

BCHCT-147

**ORGANOMETALLICS,
BIOINORGANIC CHEMISTRY,
POLYNUCLEAR HYDROCARBONS
AND UV, IR SPECTROSCOPY**

VOL.

2

**METHYLENE, POLYNUCLEAR AROMATIC,
HETEROAROMATIC COMPOUNDS AND
APPLICATIONS OF SPECTROSCOPY TO
SIMPLE ORGANIC MOLECULES**

BLOCK 3

**METHYLENE, POLYNUCLEAR AROMATIC AND
HETEROAROMATIC COMPOUNDS**

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BLOCK 4

**APPLICATIONS OF SPECTROSCOPY TO SIMPLE
ORGANIC MOLECULES**

59

BCHET-147

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Block

3

**METHYLENE, POLYNUCLEAR AROMATIC AND
HETEROAROMATIC COMPOUNDS**

UNIT 8

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BLOCK-3: METHYLENE, POLYNUCLEAR AROMATIC AND HETEROAROMATIC COMPOUNDS

In the previous courses, you have studied about the chemistry of simple aliphatic and aromatic compounds. In this block, you will study about methylene compounds, polynuclear aromatic compounds and heterocyclic compounds. This block has three Units.

Unit 8 discusses the active methylene compounds. In this unit, the structure, synthesis and synthetic applications of ethyl acetoacetate have been explained in detail.

In Unit 9, you will learn another kind of aromatic compounds which are having more than one aromatic ring. We call them as polynuclear aromatic hydrocarbon (PAHs). In this unit, you will study the nomenclature of their derivatives along with their properties and uses.

In the unit 10, we shall discuss the heterocyclic hydrocarbons, i.e., rings containing another element in addition to carbon atom. The presence of lone pair of electrons on nitrogen and other hetero atoms account for the difference in properties between heterocyclic and carbocyclic aromatic hydrocarbons. For example, unlike benzene, pyridine undergoes nucleophilic substitution, yet it resembles benzene, which mainly undergoes electrophilic substitution reactions. We shall study the isolation and preparation of furan, pyrrole, thiophene and pyridine from natural sources. We shall also discuss the chemical characteristics of these compounds.

Expected Learning Outcomes

After studying this unit, you will be able to

- define active methylene compounds and give their examples;
- write the IUPAC name of ethyl acetoacetate and explain the keto-enol tautomerism in it;
- discuss the preparation of ethyl acetoacetate using Claisen ester condensation;
- outline the synthesis of some organic compounds using ethyl acetoacetate;
- classify the types of polycyclic hydrocarbon and heterocyclic compounds;
- give IUPAC names of derivatives of polynuclear hydrocarbons and heterocyclic compounds;
- discuss the different methods for preparation of polynuclear hydrocarbons and heterocyclic compounds;
- discuss the important reactions of polynuclear hydrocarbons and heterocyclic compounds.

UNIT 8

ACTIVE METHYLENE COMPOUNDS

Structure

8.1	Introduction	Condensation
	Expected Learning Outcomes	8.4
8.2	Active Methylene Compounds	Synthetic Applications of Ethyl 3-Oxobutanoate: Preparation of Some Important Compounds
8.3	Ethyl Acetoacetate (Ethyl 3-Oxobutanoate)	8.5
	IUPAC Nomenclature	Summary
	Keto-Enol Tautomerism	8.6
	Preparation <i>via</i> Claisen Ester	Terminal questions
		8.7
		Answers

8.1 INTRODUCTION

In this unit, we are going to discuss the chemistry of active methylene compounds, specifically ethyl acetoacetate.

The unit will begin with a discussion on what type of compounds are called active methylene compounds. Then, the detailed study of ethyl acetoacetate will be taken up including the IUPAC nomenclature and keto-enol tautomerism exhibited by it. This will be followed by the description of synthesis of ethyl acetoacetate *via* Claisen ester condensation. Finally, the synthetic applications of ethyl acetoacetate will be illustrated by using the examples.

Expected Learning Outcomes

After studying this unit, you will be able to

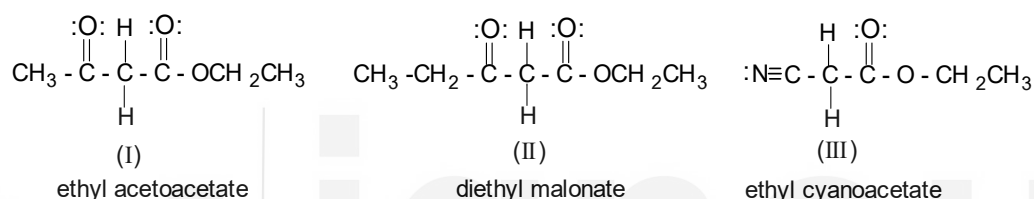
- ❖ define active methylene compounds and give their examples;
- ❖ write the IUPAC name of ethyl acetoacetate and explain the keto-enol tautomerism in it;
- ❖ discuss the preparation of ethyl acetoacetate using Claisen ester condensation; and
- ❖ outline the synthesis of some organic compounds using ethyl acetoacetate.

8.2 ACTIVE METHYLENE COMPOUNDS

You must be curious to know which type of compounds are active methylene compounds. How they are different from other compounds and what reactions do they undergo? Let us begin our journey to explore more about these compounds.

Active methylene compounds are those compounds in which the methylene, $-\text{CH}_2-$, group is *active*. But when does it happen? When the methylene, $-\text{CH}_2-$, group is present between two electron withdrawing groups such as carbonyl or cyano groups, it is easily deprotonated i.e., a hydrogen is lost from the $-\text{CH}_2-$ group in the presence of a base. That is why such compounds are called *active methylene compounds*.

Some examples of such compounds are shown below:



Ethyl acetoacetate is a colourless liquid and has a pleasant smell. It boils at 180.4°C with slight decomposition.

You can see that in all the above compounds, a $-\text{CH}_2-$ is present between either two carbonyl groups or a carbonyl group and a nitrile group. The methylene group present in all the above compounds is an **active** methylene group.

At this stage, you need not worry about their IUPAC nomenclature because we will be dealing with that in the next section.

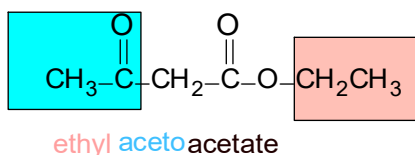
Also, in this unit, we will be discussing the chemistry of ethyl acetoacetate in detail. The chemistry of other similar compounds is parallel to that of the ethyl acetoacetate.

8.3 ETHYL ACETOACETATE (ETHYL 3-OXOBUTANOATE)

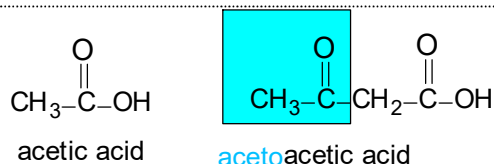
Ethyl acetoacetate is a very important active methylene compound. In this section, you will first study about the nomenclature of ethyl acetoacetate and then, the keto- enol tautomerism exhibited by it will be explained. After that its preparation *via* Claisen ester condensation will be discussed.

8.3.1 IUPAC Nomenclature

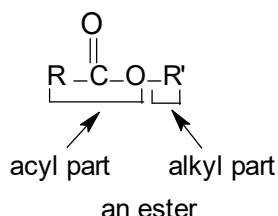
Ethyl acetoacetate has the following structure:



You can see in the structure that it is an ethyl ester of acetoacetic acid.

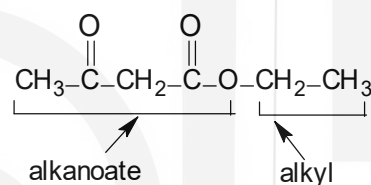


You already know from BCHCT-135 course, Block 3, Unit 10, Sec. 10.6 that esters are named as **alkyl alkanoates** according to the IUPAC nomenclature.

