

II.M.Sc.,CHEMISTRY
ORGANIC CHEMISTRY -III
SEMESTER-III

UNITS – 5

FREE RADICALS

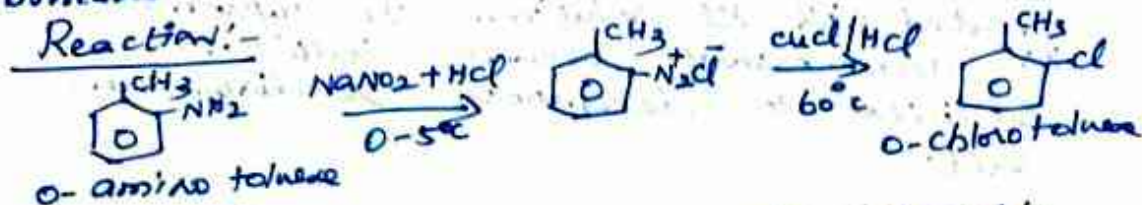
By,
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ASSOCIATE PROFESER OF CHEMISTRY ,
PERIYAR ARTS COLLEGE,
CUDDALORE – 1.

Sandmeyer Reaction:-

Definition:-

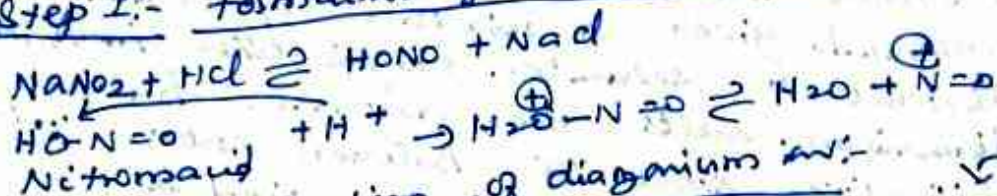
Conversion of an aromatic primary amine into an aryl diazonium salt by treatment with nitrous acid in the presence of mineral acids at low temperature (0-5°C). Subsequent decomposition of the diazonium salt by heating with cuprous chloride or bromide in the presence of the corresponding halogen acid gives acylchloride/bromide.

Reaction:-

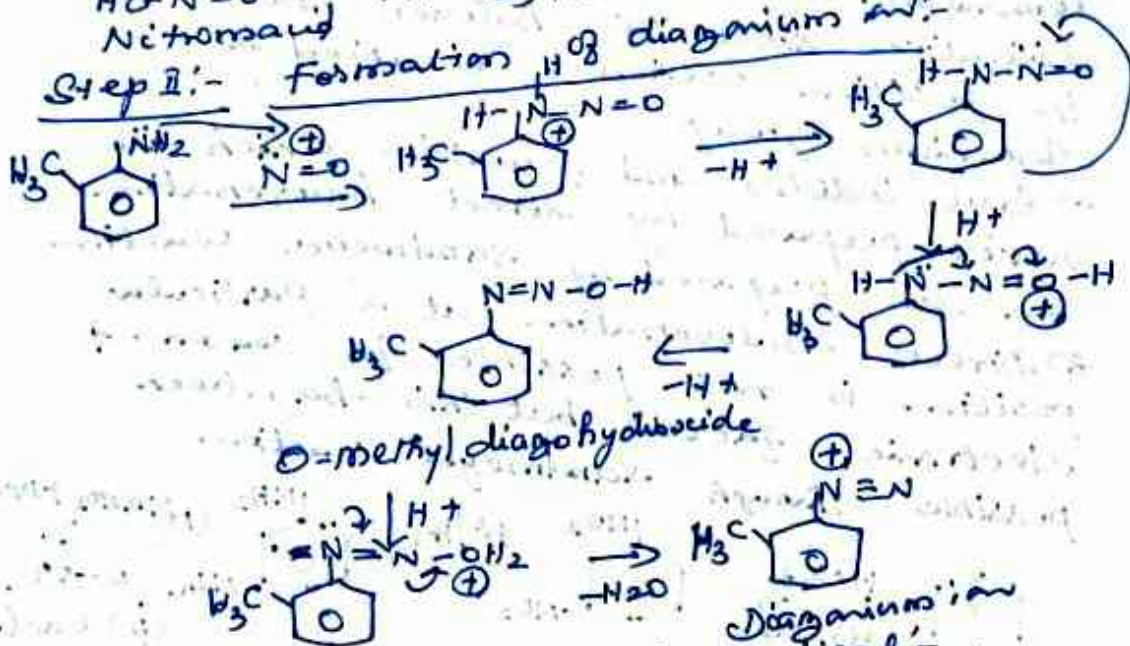


Mechanism:-

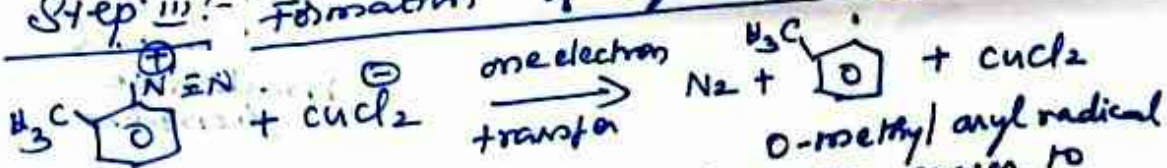
Step I:- Formation of electrophilic reagent:-



Step II:- Formation of diazonium ion:-



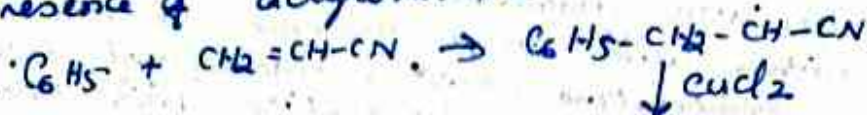
Step III:- Formation of aryl radical:-



Cuprous copper has the power to reduce diazonium ion to aryl radical by oxidation-reduction involving one e- transfer.

PROOF FOR THE FORMATION OF ARYL RADICAL:-

Though free radical addition, 2-chloro-3-phenylpropionitrile is got by the decomposition of benzene diazonium chloride in the presence of acrylonitrile.



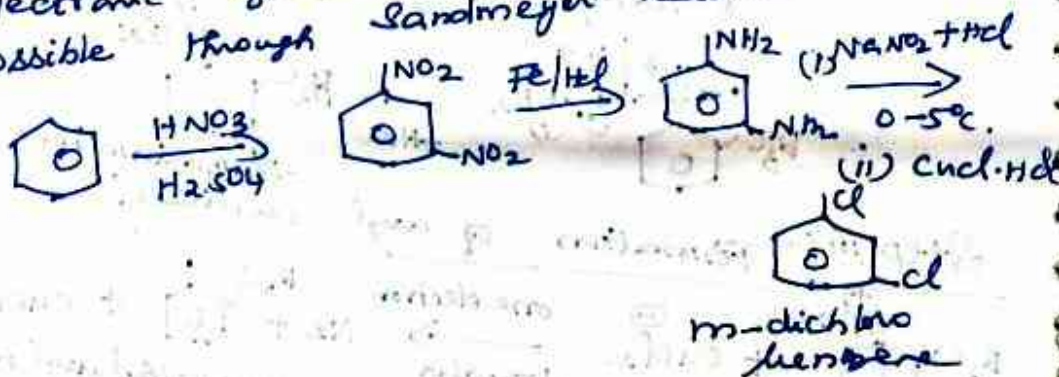
For the preparation of aryl iodide, the aryl diazonium salt is treated with KI solution. The cuprous catalyst is unnecessary, because iodide is sufficient to decompose the diazonium salt.

APPLICATIONS:-

1) Direct halogenation of aromatic compounds gives a mixture of isomers and difficult to separate. On the other hand, the diazonium salts give only one halogen derivative since the halogen enters at the position previously occupied by diazonium group.

2) Aryl iodides and fluorides which are never prepared by direct halogenation can be prepared by Sandmeyer reaction.

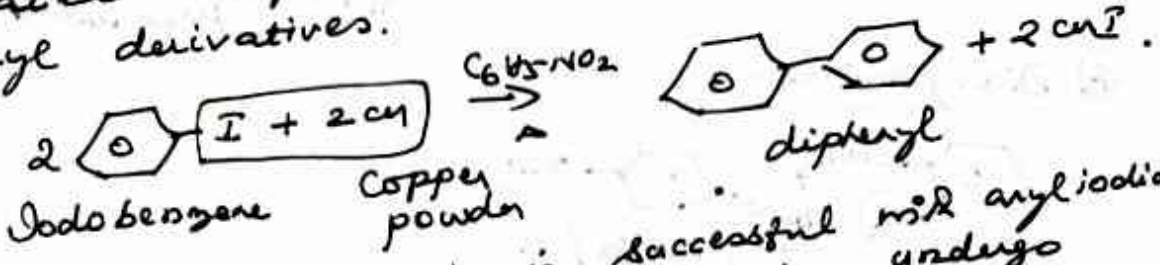
3) Direct halogenation at a particular position is not possible for reasons of electronic factors but this has been possible through Sandmeyer reaction.



