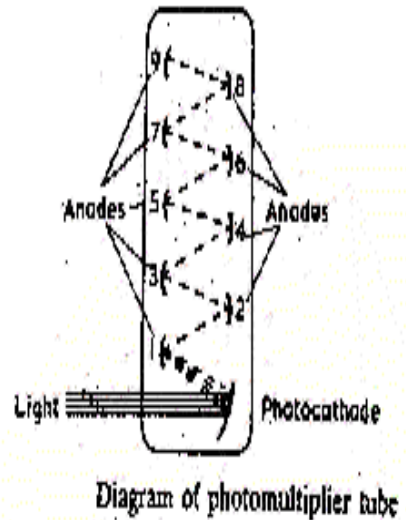
A power supply maintains the anode positive with respect to the cathode so that the photoelectrons are collected at the anode.

This current is directly proportional to the light intensity. Phototubes are available for use over the entire UV/visible region of the spectrum, but no single tube covers the entire range satisfactorily.

Therefore many instruments with phototube detectors employ interchangeable blue and red sensitive phototube in order to provide sufficient sensitivity over the entire spectrum.

c) Photo multiplier tube:

It is very sensitive detectors with very short response times. It contains a photo cathode and a series of dynodes, which are also photosensitive.

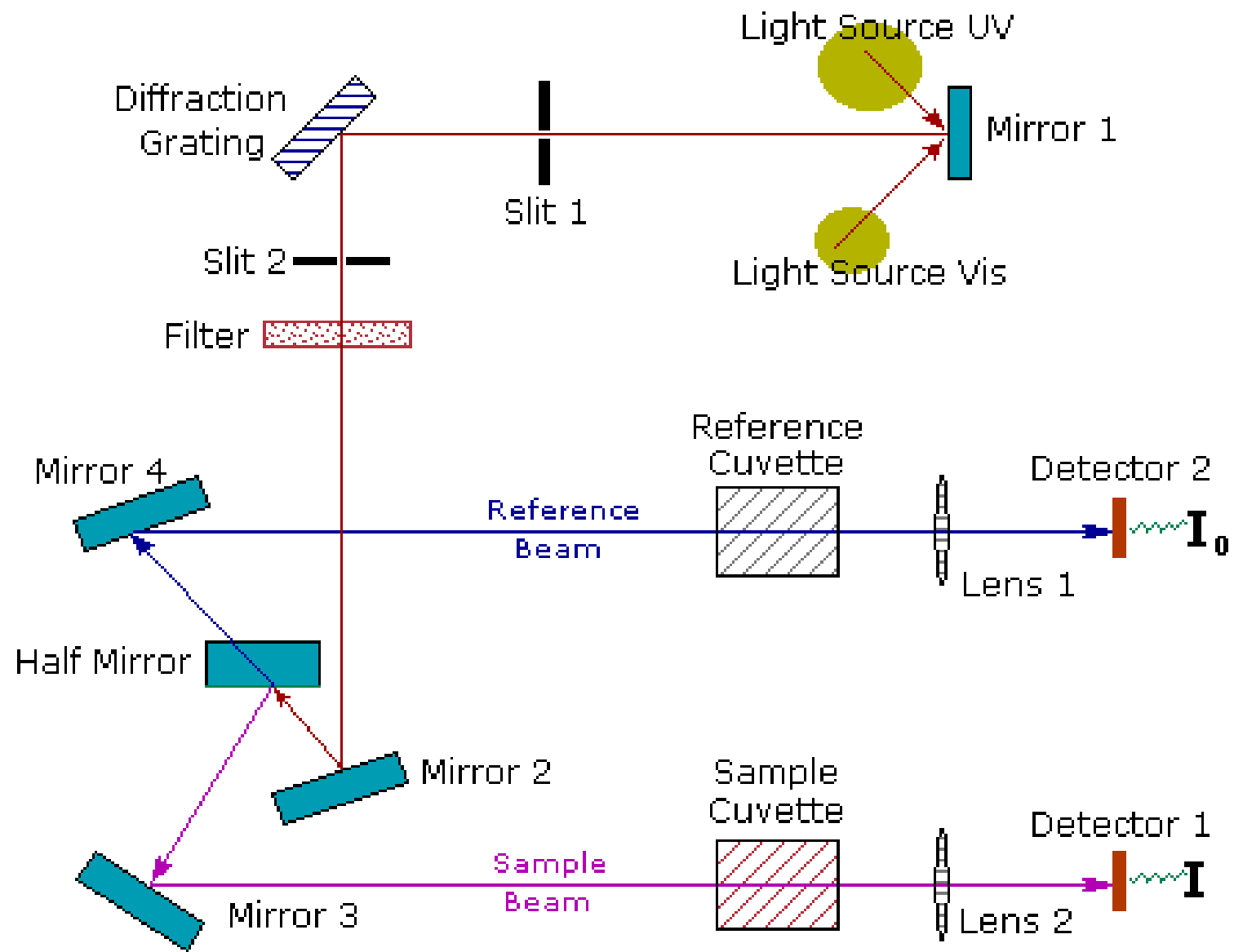


A higher successive potential is maintained between each dynodes.

A photoelectrons released from the photo cathode is accelerated toward the first dynode by their voltage difference, where it strikes to release several electrons.

The secondary electrons are then accelerated toward the second dynode where the process repeats. In this way multiplication of the electrons can be achieved.

The current from phototubes and photo multiplier tubes never falls to zero. A small residual current called dark current is produced, due to long exposure of the light.



APPLICATIONS:

1. Qualitative Analysis:

The UV spectra of most compounds are of limited value for qualitative analysis as compared to IR and Mass spectra. Qualitative analytical use of UV spectra has largely involved λ -max and absorptivities, occasionally includes absorption minima. In pharmacopoeias, absorption ratios have found use in identity tests, and are referred to as Q-values in USP.

2. Quantitative Analysis:

UV spectroscopy is perhaps the most widely used spectroscopic techniques for the quantitative analysis of chemical substances as pure materials and as components of dosage forms.