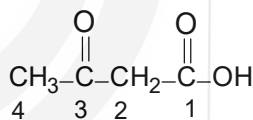


The **alkyl** part or group is cited first followed by the name of the **alkanoyl** (acyl) group which is obtained by replacing the *ic* ending of the carboxylic acid by the suffix *ate*.

Hence, ethyl acetoacetate has the **alkyl group** as *ethyl group* and the



alkanoate part is coming from the **substituted butanoic acid** which is 3-oxobutanoic acid.



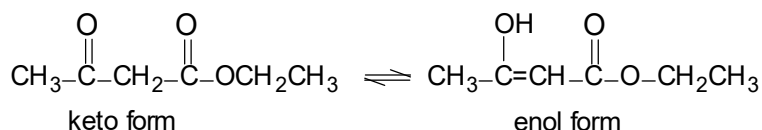
Thus, the IUPAC name of ethyl acetoacetate will be ethyl 3-oxobutanoate.

Having understood the nomenclature of ethyl acetoacetate, let us study an important feature of its structure, i.e. keto-enol tautomerism.

8.3.2 Keto-Enol Tautomerism

You have already studied in Block-4, Unit 18, Sec. 18.4 of BCHCT-133 course that in aldehydes and ketones, the *alpha hydrogen* (i.e. the hydrogen present on the carbon atom at α -position to the carbonyl group) is *acidic in nature*. You also studied there in Unit 18 in sub-Sec. 18.4.2 that *keto* and *enol* forms exist in a dynamic equilibrium, called *tautomerism*, in such compounds.

Similar equilibrium between keto and enol forms is possible in case of ethyl acetoacetate or ethyl 3-oxobutanoate. This is shown below:



Prior to 1910, chemists observed the reactions corresponding to the *keto* group and *enol* (*ene+ol*) group and the structure of ethyl 3-oxobutanoate could not be decided at that time. However, in 1911, Knorr could isolate both the keto and enol forms. Hence, it was established that ethyl 3-oxobutanate exhibits *keto-enol tautomerism*.

The next question that comes to your mind may be - which form out of the two - keto or enol, is predominant?

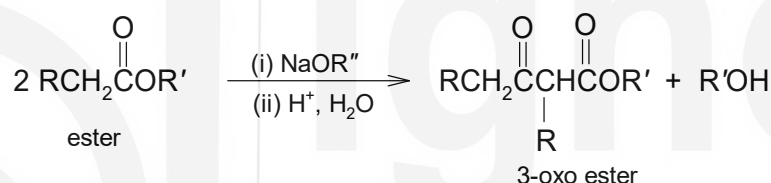
Well, since the keto and enol forms are in equilibrium, the equilibrium is affected by the factors such as solvent, temperature etc.

The *keto* form is more stable than the *enol* form and it predominates to the extent of 90% in the equilibrium mixture.

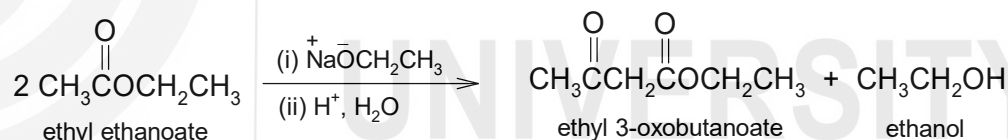
8.3.3 Preparation *via* Claisen Ester Condensation

3-Oxo esters are generally prepared by a condensation reaction, called **Claisen condensation**. Esters undergo *self condensation* on treatment with alkoxide bases to yield 3-oxo ester and an alcohol.

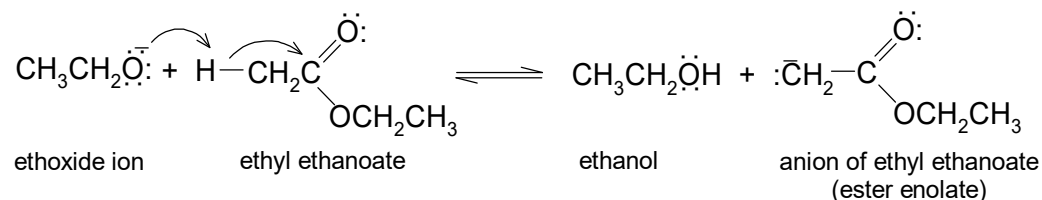
Claisen condensation is the ester equivalent form of aldol condensation about which you studied in Unit 18 of BCHCT-133 course.



Thus, ethyl ethanoate reacts with sodium ethoxide to yield ethyl 3-oxobutanoate and ethanol.

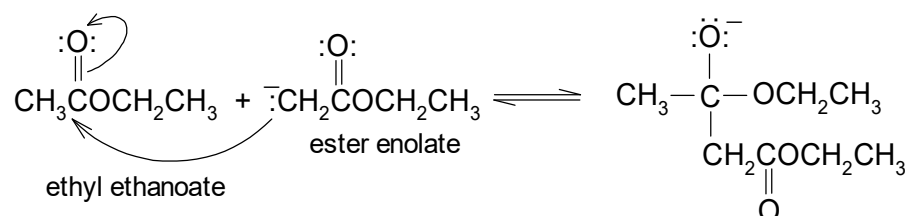


The reaction involves a series of equilibrium reactions. The first step is the abstraction of a proton from the ester by the base, i.e.,

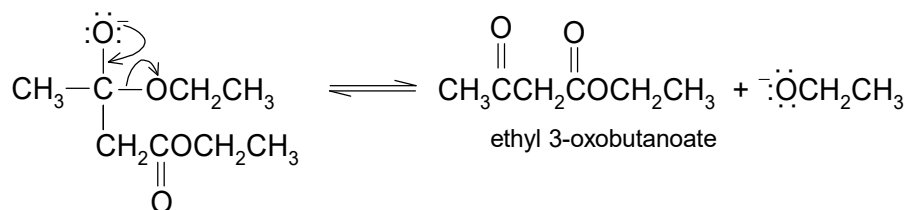


The ester enolate being a powerful nucleophile attacks the carbonyl carbon of the second ester molecule as shown below:

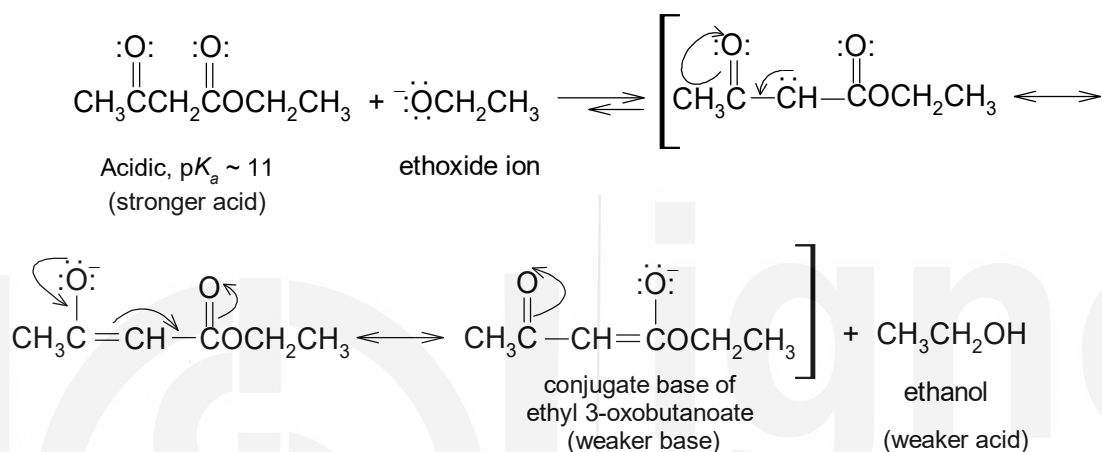
nucleophilic addition



This is followed by the elimination of ethoxide ion to yield ethyl 3-oxobutanoate.