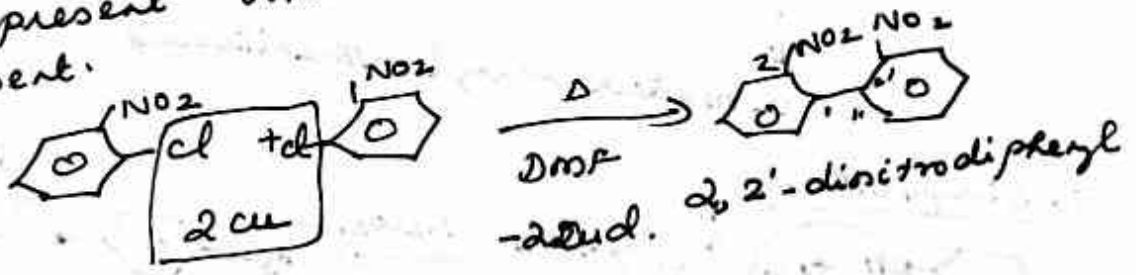
ULLMANN REACTION:-

Definition:-

Condensation of arylhalides in the presence of finely divided copper or copper bronze at an elevated temperature (100-350°C) to yield diaryl derivatives.

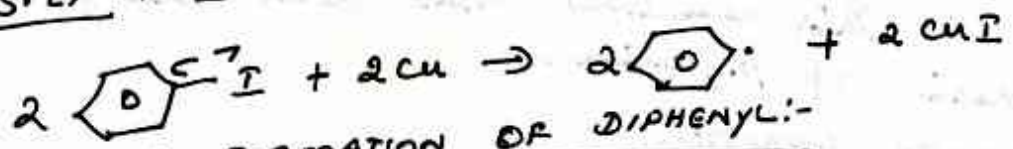


The reaction is successful with aryl iodides. Aryl bromides & aryl chlorides also undergo this reaction when electronegative substituents are present which activate the halogen.

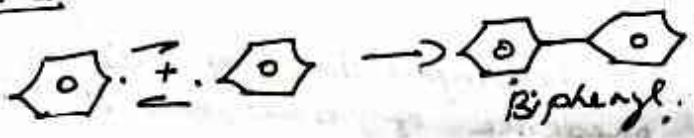


Mechanism:-

STEP I:- FORMATION OF PHENYL RADICAL:-

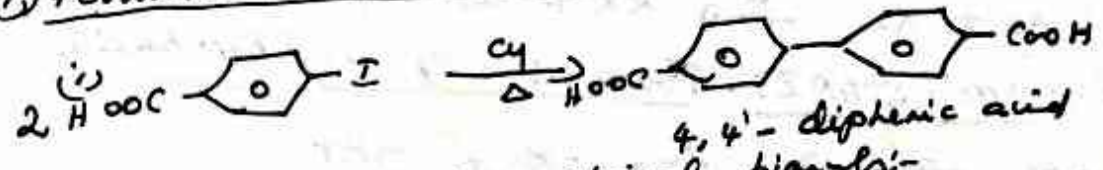


STEP II:- FORMATION OF DIPHENYL:-

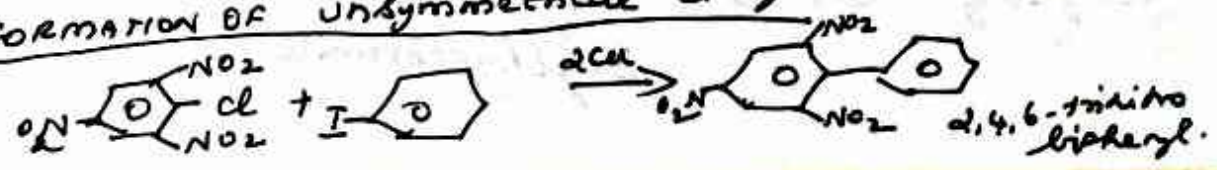


APPLICATIONS:-

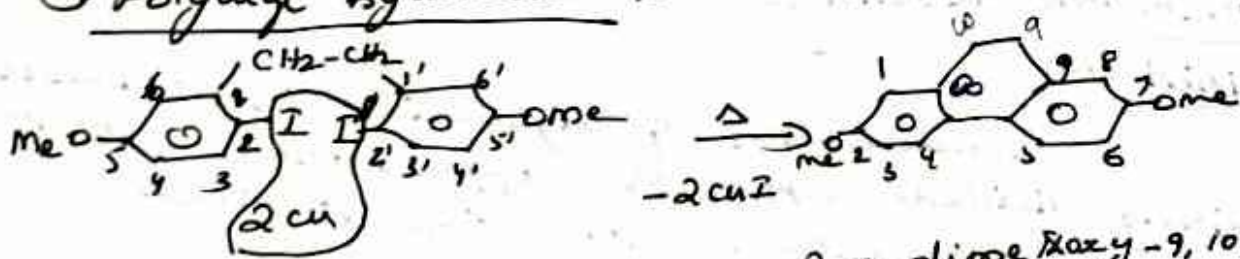
1) Formation of symmetrical diaryls:-



2) Formation of unsymmetrical diaryls:-

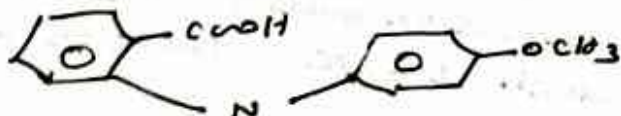
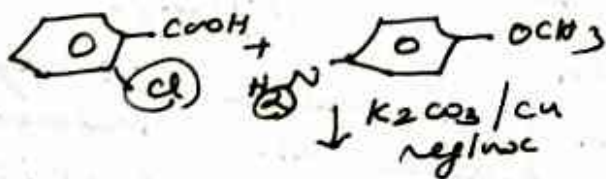


③ Polyaryl hydrocarbons:-



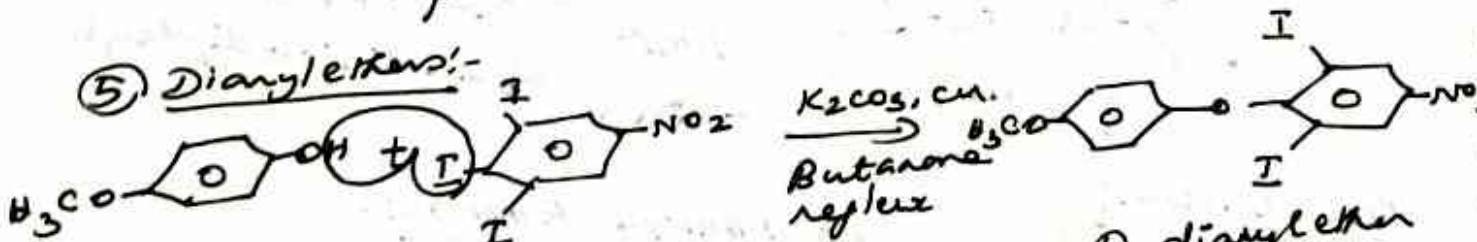
2,7-dimethoxy-9,10-dihydrophenanthrene.

④ Diaarylamines:-



p-methoxyphenylbenzamide.

⑤ Diarylethers:-



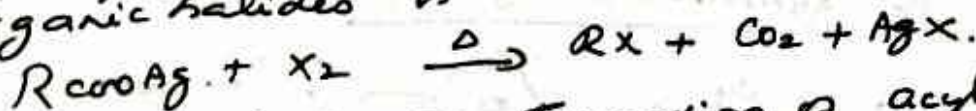
D. diarylether has been employed in

the synthesis of thyroxine.

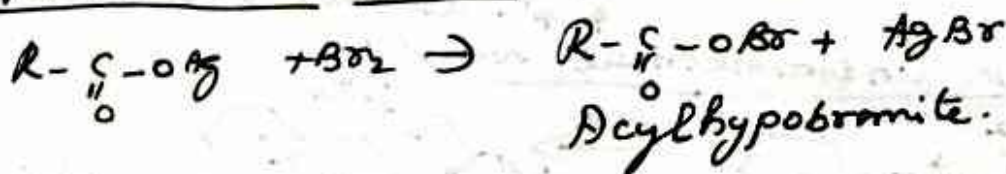
HUNSDIECKER REACTION:-

Definition:-

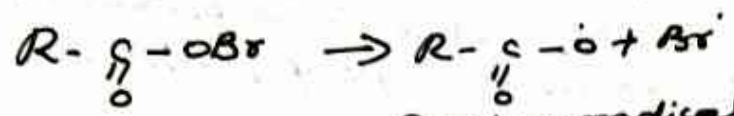
Thermal decomposition of silver salt of carboxylic acids in presence of halogens to give organic halides is known as Hunsdiecker reaction.