Why should we learn this stuff?

After all, nobody solves structures with UV any longer!

Many organic molecules have chromophores that absorb UV

UV absorbance is about 1000 x easier to detect per mole than NMR

Still used in following reactions where the chromophore changes. Useful because timescale is so fast, and sensitivity so high. Kinetics, esp. in biochemistry, enzymology.

Most quantitative Analytical chemistry in organic chemistry is conducted using HPLC with UV detectors
One wavelength may not be the best for all compound in a mixture. Affects quantitative interpretation of HPLC peak heights

1) Structural Elucidation

Detection of conjugation

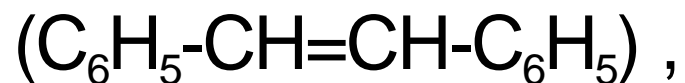
- ♠ It helps to show the relationships between different groups, particularly with respect to conjugation.
- ♠ The conjugation may be
 - Between two or more C-C double/triple bonds.
 - Between C=C or C=O double bonds. Between double bond and aromatic ring.
- ♠ From the spectra the presence of an aromatic ring and its number can be revealed.
- ♠ Locations of substituents attached to the C atom in the conjugation system can also be revealed.

2) Detection of Geometrical Isomers

- ♠ In case of geometrically isomeric compounds, the *trans* isomers exhibit λ_{\max} at slightly longer wavelength than *cis* isomers.
- ♠ Also, *trans* isomers will possess larger extinction coefficients than *cis* isomers.

♠ For example,

Of the two Stilbenes



	λ_{\max}	ϵ
Trans isomer	294 nm	24000
Cis isomer	278 nm	9350

3) *Detection of Impurities*

♠ This is one of the best methods for detecting impurities. The reasons for this are:

1. The band due to impurities are very intense.

e.g. An impurities in the amount of 0.05% has an ϵ value of 2000. Therefore such impurities can be detected in a transparent major component.