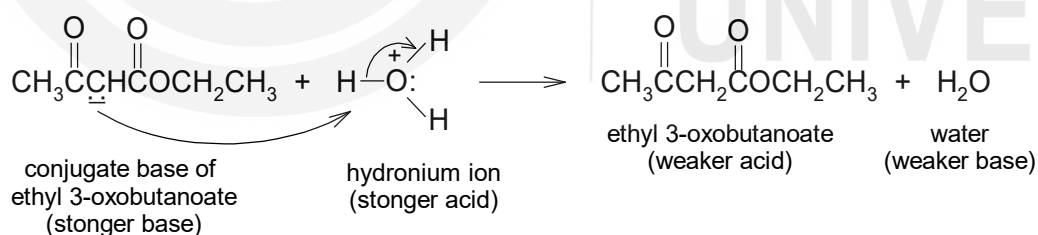


Ethyl 3-oxobutanoate so obtained is a *stronger acid* and hence, reacts with ethoxide ion to produce ethanol and the conjugate base of ethyl 3-oxobutanoate (a weaker base), as shown below:



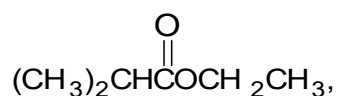
The equilibrium for this reaction lies towards the right hand side and provides the driving force for the reaction.

Subsequent acidification converts the above anion to its neutral form which is then isolated.



The formation of the final enolate ion is crucial for the Claisen condensation to occur. If a stable anion is not formed by deprotonation, the product is obtained only in trace amounts at equilibrium.

For example, starting from ethyl 2-methylpropanoate



if you write the similar steps you will see that the product has no acidic hydrogen and therefore formation of the final enolate is *not* possible.

Hence, the esters *having only one hydrogen at the carbon atom adjacent to the carbonyl group of the ester do not undergo Claisen condensation*.

SAQ 1

Write the possible series of reactions when ethyl 2-methylpropanoate is subjected to Claisen condensation and comment.

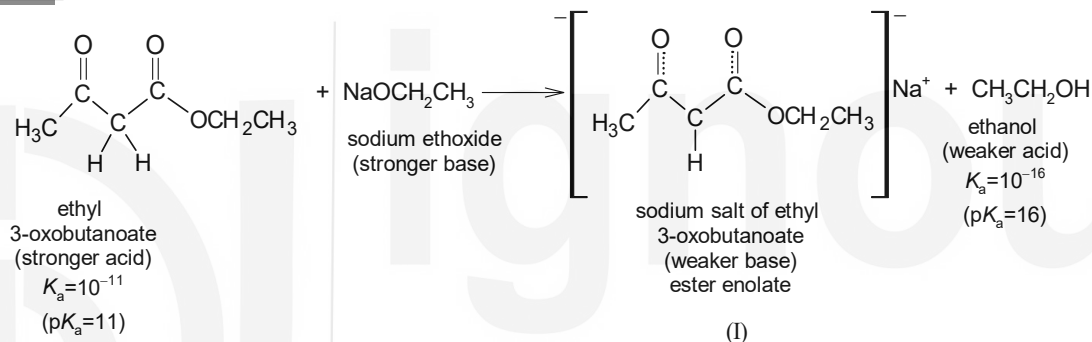
8.4 SYNTHETIC APPLICATIONS OF ETHYL ACETOACETATE: PREPARATION OF SOME IMPORTANT COMPOUNDS

R and R' groups can be alkyl, aryl or allyl groups. Primary and secondary halides can be used for the alkylation.

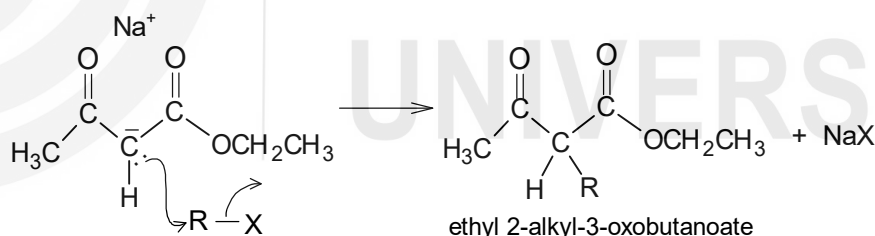
Having studied the preparation of ethyl 3-oxobutanoate, let us study its synthetic applications.

1. Formation of 3-Substituted and 3,3-Disubstituted Methylketones

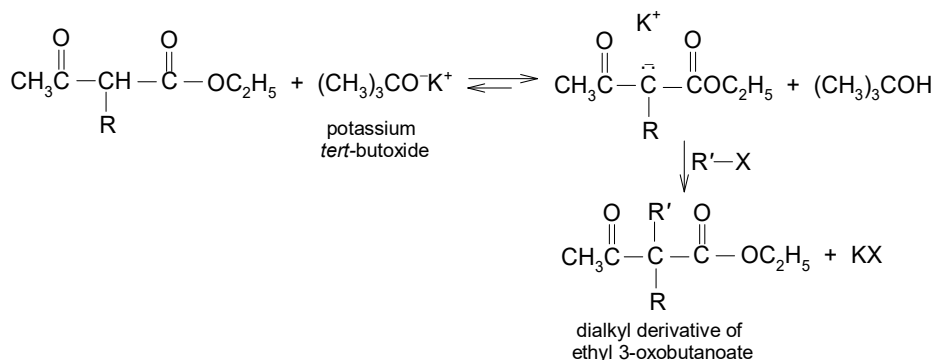
You have studied above that ethyl 3-oxobutanoate on treatment with sodium ethoxide yields the ester enolate.



The ester enolate (I) is nucleophilic and can be alkylated on treatment with alkyl halide.



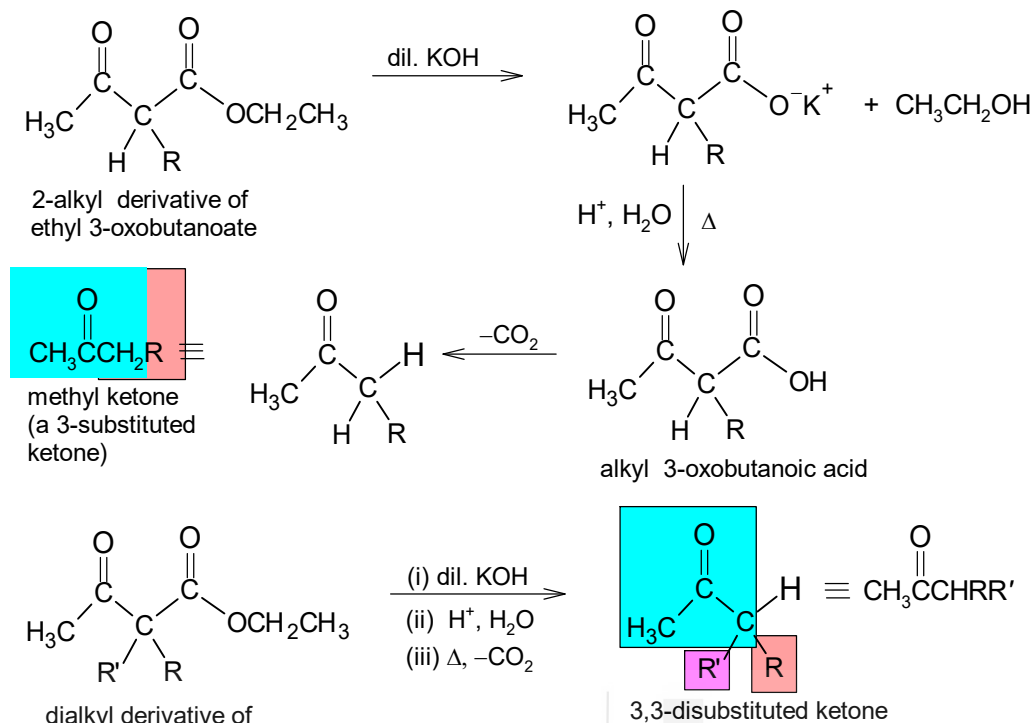
The 2-alkyl derivative still has one appreciably acidic hydrogen and we can carry out a second alkylation as shown below:



Ketonic hydrolysis

Ethyl 3-oxobutanoate and its alkyl derivatives on treatment with dilute aqueous or ethanolic KOH solution give *ketone* as a main product. Therefore, this hydrolysis is called *ketonic hydrolysis*. The ketone so obtained always contains the $\text{CH}_3\text{CO}-$ group.