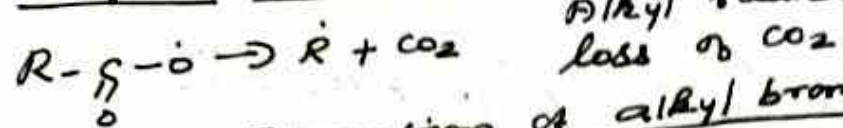
Mechanism:- STEP I:- Formation of acylhypohalite:-



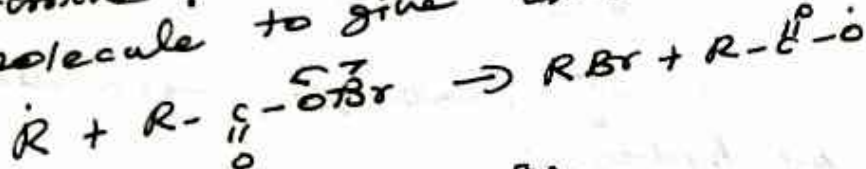
Step I:- Formation of acyloxy radical:-



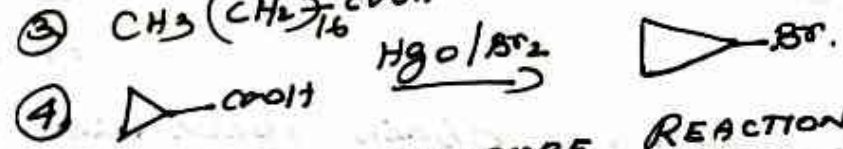
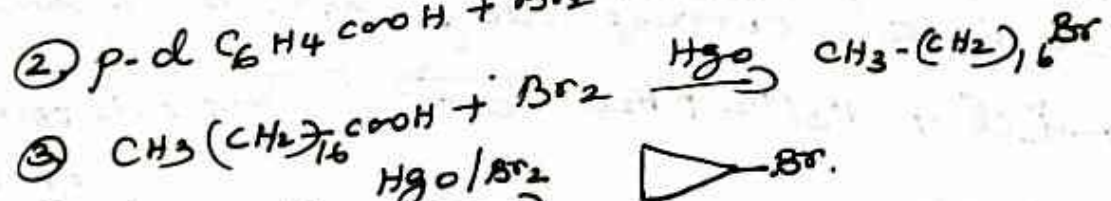
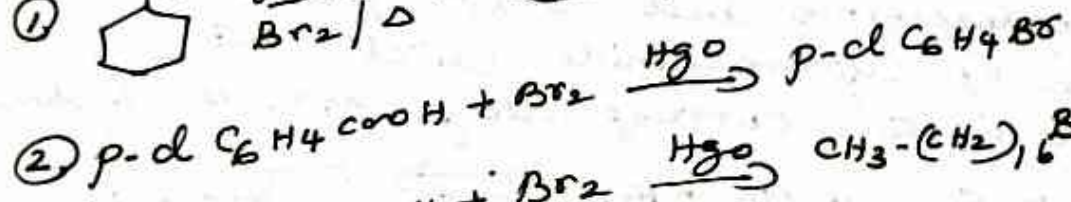
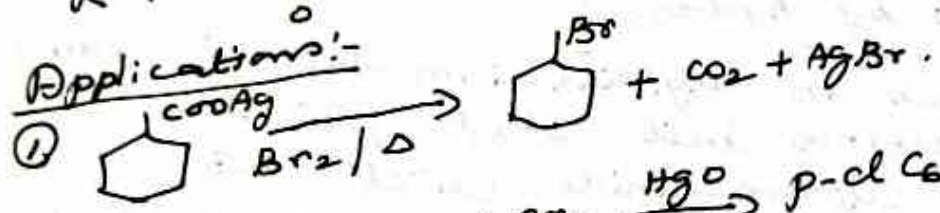
Step II:- formation of alkyl radical:-



Step III:- formation of alkyl bromide:-
Alkyl radical formed in step II abstracts bromine from the second acyl hypobromite molecule to give alkyl bromide.

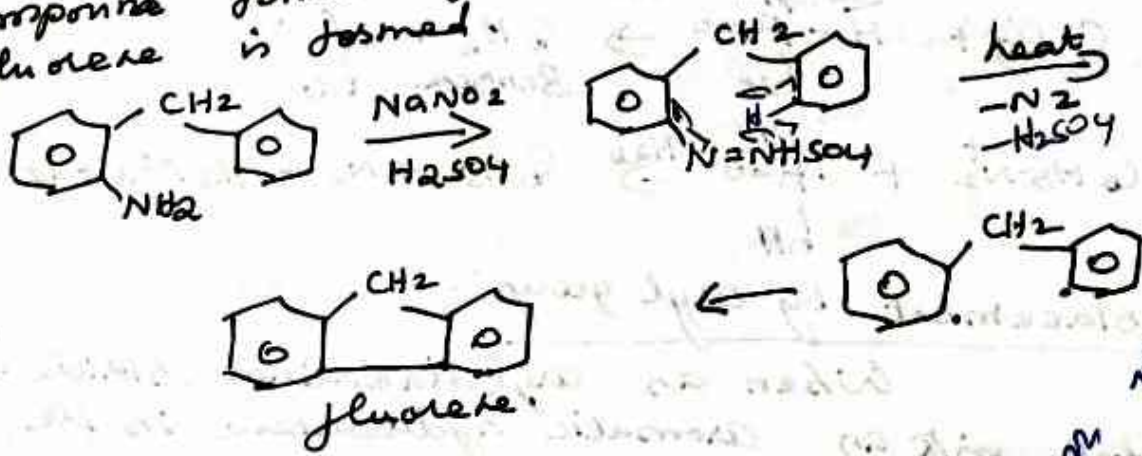


Applications:-



PSCHOOR-RING CLOSURE REACTION:-

This is radical substitution reaction. O-amido diphenylmethane is converted into azo compound followed by the elimination of N₂ and fluorene is formed.

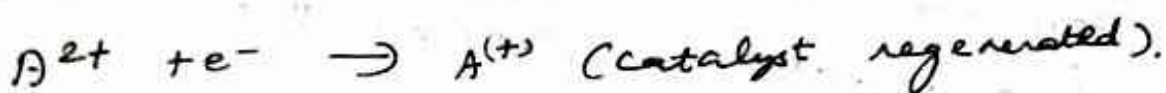
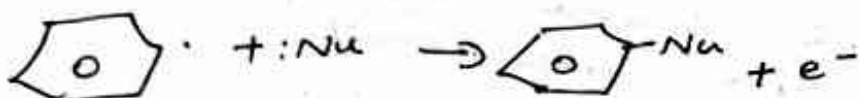
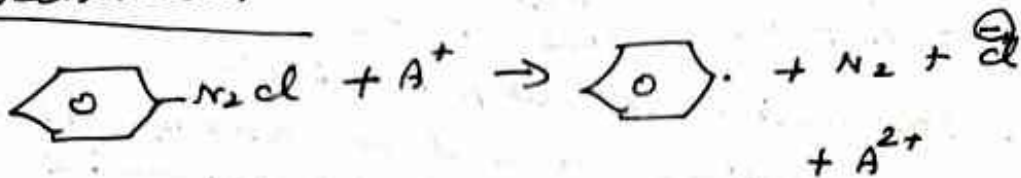


322 774 1220 1216 1220

Decomposition of diazo compounds-

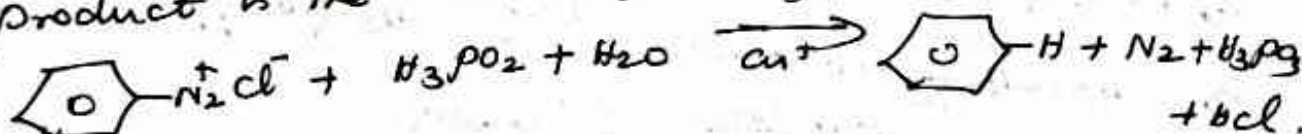
In Aryldiazonium salts, N_2X is replaced by another univalent atom or group, with the liberation of N_2 gas.

Mechanism:-



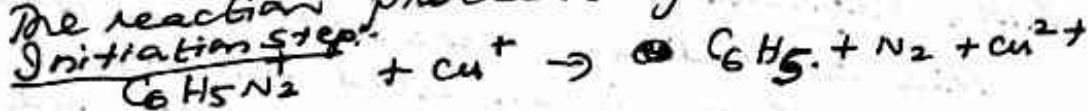
Replacement by hydrogen:-

When an aryldiazonium salt is reduced by hypophosphorous acid (H_3PO_2) in the presence of cuprous chloride (Cu^+Cl^-) the product is the corresponding aromatic hydrocarbon.

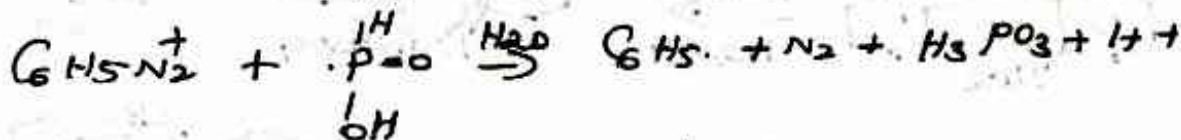
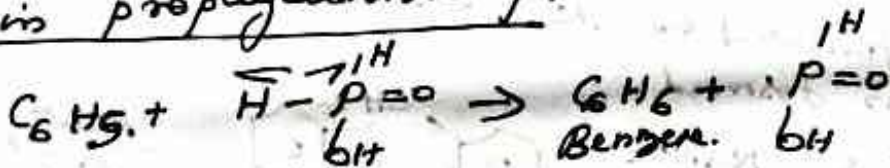


Mechanism:-

The reaction proceeds by a chain mechanism.



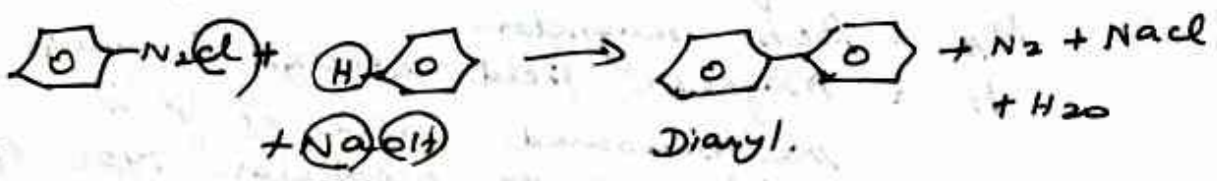
Chain propagation step:-



Replacement by aryl group:-

When an aryldiazonium chloride is treated with an aromatic hydrocarbon, in the

in the presence of NaOH, diaryl results.