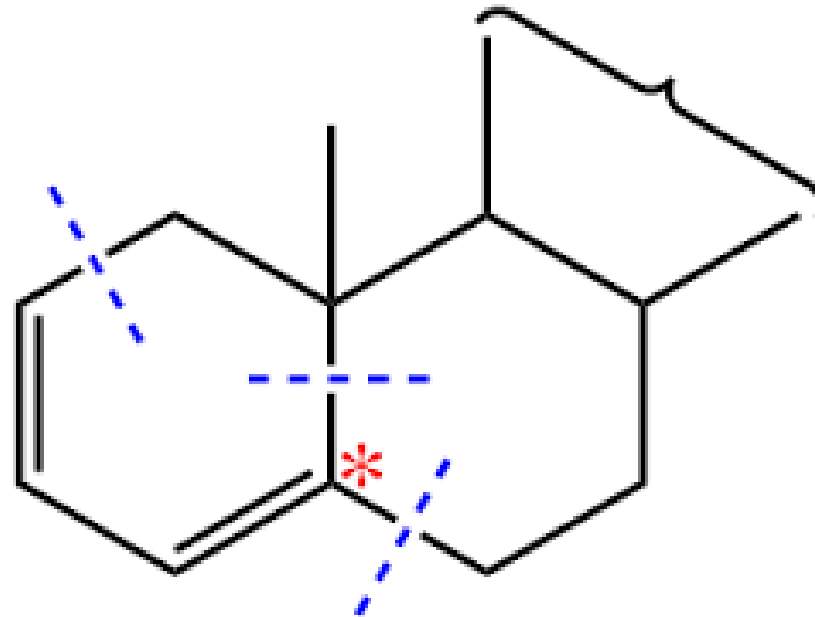
2. The organic compounds can be classified into:

- Saturated compounds having little absorption.
- Unsaturated compounds having strong absorption bands.

Woodward - Fieser Rules

Woodward-Fieser Rules for Calculating the λ_{max} of Conjugated Dienes and Polyenes

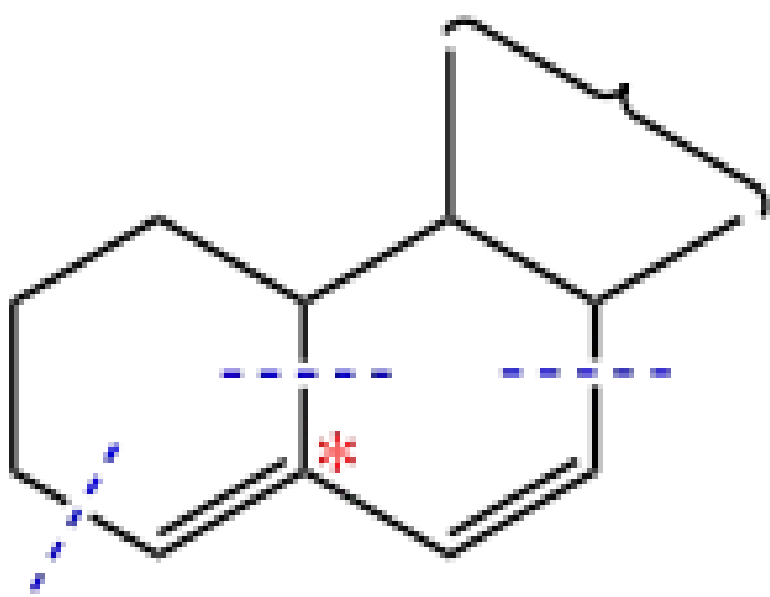
Empirical Rules for Absorption Wavelengths of Conjugated Systems



Homo annular Ring
Base Value = 260 / 253

Double bonds present in the same ring and

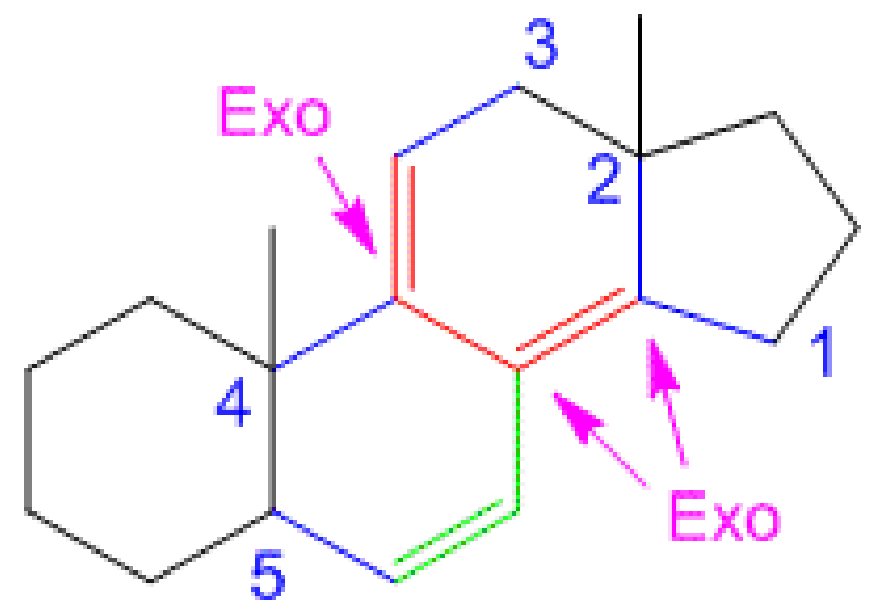
* Represents that the carbon has Exocyclic double bond



Hetero Annular

Base Value = 215

Double bond extending from ring to another



Exocyclic double bonds

Two exocyclic double bonds

Each exocyclic double bond adds 5 nm.