Saponification of mono- and dialkyl derivatives as obtained above, followed by acidification will yield mono- and disubstituted ketones, respectively.

**Acid hydrolysis**

Ethyl 3-oxobutanoate and its alkyl derivatives on treatment with *concentrated* ethanolic KOH solutions yield potassium salts of carboxylic acids as product. These after acidification with inorganic acid yield *carboxylic acids*. That is why this hydrolysis is called *acid hydrolysis*.

Such a hydrolysis resulting in ketones as the product is called **ketonic hydrolysis**.

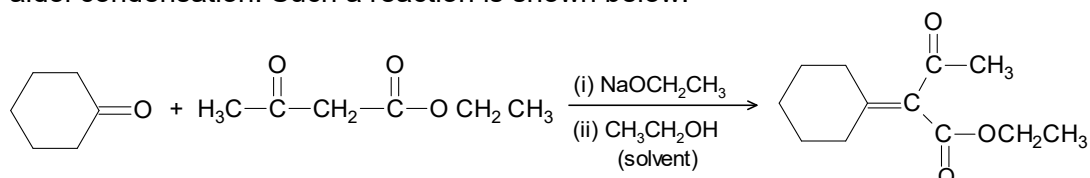
Thus, in the structure of 3-substituted ketone as the product, $\text{CH}_3\text{COCH}_2-$ part comes from the ethyl 3-oxobutanoate and rest of the part of the molecule comes from the respective alkyl/aryl/allyl halide.

SAQ 2

Using ethyl 3-oxobutanoate, how will you prepare 5-hexen-2-one? Write the other reagents used in the reaction.

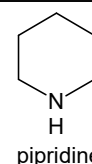
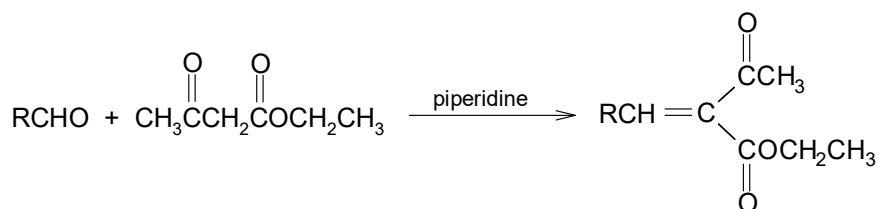
2. Formation of Unsaturated Carboxylic Acids: Reaction with aldehydes and ketones: Knoevenagel Condensation

Ethyl 3-oxobutanoate like other β -dicarbonyl compounds can undergo condensation with aldehydes and ketones which themselves do not undergo aldol condensation. Such a reaction is shown below:



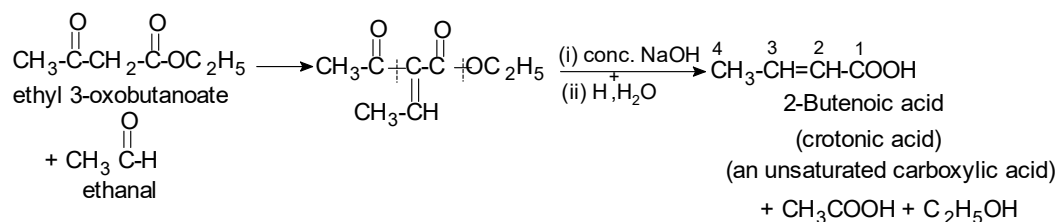
This reaction is called Knoevenagel condensation.

A reaction of ethyl 3-oxobutanoate with aldehydes takes place as is shown below:



The hydrolysis of the compound so obtained on acidification yields an unsaturated carboxylic acid as the product.

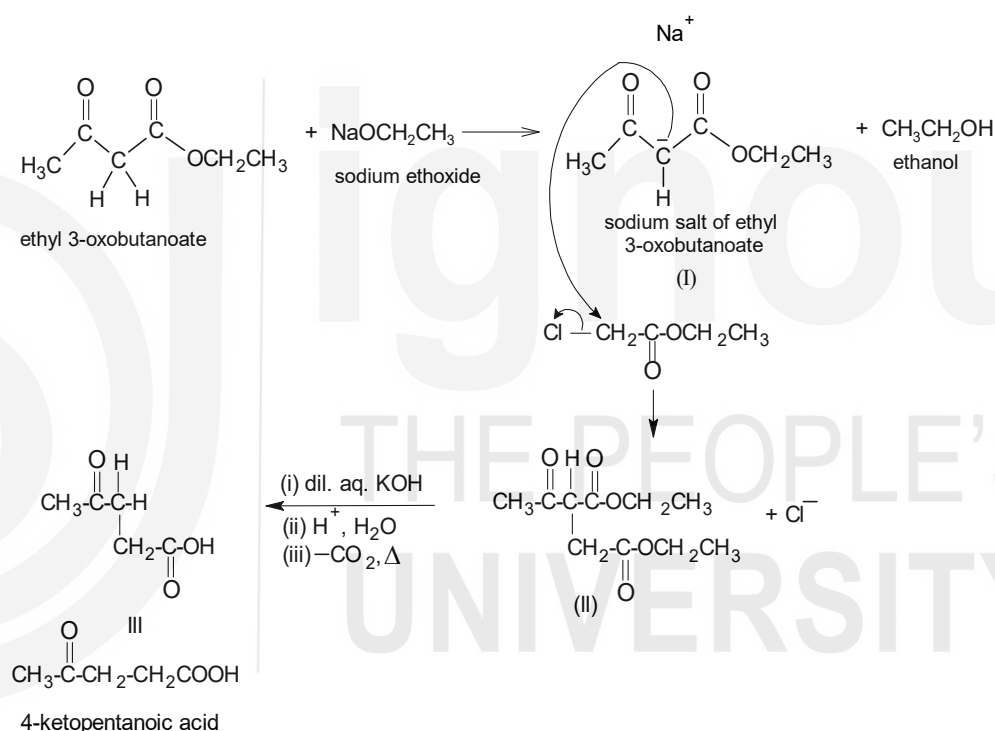
Let us understand this with the example of reaction of ethyl 3-oxobutanoate with ethanal.



3. Formation of Keto Acids: Reaction with alpha α -Halo esters

Sodium salt of ethyl 3-oxobutanoate (I) reacts with α -halo esters to first give the substituted product which on hydrolysis yields the keto acid as the product.

The reaction is shown below using α -chloro ester.

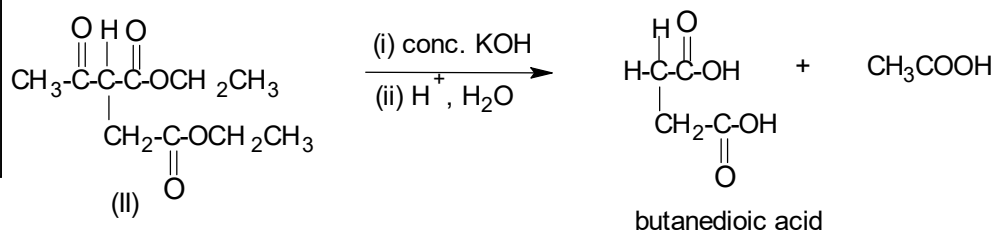


Such a hydrolysis yielding a carboxylic acid as the product is called **acidic hydrolysis**.