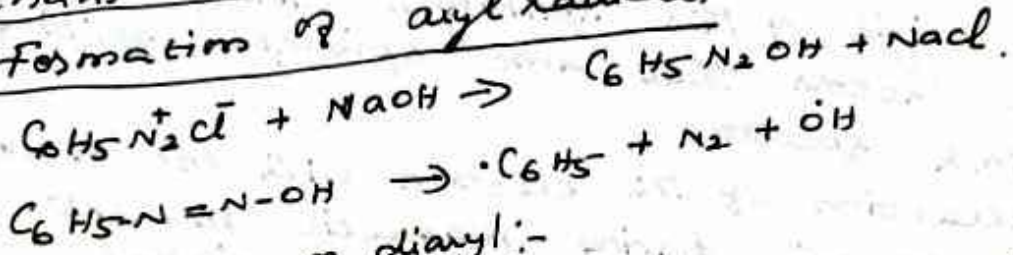


Mechanism:-

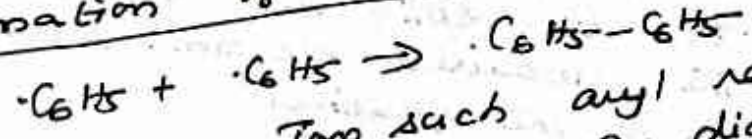
The reaction is believed to occur by a free-radical mechanism.

Chain initiation step:-

Formation of aryl radical:-

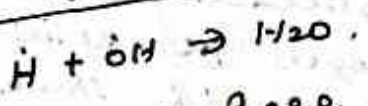


Formation of diaryl:-



Two such aryl radicals combine and there is formation of diaryl

Chain termination step:-



Detection of free radicals by ESR:-

① Electron spin resonance spectroscopy is a highly specific tool for detecting radical species because only molecules with unpaired electrons give rise to ESR spectra.

② One feature that is determined is the g value, which specifies the separation of the two spin states as a function of the magnetic field strength of the spectrometer.

$$\textcircled{3} \quad \Delta E = g \mu_B H$$

μ_B = Bohr magneton

H = Magnetic field strength in gauss

The measured value of g' is the characteristic of the particular type of radical just as the line position in NMR spectra is characteristic of the absorbing nucleus.

④ More detailed structural information can be deduced from the hyperfine splitting in ESR spectra

⑤ The origin of this splitting is closely related to the factors that cause spin-spin splitting in ^1H -NMR spectra.

⑥ Interaction of the electron with one or more of the nuclei having magnetic moment like ^1H , ^{13}C , ^{14}N etc splits the signal arising from the unpaired electron. The no of lines is given by the equation

$$= (2nI + 1)$$

I = Nuclear spin quantum number

n = No of equivalent interacting nuclei.

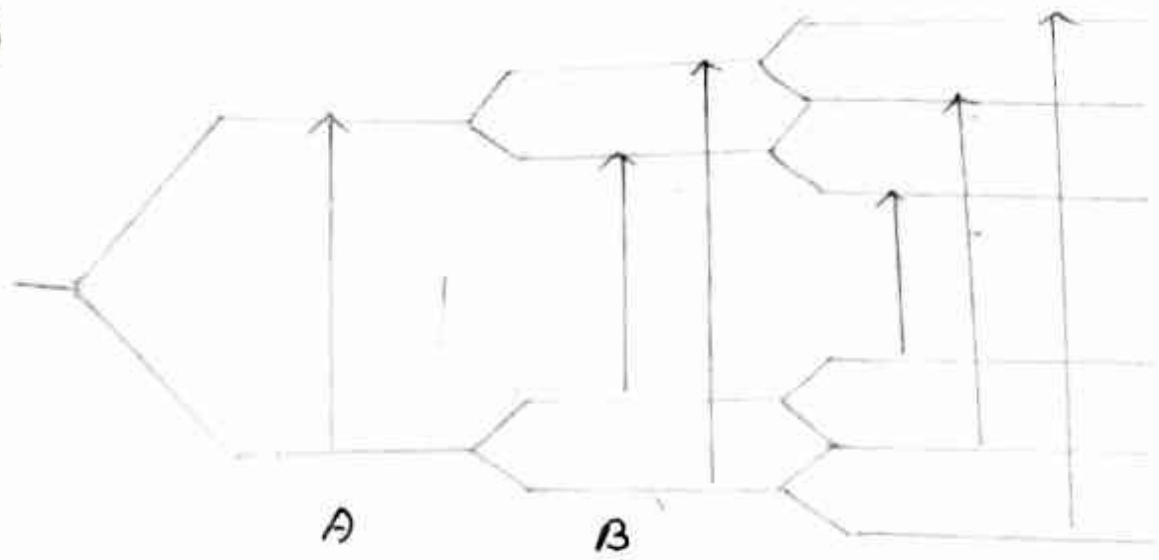
⑦ If $I = 1/2$, a single hydrogen (~~atom~~) splits a signal into a doublet. Interaction with three equivalent hydrogens as in a methyl group, gives splitting into four lines.

⑧ ^{12}C and ^{16}O has no nuclear magnetic moment and they causes no signal splitting in ESR spectra.

⑨ The no of lines indicates the number of interacting hydrogens if we limit our discussion for the moment of radicals without heteroatoms.

⑩ The magnitude of the splitting, given by hyperfine splitting constant a is a measure of the unpaired electron density in the hydrogen 1s orbital.

11



Hyperfine splitting in ESR

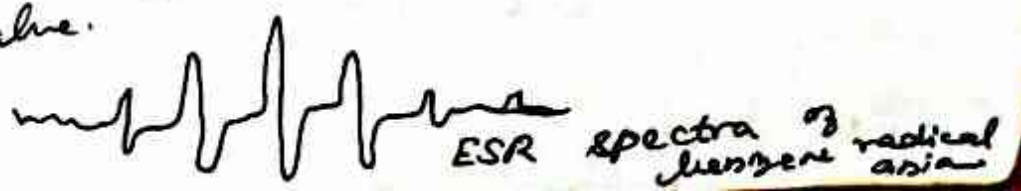
- A - No interacting nuclei. One absorption line
- B - One interacting hydrogen. two absorption lines.
- C - Two interacting hydrogens. Three absorption lines.

12 For planar conjugated systems in which the unpaired electron resides in a π -orbital system, the relationship between electron spin density and the splitting constant is given by McConnell equation

$$a = \rho Q$$

- a = Hyperfine coupling constant for a proton.
- Q = proportionality constant
- ρ = spin density on the carbon to which the hydrogen is attached.

13 $Q = 23.0 G$, the hyperfine splitting in the benzene radical anion can be readily calculated by taking $\rho = 1/6$, because the one unpaired electron must be distributed equally among 6 σ^2 atoms. The calculated value of $a = 3.83$ is in good agreement with the observed value.



ESR spectra of benzene radical anion

- ⑭ ESR spectra of free radicals can be studied even in very low concentration.
- ⑮ ESR spectrum of $C_6H_6^{\cdot -}$ has seven equally spaced lines which show that all six hydrogens are equivalent.



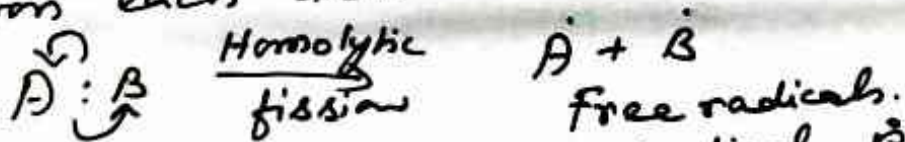
ESR spectrum of $C_6H_6^{\cdot -}$ showing the hyperfine splitting through equal coupling with six protons.

- ⑯ The unpaired electron is coupling equally with all six hydrogens, rather than localised at one particular position. Since ^{12}C is nonmagnetic, no further hyperfine splitting is produced.

FREE RADICALS:-

Definition:-

When a covalent bond undergoes homolytic fission, the two departing atoms take one electron of the bonding pair of electrons. The two fragments produced carry an odd electron each and are called free radicals.

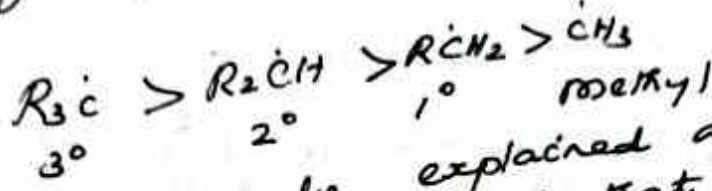


The term free radical is used for any species which possess an unpaired electron. The high reactivity of free radicals is due to the tendency of the odd electrons to pair up with another available electron.