*When a homoannular (same ring) a base value of 260 nm should be chosen.

*When a heteroannular (different ring) a base value of 215 nm should be chosen.

λ_{\max} (calculated) = Base (215 or 260) + Substituent Contributions

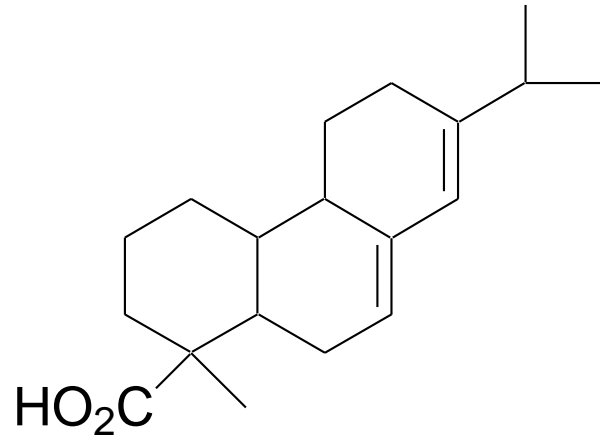
Substituent and Influence

R- (Alkyl Group)	+5 nm
RO- (Alkoxy Group) ..	+6
X- (Cl- or Br-)	+10
RCO ₂ - (Acyl Group)	0
RS- (Sulfide Group) ..	+30
R ₂ N- (Amino Group) ..	+60