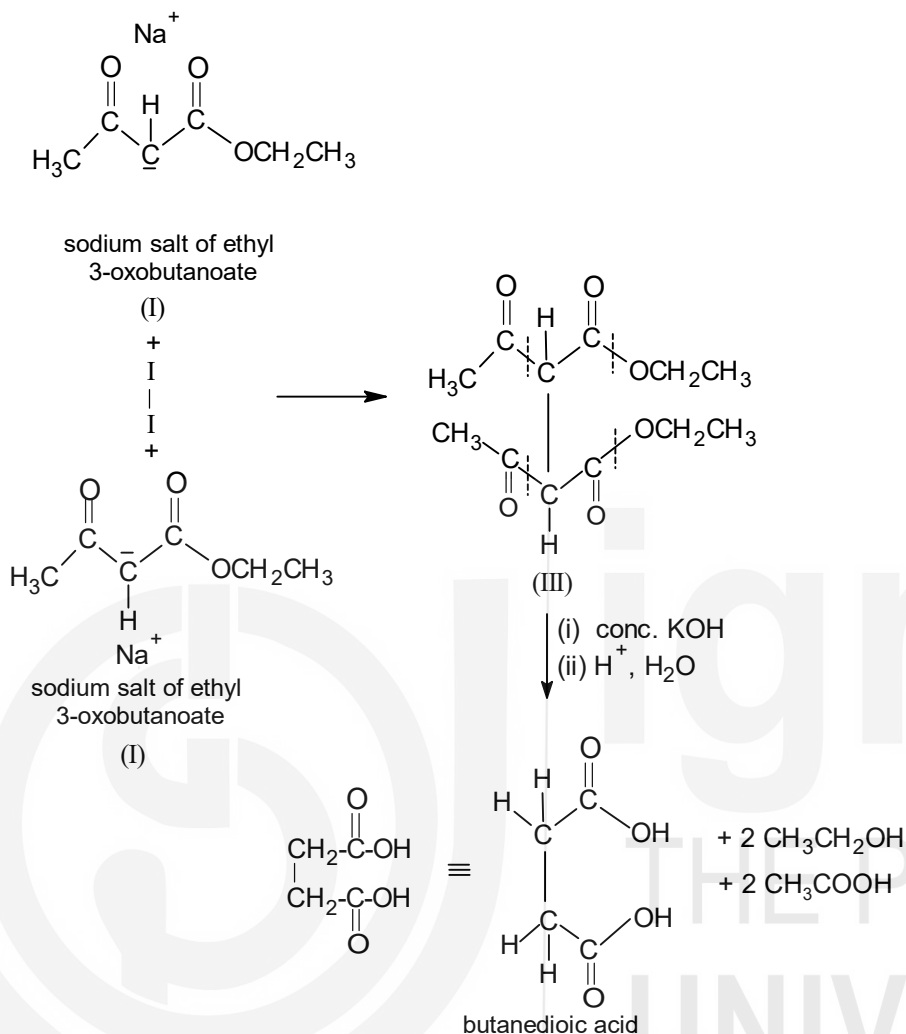
4. Synthesis of Dicarboxylic Acids

Compound (II) formed in the reaction of sodium salt of ethyl 3-oxobutanoate (I) with α -chloroester, when subjected to acid hydrolysis using conc. KOH followed by the acidification yields butanedioic acid as shown below:

If the hydrolysis is done using conc. alkali such as KOH or NaOH followed by acidification, then we get a dicarboxylic acid as the product.



Dicarboxylic acids can also be prepared starting from sodium salt ethyl 3-oxobutanoate (ester enolate) (I) by reaction with iodine. Compound (III) so obtained on acidic hydrolysis yields butanedioic acid (succinic acid) which is a dicarboxylic acid. This sequence of reactions is illustrated below:



Higher dicarboxylic acids can be obtained when the above reaction is carried out with suitable dihalo alkanes. Why don't you try the following SAQ.

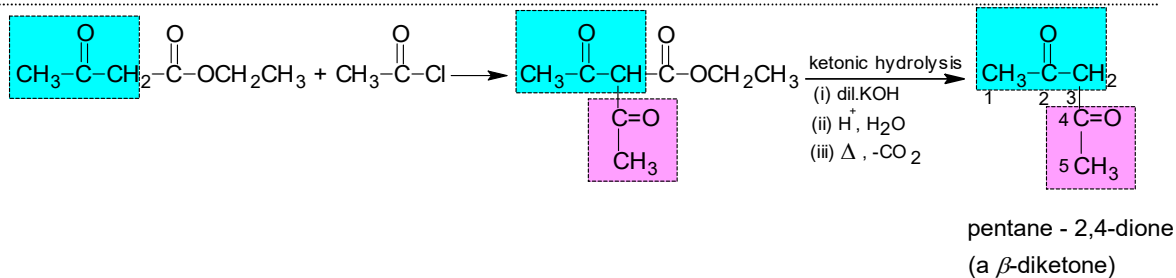
SAQ 3

Write the sequence of reactions when sodium salt of ethyl 3-oxobutanoate reacts with CH₂Cl₂ and the resulting compound is made to undergo acid hydrolysis. Also name the product formed.

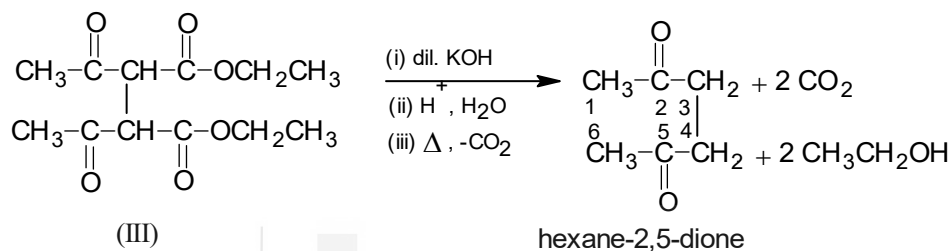
5. Formation of Diketones

1,3-Diketones, e.g. pentone -2,4-dione can be obtained by the reaction of ethyl 3-oxobutanoate with ethanoyl chloride as the alkanoyl chloride. Since the alkanoyl chloride used will react with the alcohol if used as the solvent.

Therefore, instead of taking alcohol as the solvent, the reaction is caused out in benzene in the presence of magnesium. The product so obtained is then subjected to hydrolysis followed by decarboxylation to yield the product as 1,3-diketone.

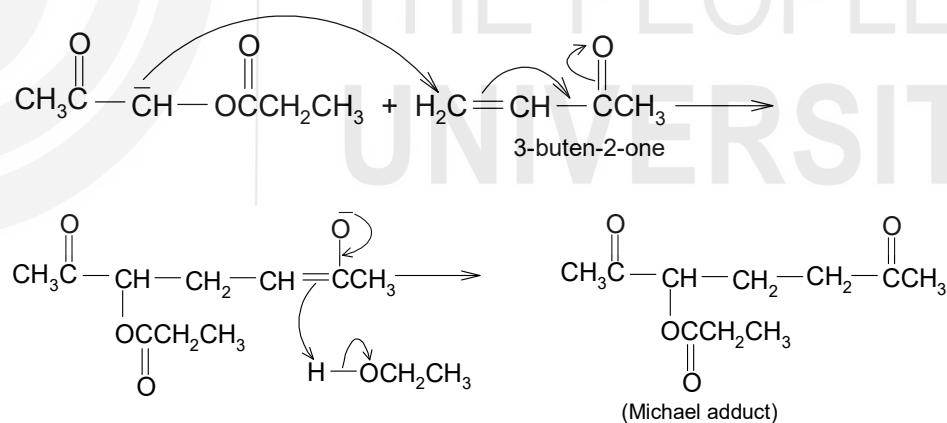


If instead of β -diketone, a γ -diketone is desired as the product, then compound (III) formed by the reaction of sodium salt of ethyl 3-oxobutanoate with I_2 can be taken. The ketonic hydrolysis of (III) will yield hexane-2,5-dione as the γ -diketone.