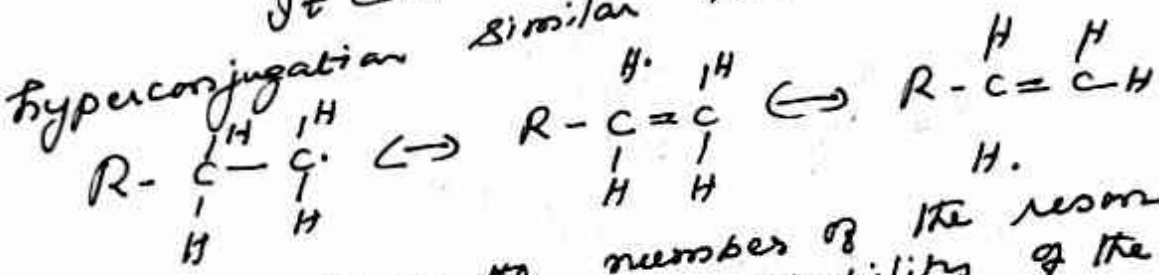
Stability of free radicals:-

SHORT & LONG LIVED FREE RADICALS:-

① Simple alkyl free radicals are highly reactive like carbocations and carbanions their lifetime is extremely short in solution. The relative stability of simple alkyl radicals has the order.

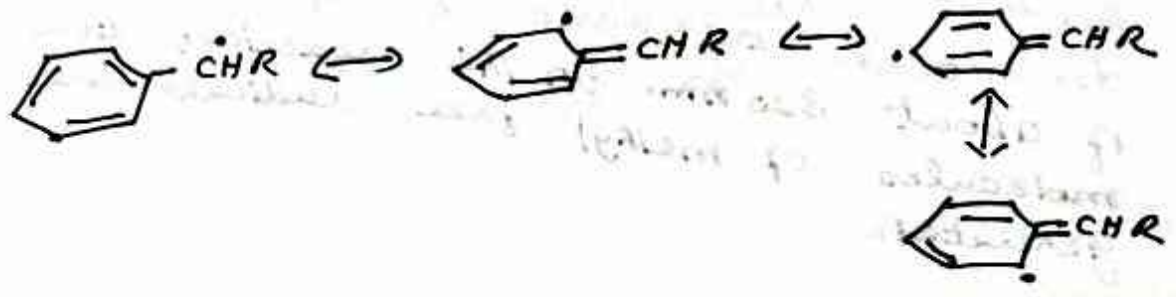
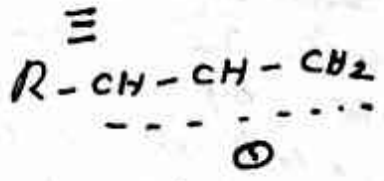
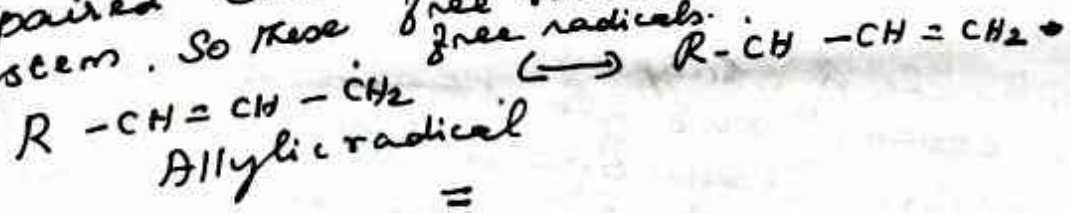


It can be explained on the basis of hyperconjugation similar to that in carbocation.

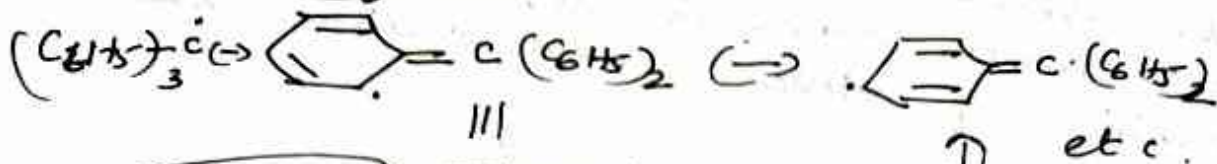


More the number of the resonating structures, greater is the stability of the free radical.

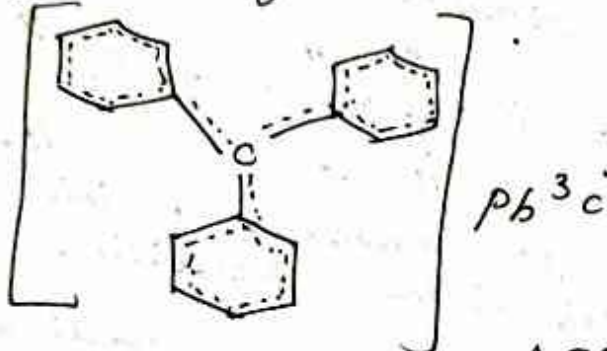
② Allylic and benzylic free radicals are more stable and comparatively less reactive than simple alkyl radicals. The reason is the delocalisation of the unpaired electron over the π-orbital system. So these free radicals are long lived.



③ Triphenyl methyl and triarylmethyl radicals are much more stable in solution at room temperature. The stability of such radicals is due to resonance. They are also long lived free radicals.



Steric hindrance to dimerisation is probably the major cause of their stability.

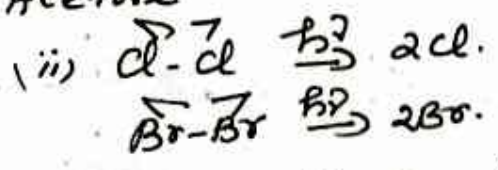
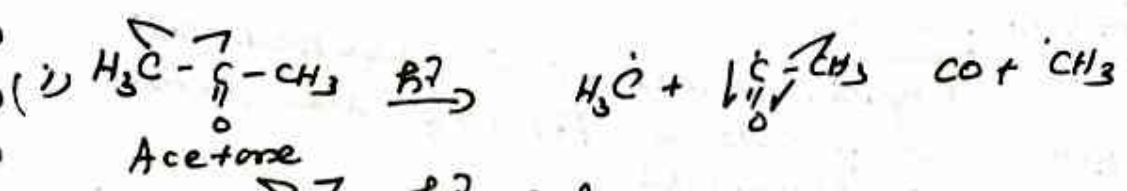


Regeneration of free radicals:-

Homolytic cleavage of a double bond generates a pair of free radicals.

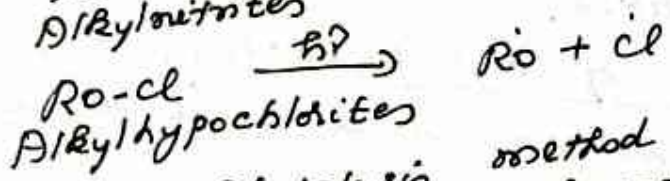
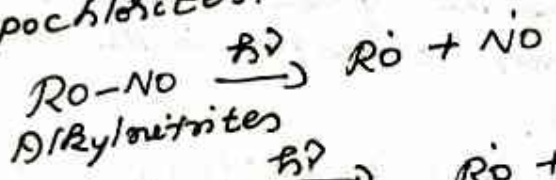
Ⓐ Photolysis:-

In this method, a suitable organic molecule is subjected to UV radiation. The organic molecule should be able to absorb radiation in the ultraviolet or visible range. The cleavage of a molecule into two parts by using UV light is known as photolysis. Acetone in vapour phase is decomposed by light having a wavelength of about 320 nm. In this reaction, two molecules of methyl free radicals are generated.



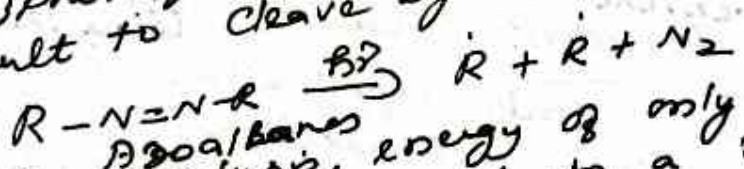
These free radicals (Br. & Cl.) can initiate the halogenation of alkanes or addition to alkenes.

(iii) Alkoxy free radicals are generated by photolysis of alkyl nitrites and alkyl hypochlorites.

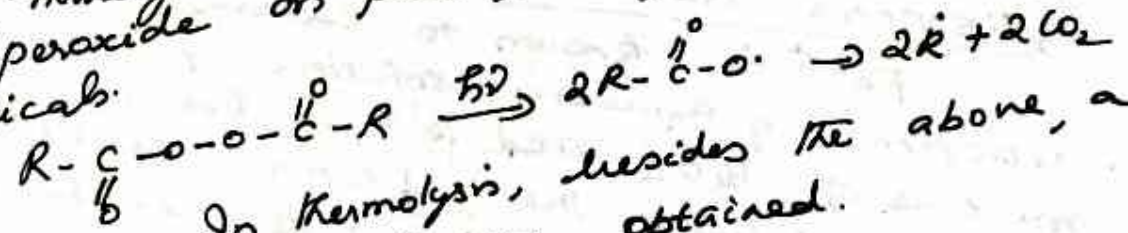


Photolysis method has two basic advantages over the thermolysis for the generation of free radicals.

(a) Photolysis cleave strong bonds that are difficult to cleave by thermolysis.