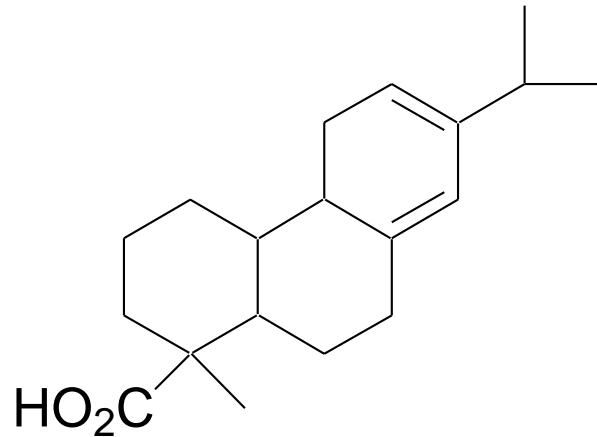
Further π -Conjugation

C=C (Double Bond) ...	+30
C ₆ H ₅ (Phenyl Group) ...	+60

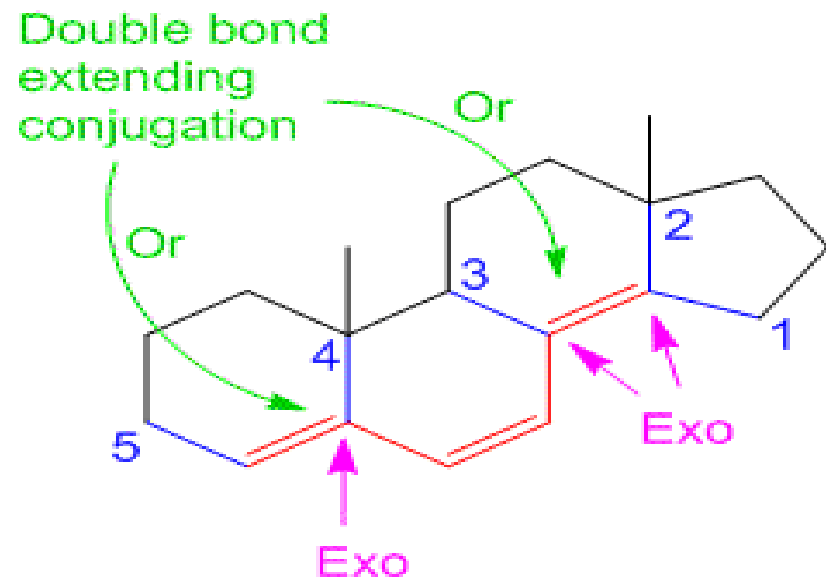
Distinguishing Isomers



Base value	215
4 X alkyl subst.	20
exo DB	5
Total	240
Obs	238



Base value	260
2Xalkyl subst	10
Total	270
Obs	273



$\lambda_{\max} = ? \text{ nm}$

Woodward-Fieser Rules for Dienes

	Homoannular (cisoid)	Heteroannular (transoid)
Parent	$\lambda=253$ nm	$\lambda=214$ nm =217 (acyclic)

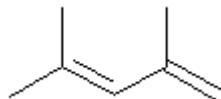
Increments for:

Double bond extending conjugation	30	30
Alkyl substituent or ring residue	5	5
Exocyclic double bond	5	5

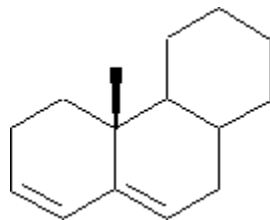
Polar groupings:

-OC(O)CH ₃	0	0
-OR	6	6
-Cl, -Br	5	5
-NR ₂	60	60
-SR	30	30

Example 1:



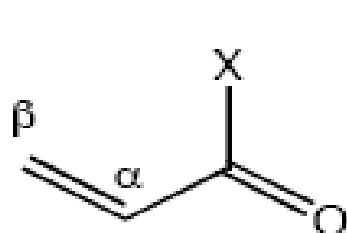
Transoid:		217 nm
Alkyl groups or ring residues:	3 x 5 =	<u>15 nm</u>
Calculated:		232 nm
Observed:		234 nm



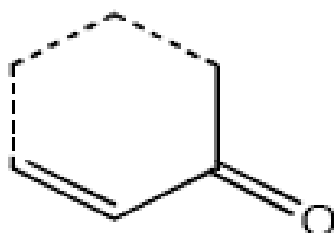
Hetero annualr:		214 nm
Alkyl groups or ring residues:	3 x 5 =	15 nm
Exocyclic double bond:		<u>5 nm</u>
Calculated:		234 nm
Observed:		235 nm

UV/VIS SPECTROSCOPY: CARBONYL COMPOUNDS

Woodward rules



X = alkyl 215 nm
 X = H 207 nm
 X = OH, Oalkyl 193 nm



215 nm

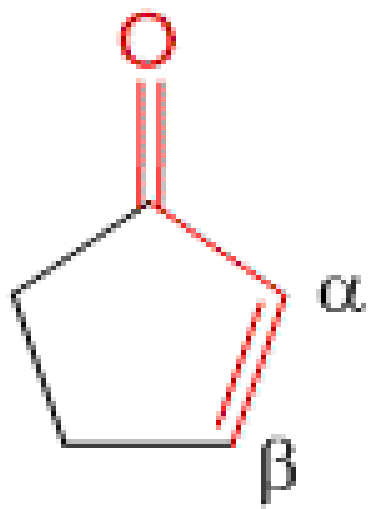


202 nm

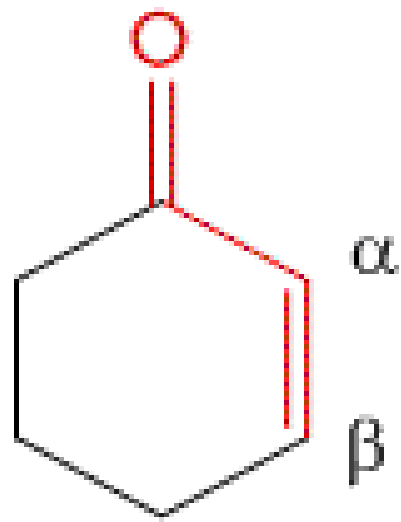
additional conjugated double bond +30 nm
 exocyclic double bond +5 nm
 homoannular C=C-C=C +39 nm

substituent:

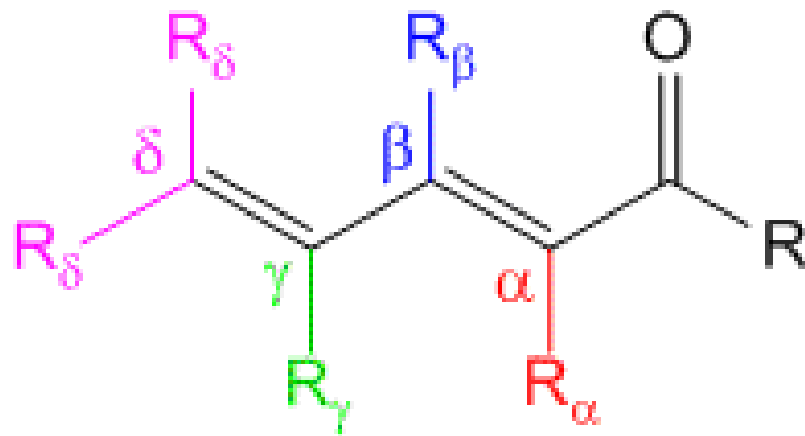
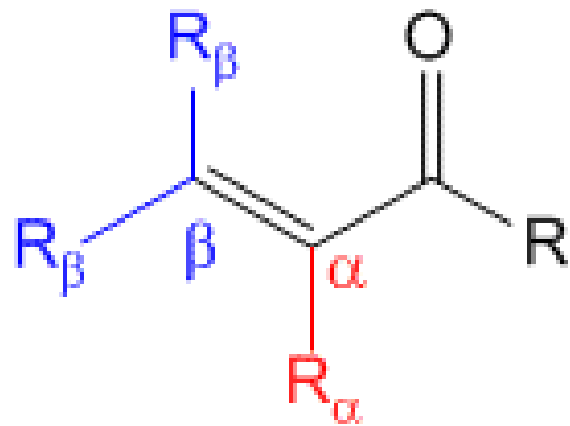
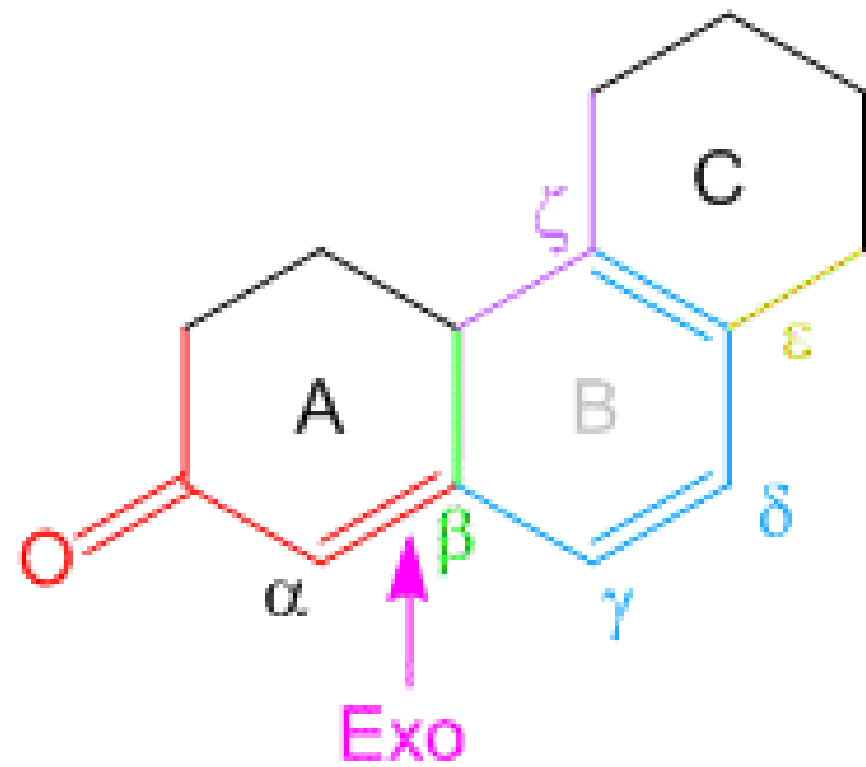
Substituent	α	β	γ	δ
R	10	12	18	18
OH	35	30		50
O ₂ CR	6	6	6	6
Oalkyl	35	30	17	31
Cl	15	21		
Br	25	30		
N(alkyl) ₂		95		



Cyclopentenone

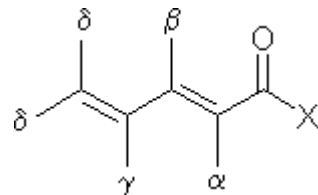
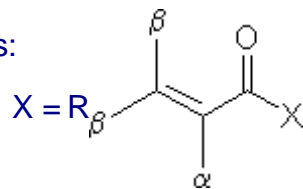