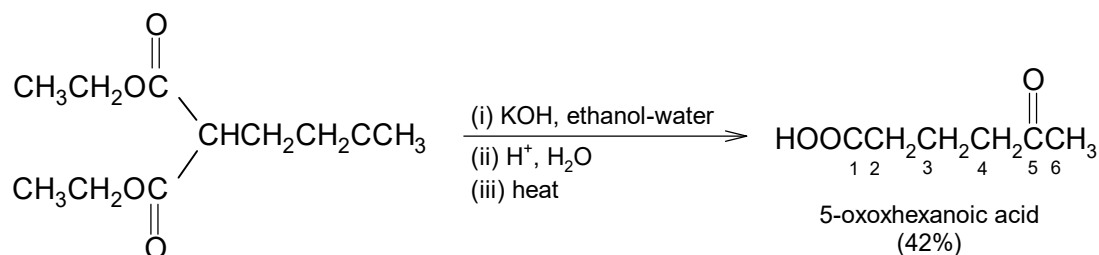


6. Reaction with α, β -unsaturated carbonyl compounds: Michael addition

Anion of sodium salt of ethyl 3-oxobutanoate reacts with α, β -unsaturated carbonyl compounds in the presence of catalytic amounts of a base by adding on to the β carbon atom. The reaction works with saturated aldehydes, ketones, nitriles and carboxylic acid derivatives such as esters, amides, etc., and is called **Michael addition**.



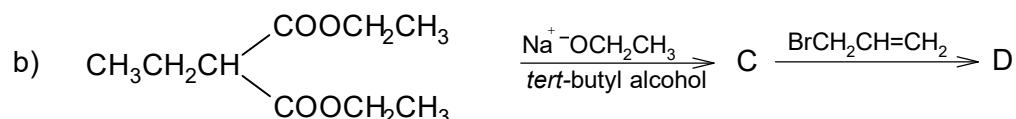
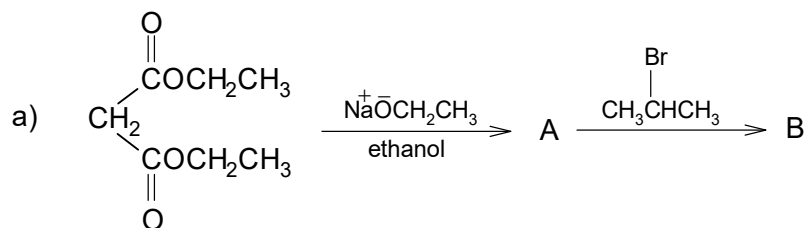
The Michael adduct so obtained on ester hydrolysis and decarboxylation yields a 5-keto acid.



Thus, you can see that we can synthesise a wide variety of compounds using ethyl 3-oxobutanoate.

Using the knowledge acquired in the above section, answer the following SAQ.

SAQ 4



8.5 SUMMARY

In this unit, you have learnt the following:

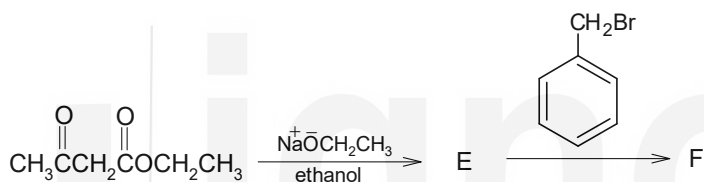
- Active methylene compounds are those compounds in which the methylene, $-\text{CH}_2-$, group is active because $-\text{CH}_2-$, group is present between two electron withdrawing groups
- The IUPAC name of ethyl acetoacetate is ethyl 3-oxobutanoate
- Ethyl 3-oxobutanoate exhibits keto-enol tautomerism.
- 3-Oxo esters are generally prepared by a condensation reaction, called Claisen condensation.
- Ethyl 3-oxobutanoate is versatile reagent in synthesis.
 - ❖ It can be used to prepare mono-and di-substituted ketones.
 - ❖ It yields unsaturated esters on reaction with aldehydes and ketones.
 - ❖ It can be used to synthesise diketones.
 - ❖ It undergoes Michael addition with unsaturated aldehydes, ketones.

Thus, it can be used to synthesise a large variety of organic compounds.

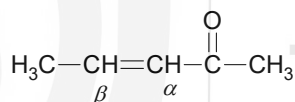
8.6 TERMINAL QUESTIONS

1. Which one of the following esters cannot undergo the Claisen condensation reaction? Write the Claisen condensation products of the other two.
 - a) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{COOCH}_2\text{CH}_3$
ethyl pentanoate
 - b) $\text{C}_6\text{H}_5\text{COOCH}_2\text{CH}_3$
ethyl benzoate

- c) $\text{C}_6\text{H}_5\text{CH}_2\text{COOCH}_2\text{CH}_3$
ethyl phenylethanoate
2. Using ethyl 3-oxobutanoate, how will you prepare the following ketones? Write the other reagents used in the reaction.
- a) 1-phenyl-1,4-pentanedione
- b) 4-phenyl-2-butanone
3. How can you obtain hexanedioic acid starting from ethyl 3-oxobutanoate? Write the reactions involved.
4. Write the sequence of the reactions and the product formed when sodium salt of ethyl 3-oxobutanoate is alkylated using a dihaloalkane instead of two different alkyl halides and the product so obtained is hydrolysed using dil. KOH and finally acidified and heated.
5. Identify compounds E and F in the following sequence of reactions:



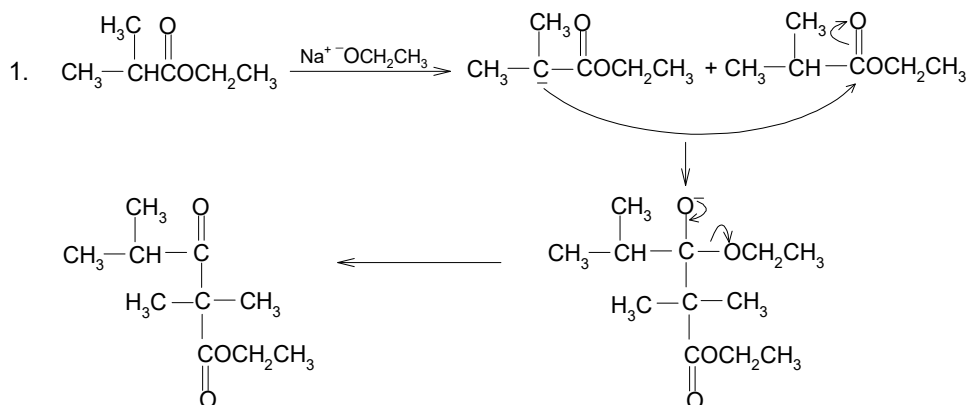
6. Write the steps involved when ethyl 3-oxobutanoate reacts with the following ketone:



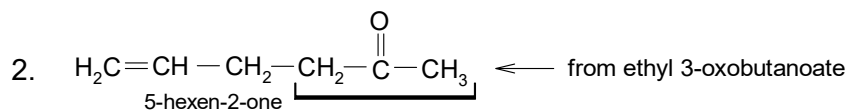
And, then the resulting product undergoes hydrolysis of the ester group followed by the decarboxylation.