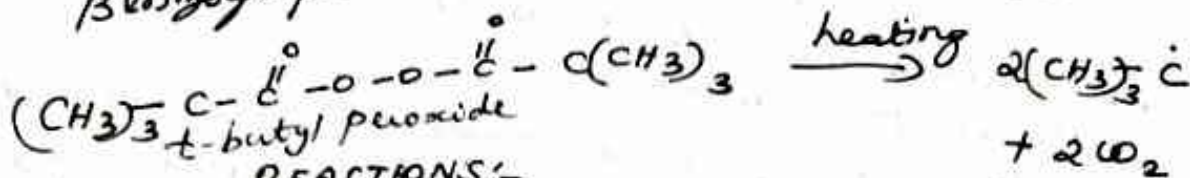
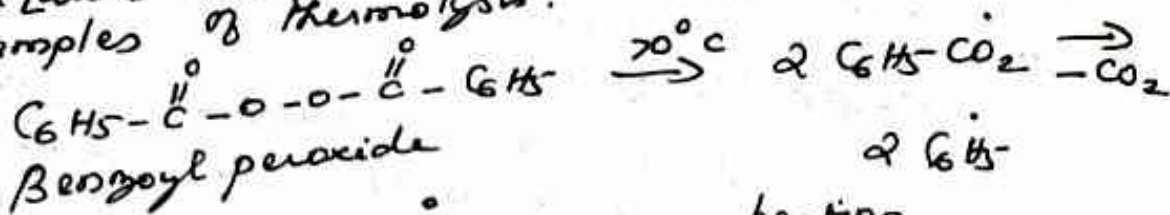
(b) In photolysis, energy of only one particular wavelength is transferred to a molecule and in this way photolysis is a specific method for homolytic cleavage than pyrolysis. Thus acylperoxide on photolysis generates the free radicals.



In thermolysis, besides the above, a no. of other byproducts are obtained.

II THERMOLYSIS:-

Organic substrate is heated at suitable temperature. Following are some examples of thermolysis.

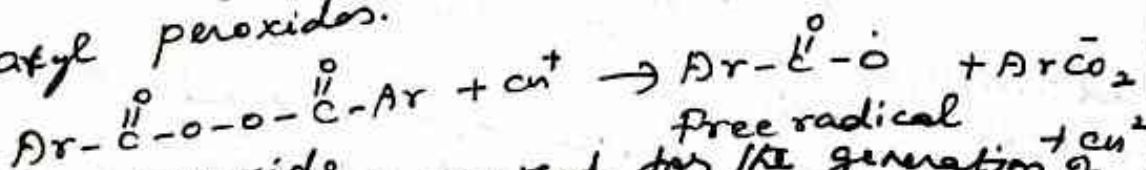


III REDOX REACTIONS:-

In redox reactions, there is one electron transfer in generating the free radicals. The source of one electron transfer is the metal ion (e.g. Cu^{2+} , Fe^{2+} etc.).

(a) Decomposition of aryl peroxides:- (Reduction)

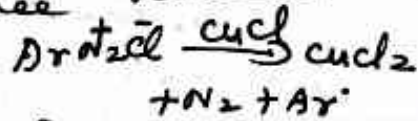
Cu^+ ions are used for the decomposition of aryl peroxides.



This is the convenient method for the generation of free radical $\text{ArCO}_2\cdot$ radical since thermolysis leads to $\text{ArCO}_2\cdot$ radical.

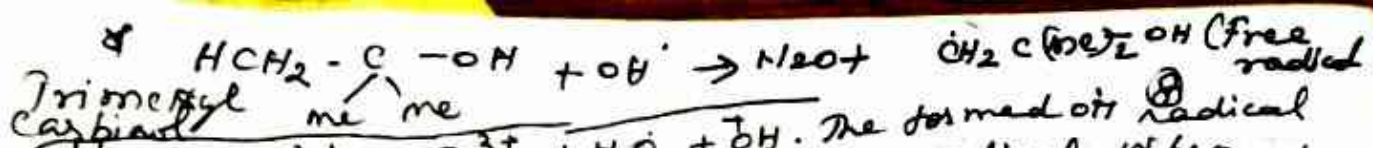
(b) Sandmeyer Reaction:- (Reduction)

Cu^{2+} also finds application in Sandmeyer reaction, involving decomposition of diazonium salt. In this reaction, the free radical $\text{Ar}\cdot$ is formed as an intermediate.



(c) FENTON'S REACTION:- (Oxidation)

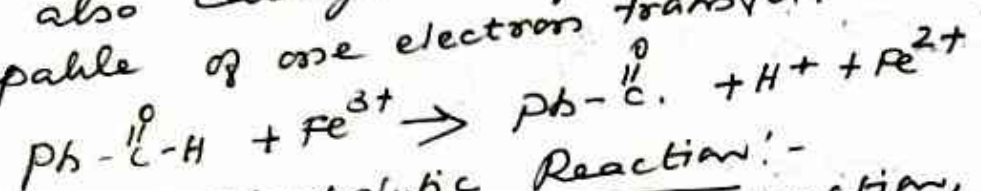
Fe^{2+} is known to catalyse the oxidation reactions of aqueous solution of H_2O_2 . The mixture of H_2O_2 and Fe^{2+} is known as Fenton's reagent. The effective oxidising agent is the hydroxy radical $\text{HO}\cdot$ and the reaction is known as Fenton's reaction.



$\text{H}_2\text{O}_2 + \text{Fe}^{2+} \rightarrow \text{Fe}^{3+} + \text{H}_2\text{O} + \text{OH} \cdot$. The formed OH radical is used to produce another free radical when suitable substrate is used.

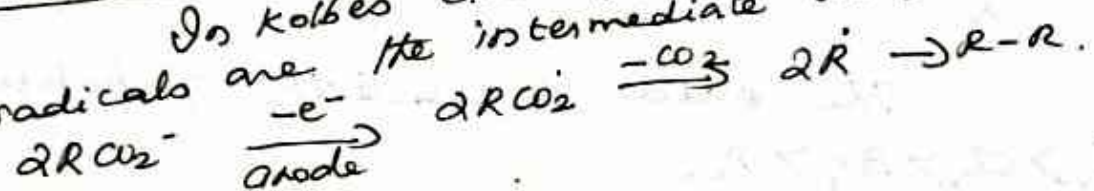
(a) Autooxidation:-

The autooxidation of benzaldehyde is also catalysed by metal ions which are capable of one electron transfer.



(e) Kolbe Electrolytic Reaction:-

In Kolbe's electrolytic reaction, free radicals are the intermediate as follows.



Addition reactions:-

Addition reactions to carbon-carbon double bond:-

- (i) Addition of halogens
- (ii) Addition of halogen acids.
- (iii) Polymerisation reactions.

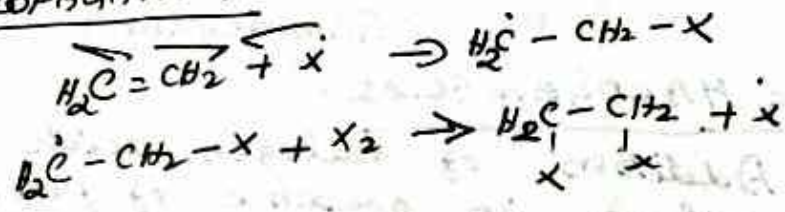
Addition to halogens:-

Addition of halogens in non-polar solvents is gas phase or by light takes through radical intermediate.

INITIATION:-

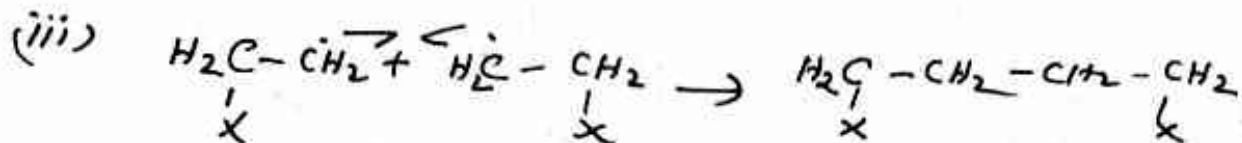
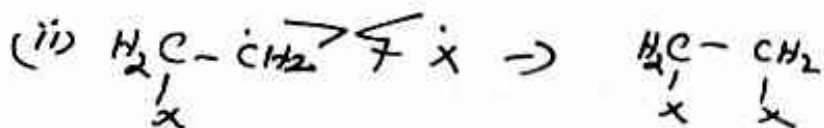
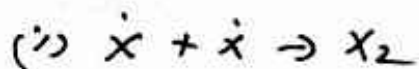


PROPAGATION:-



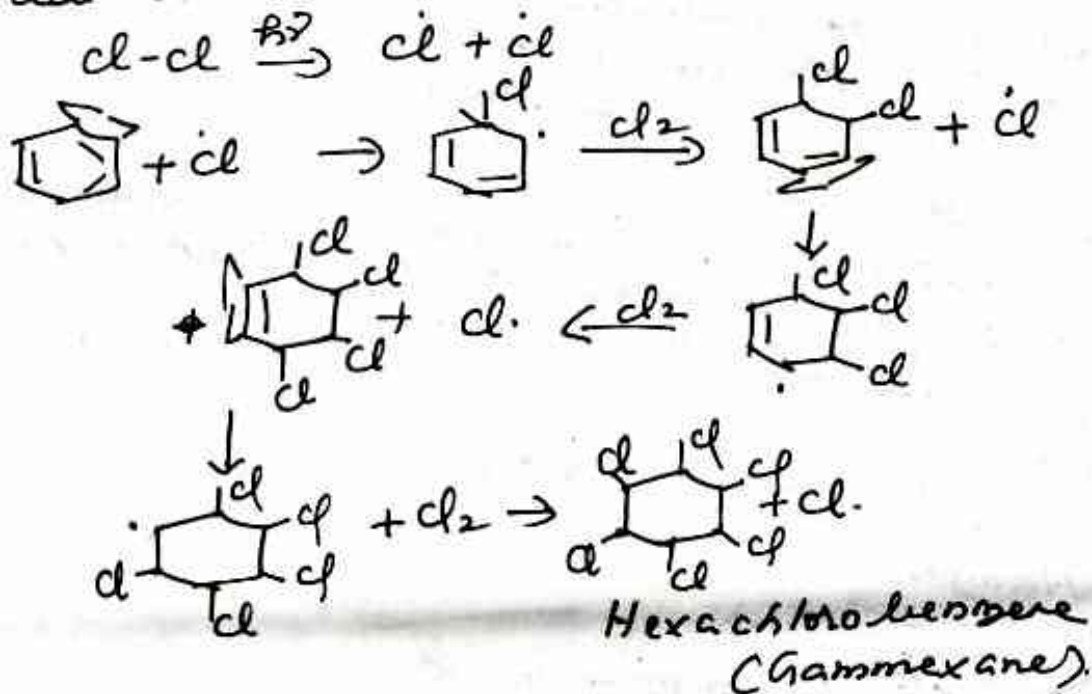
TERMINATION:-

There are 3 ways to terminate the reaction



The order of reactivity of halogens
 $F_2 > Cl_2 > Br_2 > I_2$.