Cyclohexenone



Woodward's Rules for Conjugated Carbonyl Compounds

Base values:



Six-membered ring or acyclic parent enone

$\lambda=215$ nm

Five-membered ring parent enone

$\lambda=202$ nm

$X = H$

$\lambda=208$ nm

$X = OH, OR$

$\lambda=195$ nm

Increments for:

Double bond extending conjugation

30

Exocyclic double bond

5

Endocyclic double bond in a 5- or 7-membered ring for $X = OH, OR$

5

Homocyclic diene component

39

Alkyl substituent or ring residue

α

10

β

12

γ or higher

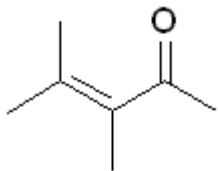
18

Polar groupings:

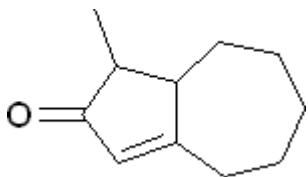
-OH	α	35
	β	30
	δ	50
-OC(O)CH ₃	$\alpha, \beta, \gamma, \delta$	6
-OCH ₃	α	35
	β	30
	γ	17
	δ	31
-Cl	α	15
	β, γ, δ	12
-Br	β	30
-NR ₂	α, γ, δ	25
	β	95

*Solvent shifts for various solvents:

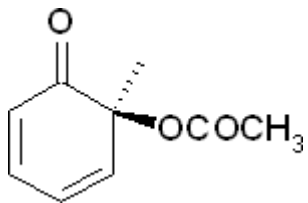
Solvent	λ_{\max} shift (nm)
water	+ 8
chloroform	- 1
ether	- 7
cyclohexane	- 11
dioxane	- 5
hexane	- 11



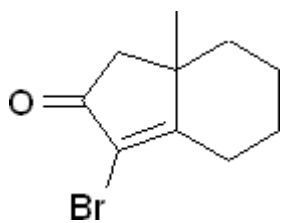
Acyclic enone:		215 nm
α -Alkyl groups or ring residues:		10 nm
β -Alkyl groups or ring residues:	$2 \times 12 =$	<u>24 nm</u>
Calculated:		249 nm
Observed:		249 nm



Five-membered ring parent enone:		202 nm
β -Alkyl groups or ring residues:	$2 \times 12 =$	24 nm
Exocyclic double bond:		<u>5 nm</u>
Calculated:		231 nm
Observed:		226 nm



Six-membered ring or alicyclic parent enone:		215 nm
Extended conjugation:		30 nm
Homocyclic diene component:		39 nm
δ-Alkyl groups or ring residues:		<u>18 nm</u>
Calculated:		302 nm
Observed:		300 nm



Five-membered ring parent enone:		202 nm
α-Br:		25 nm
β-Alkyl groups or ring residues:	2 x 12 =	24 nm
Exocyclic double bond:		<u>5 nm</u>
Calculated:		256 nm
Observed:		251 nm

Limitation: Woodward's rule is applicable upto 2-4 conjugation.

Fieser-Kuhn rule:

- Another empirical rule to calculate the absorption band maxima and *extinction coefficients* of *conjugated molecules* specially polyenes.

Long chains (Fieser-Kuhn rules)

$$\lambda_{\max} = 114 + 5M + n(48.0 - 1.7n) - 16.5 R_{\text{endo}} - 10 R_{\text{exo}}$$