8.7 ANSWERS

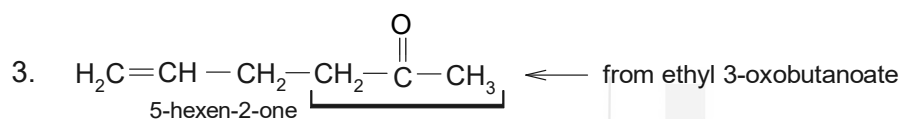
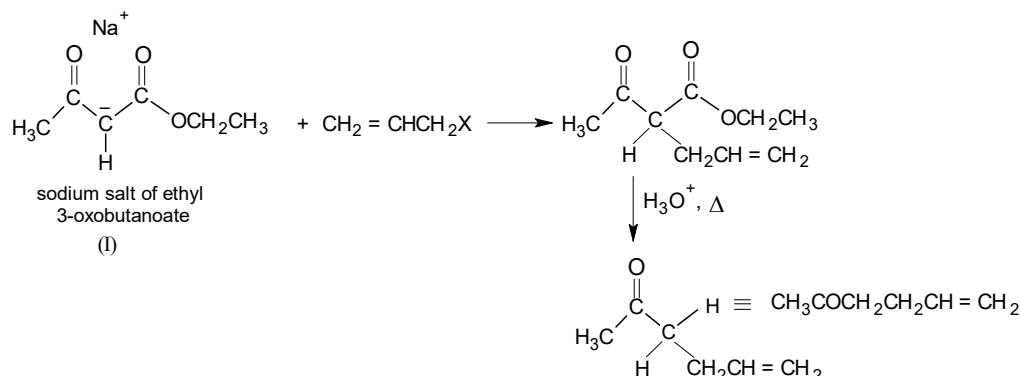
Self Assessment Questions



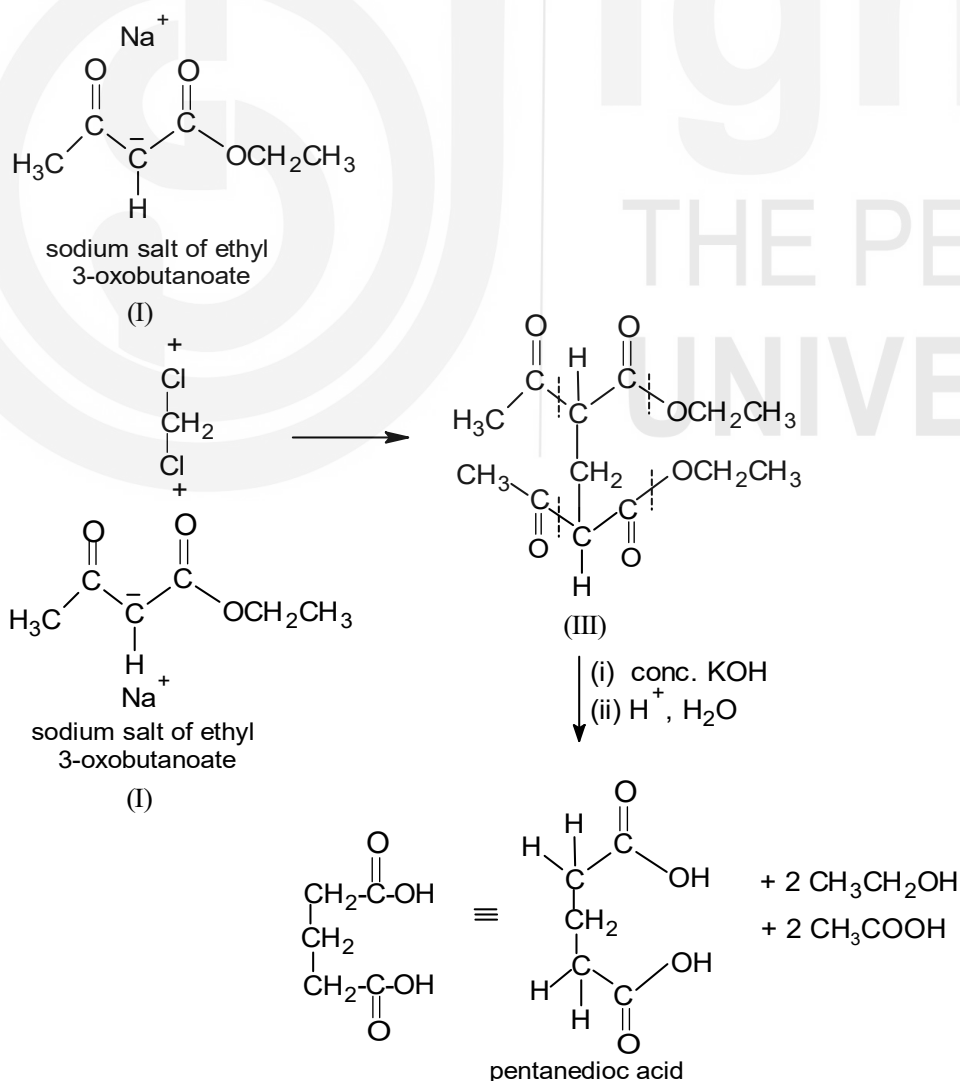
Since there is no hydrogen on the carbon atom adjacent to the ester carbonyl carbon, the equilibrium cannot shift towards the right hand side to yield the 3-oxo ester.



Therefore, the required halide is $\text{H}_2\text{C}=\text{CH}-\text{CH}_2\text{X}$

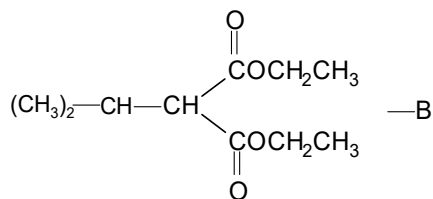
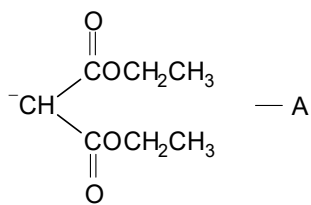


Therefore, the required halide is $\text{H}_2\text{C}=\text{CH}-\text{CH}_2\text{X}$

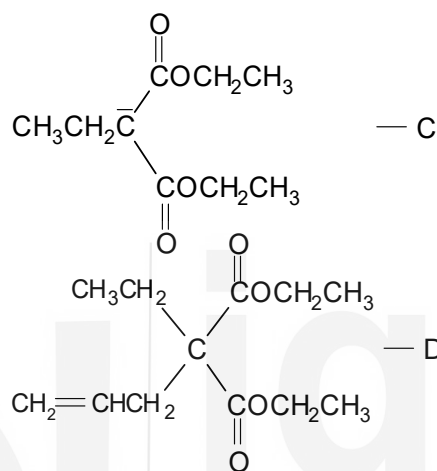


The product formed in this reaction is 1, 5-pentanedioic acid.

4. a)



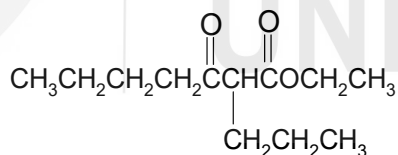
b)



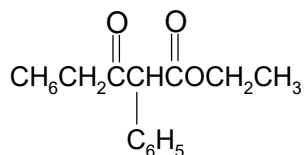
Terminal Questions

1. Ethyl benzoate b) cannot undergo the Claisen condensation as it does not have α -hydrogen. The Claisen condensation products of compounds given in a) and c) are given below.

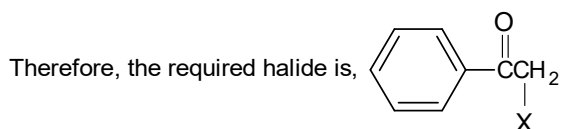
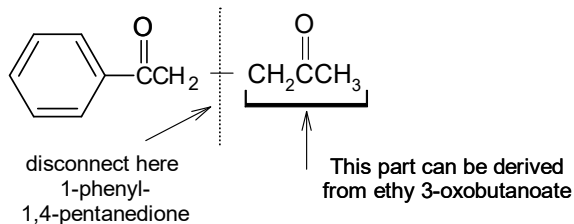
a)



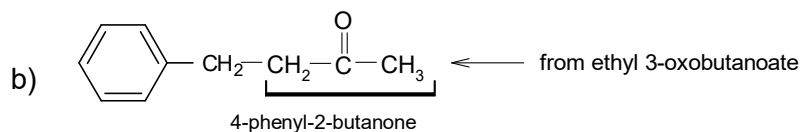
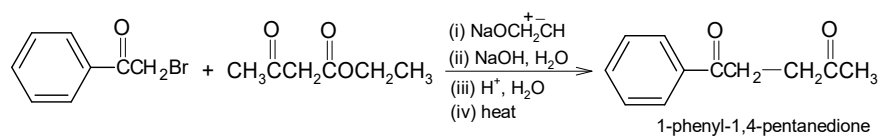
b)