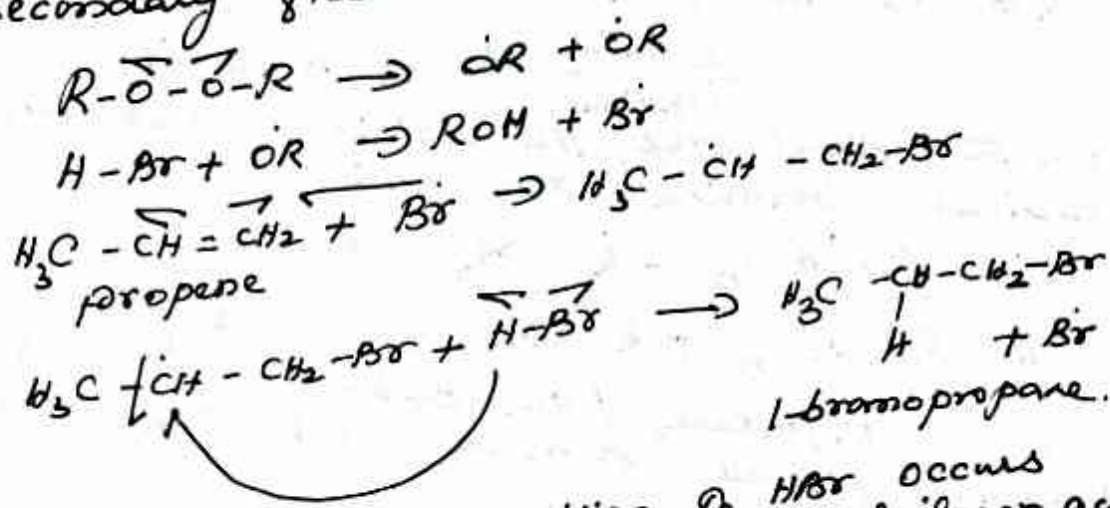
Addition of halogen particularly chlorine to benzene is also an example of radical addition.



II ADDITION OF HALOGEN ACIDS:-

(a) Addition of halogen acids to unsymmetrical alkene in presence of peroxides

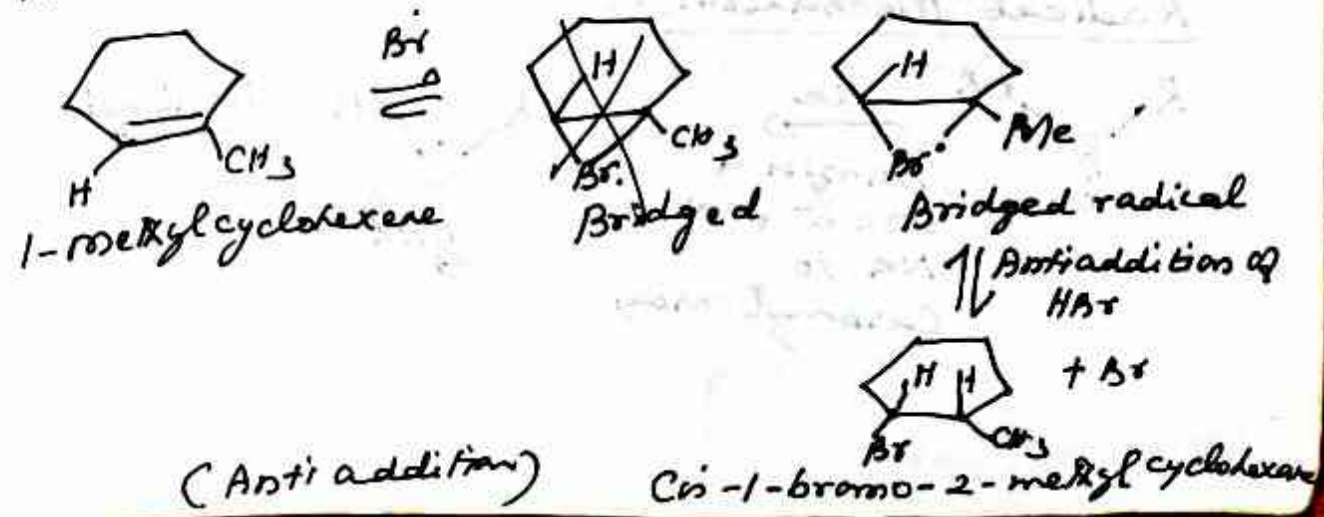
Proceeds through radical intermediate giving Anti-Markovnikov addition. This is generally referred as peroxide effect. In this reaction, halogen radical attacks unsymmetrical alkene to generate a more stable secondary free radical.



Only the addition of HBr occurs with peroxide effect but other halogens acids undergo addition according to Markovnikov's rule. This is due to the fact that addition of HBr is an exothermic process while addition of other halogen acids takes place through endothermic step.

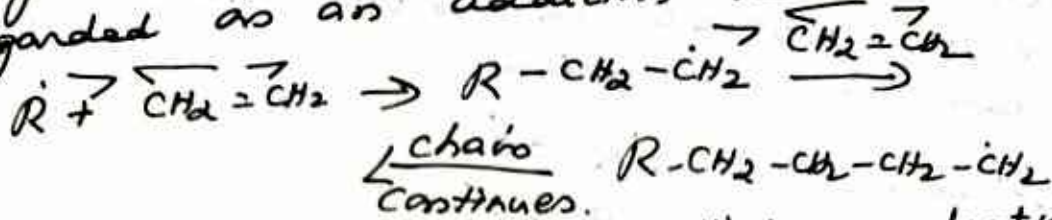
(b) ADDITION TO SUBSTITUTED CYCLOHEXENES:-

Radical addition of HBr to substituted cyclohexenes is stereospecific anti.
~~trans~~, anti addition.

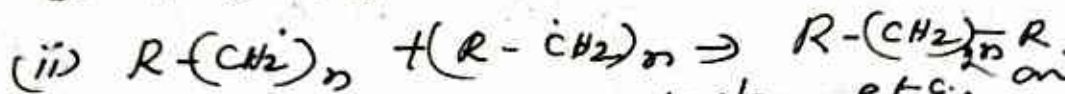
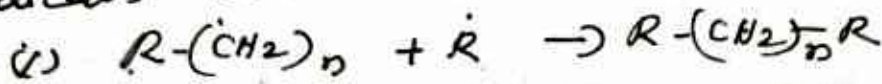


III POLYMERISATION:-

Radical reactions can produce polymers of great importance. Polymerisation may be regarded as an addition reaction. Thus

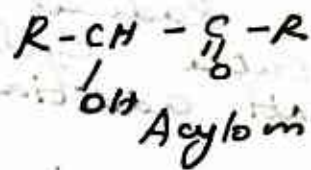
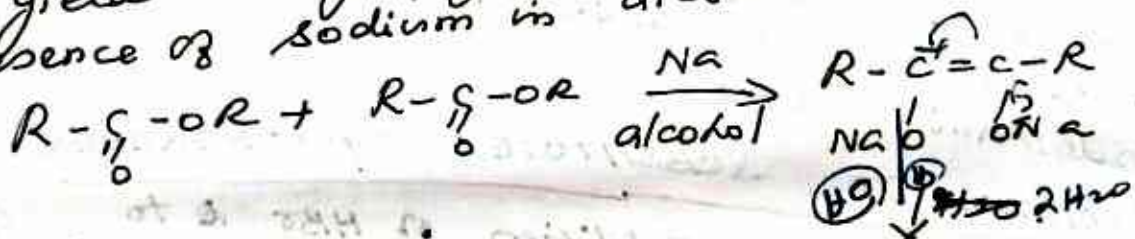


In the final step, the collisions between radicals terminate the chain.