and

$$E_{\max} = (1.74 \times 10^4)n$$

n = nos. of conjugated double bonds

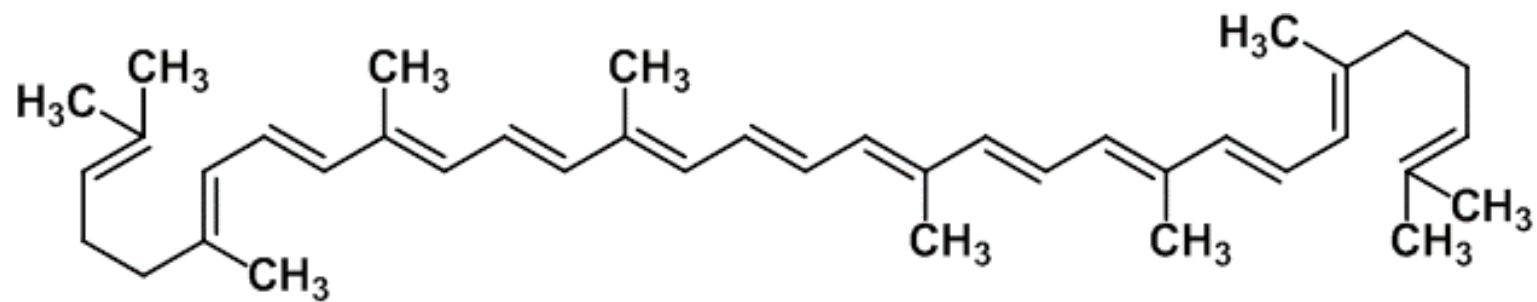
M = nos. of alkyl substituents on the conjugated system

R_{endo} = no. of rings with endocyclic double bonds in the

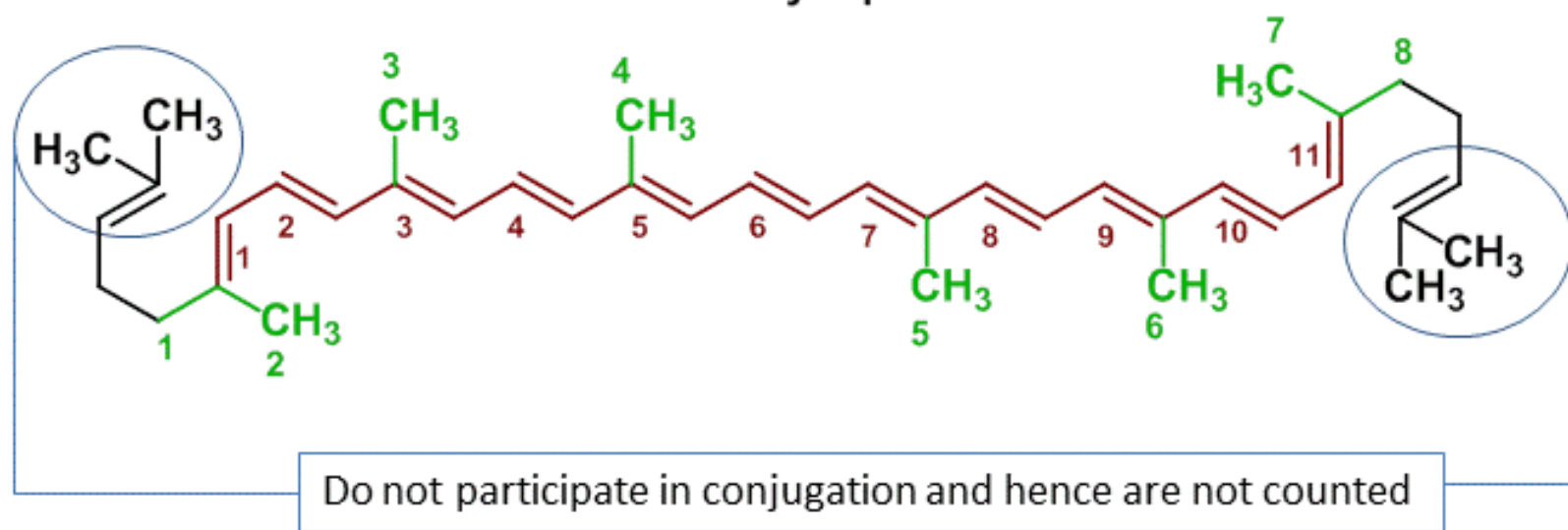
conjugated system

R_{exo} = no. of rings with exocyclic double bonds in the

conjugated system



all-*trans*-lycophene



For Lycopene :

For this compound with eleven conjugated double bonds

$$\lambda_{\text{max}}(\text{cal}) = 114 + 5(8) + 11 [48 - 1.7 (11)] - 0 - 0 = 476 \text{ nm}$$

$$\lambda_{\text{max}} = 476 \text{ nm}$$

Question Bank

- Explain interaction of electromagnetic radiation with molecules
- Explain Lambert's law and Lambert's – Beers law?
- What are Electronic Transitions? Explain various types of Electronic transitions
- Explain a) Chromophore b) Auxochrome.

THANK YOU