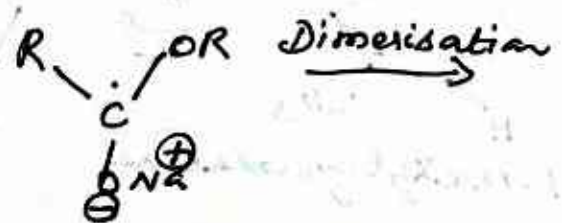
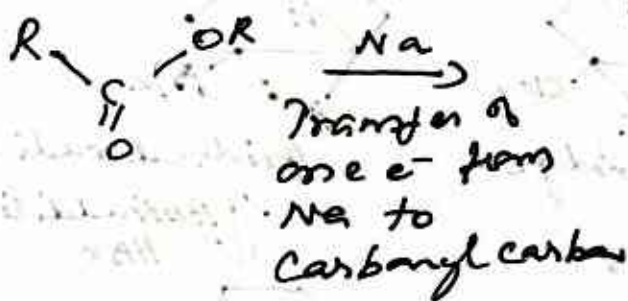


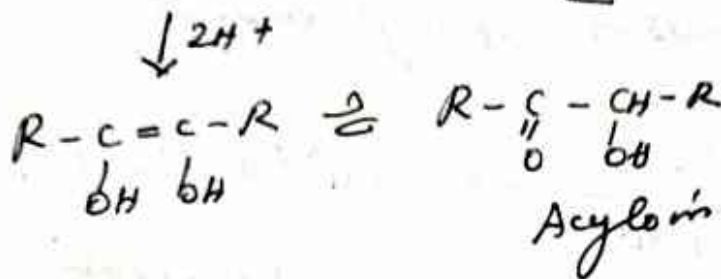
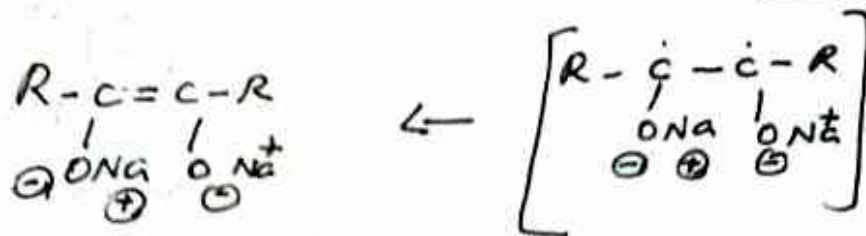
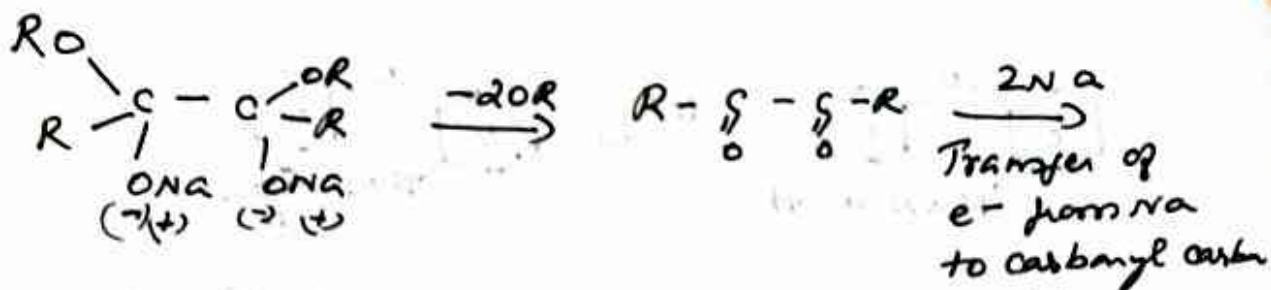
polymers formed from the respective monomers by radical pathway.
 polythene, PVC, teflon etc., are the

Acylloin condensation may be regarded as an example of radical addition reaction. It is a case of dimerisation of ester to yield α -hydroxy ketone (acyloin) in presence of sodium in alcohol.

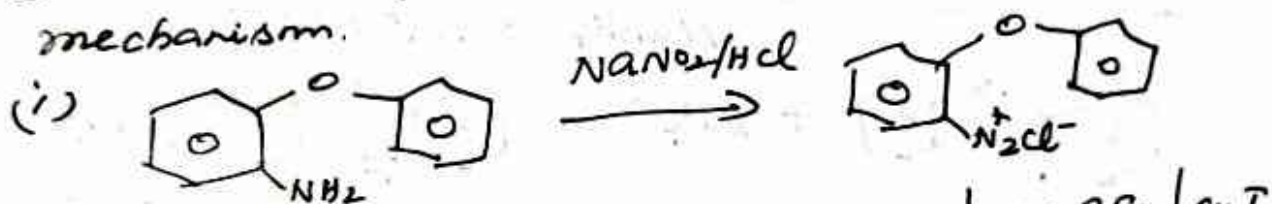


Radical Mechanism:-

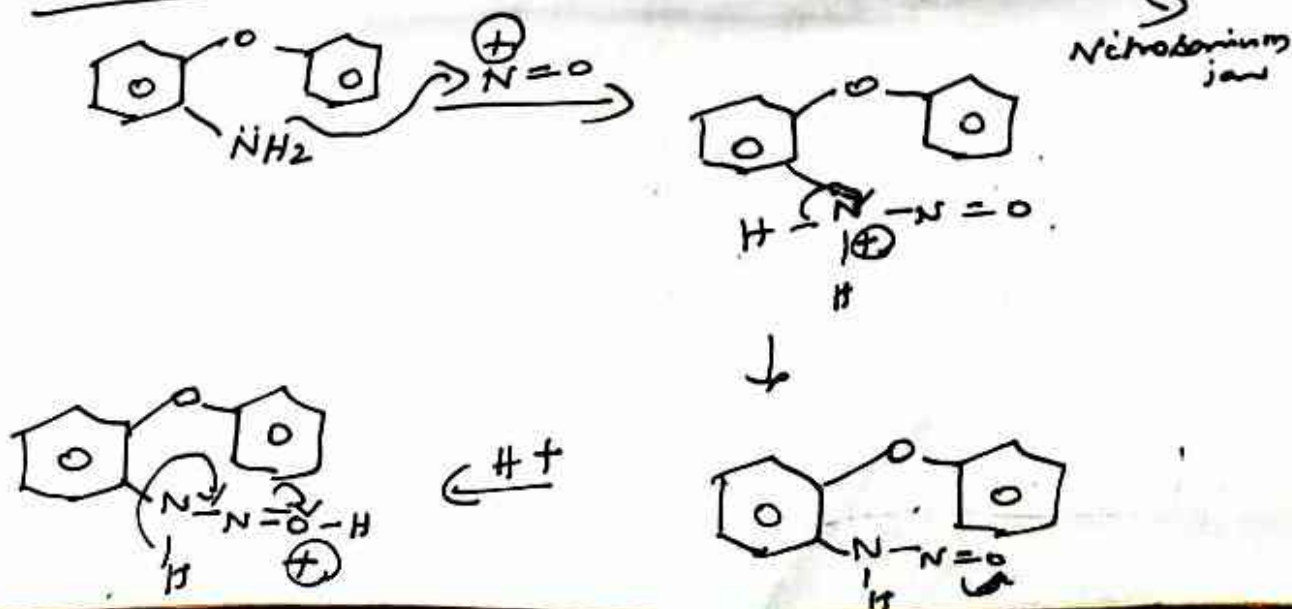


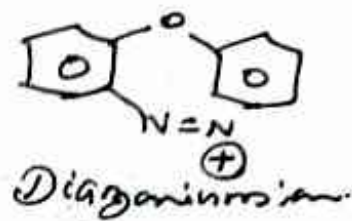
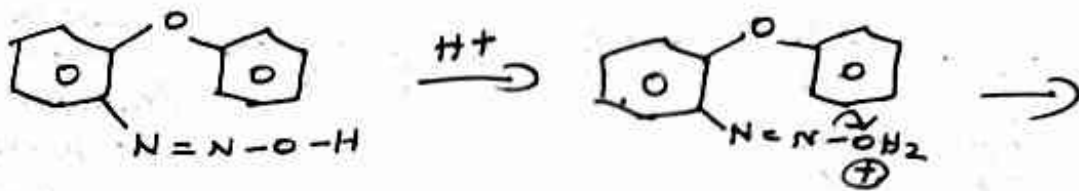


① Predict the products and suggest suitable mechanism.

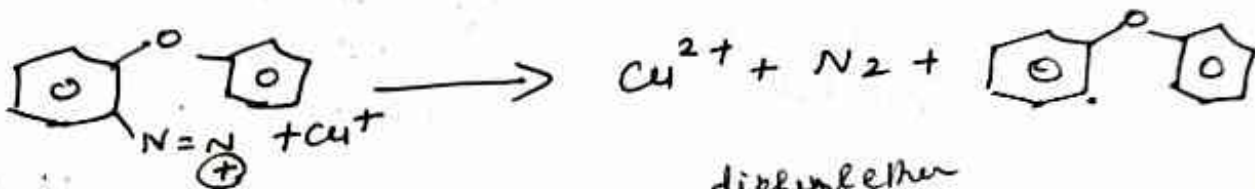


Mechanism:- Step I Formation of nitrosating agent
 $\text{NaNO}_2 + \text{HCl} \rightarrow \text{HONO} + \text{NaCl}$
 $\text{HONO} + \text{H}^+ \rightarrow \text{H}_2\text{O} + \text{N}^+=\text{O} \rightarrow \text{NO}^+$
Step II:- Formation of diazonium ion:-





Step III Formation of aryl radical:-



Step IV Formation of ^{no diphenyl ether} 2-fluorobenzene:-