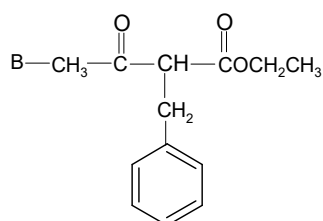
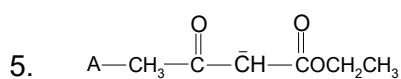
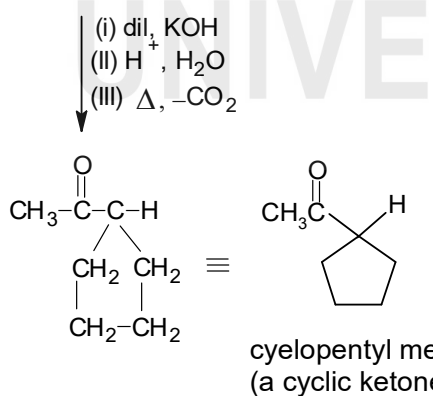
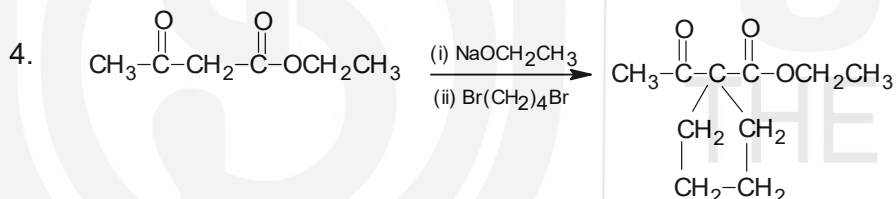
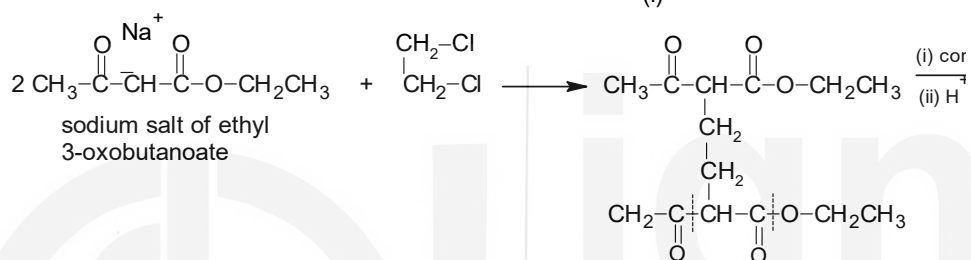
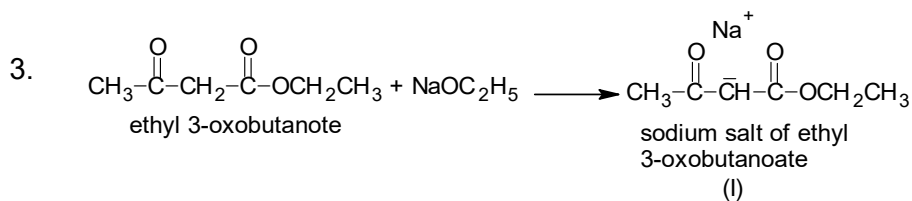
2. a)



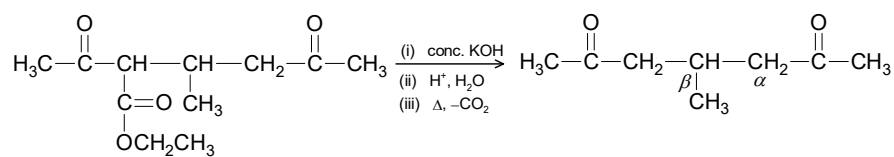
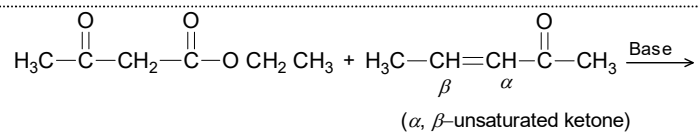
The reaction can be written as,



The required halide is



6.



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UNIT 9

POLYNUCLEAR AROMATIC HYDROCARBONS

Structure

9.1 Introduction	9.7 Reactions of Polycyclic Aromatic Hydrocarbons
Expected Learning Goals	Electrophilic Substitution Reactions
9.2 Polynuclear Aromatic Hydrocarbons: An Introduction	Mechanism of Electrophilic Substitution Reactions of Naphthalene
9.3 Sources	Oxidation of Naphthalene
9.4 Properties and Uses	Reduction of Naphthalene
9.5 Nomenclature of Naphthalene and Anthracene Derivatives	9.8 Summary
9.6 Aromaticity of Polynuclear Hydrocarbons	9.9 Terminal Questions
Huckel's Rule	9.10 Answers

9.1 INTRODUCTION

In the previous Unit, we have learnt about Active Methylene compounds. So far our study of the aromatic cyclic systems was restricted to only one aromatic ring. In this unit, we will study aromatic compounds having more than one aromatic ring. Such compounds are known Polynuclear Aromatic Hydrocarbons (PAHs). First we will learn the basic concept of polynuclear aromatic hydrocarbons followed by their properties and uses. In the next part of this unit, we will discuss the nomenclature of the derivatives of two most common polynuclear aromatic hydrocarbons i.e. naphthalene and anthracene.

You have already learnt about the aromaticity in Unit-19 of the course BCHCT-133. In this Unit we will not discuss aromaticity of these compounds in detail but we will recall Huckel's rule and applied to naphthalene and

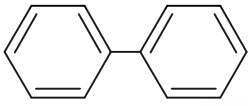
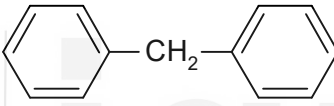
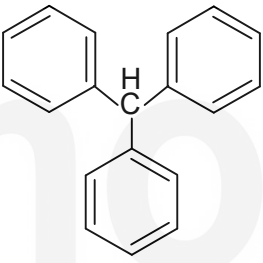
anthracene. At the we will explain some characteristic reactions of these compounds.

9.2 POLYNUCLEAR AROMATIC HYDROCARBONS: AN INRODUCTION

Polynuclear aromatic hydrocarbon is an assembly of more than one aromatic ring in the molecule. Depending upon the mode of attachment of various rings, the polynuclear aromatic hydrocarbons may be classified into two broad classes: (i) isolated benzenoid hydrocarbons, and (ii) condensed or fused benzenoid hydrocarbons.

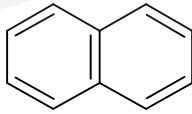
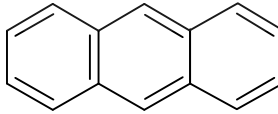
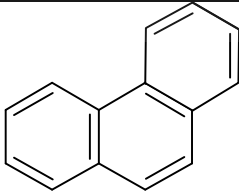
i) Isolated Benzenoid Hydrocarbons:

In isolated systems, two or more rings are joined to each other directly or through carbon chain. Some of these are biphenyl, diphenylmethane and triphenylmethane. The structure of these compounds are given bellow.

		
Biphenyl	Diphenylmethane	Triphenylmethane

ii) Condensed or Fused Benzenoid Hydrocarbon:

The condensed or fused benzenoid hydrocarbons are those in which two or more benzene rings are fused together in such a way that each pair of rings shares two carbons. These include compounds like naphthalene, anthracene, phenanthrene etc.

		
Naphthalene	Anthracene	Phenanthrene

The condensed polynuclear aromatic hydrocarbons are by far the larger and the more important groups. A large number of these compounds have been found to possess carcinogenic (cancer producing) activity. In this unit, we will discuss the chemistry of naphthalene and anthracene only.

SAQ 1

What are different types of polynuclear aromatic hydrocarbons?

9.3 SOURCES

Polycyclic aromatic hydrocarbons are a group of semi-volatile organic compounds that are present in natural sources such as bitumen, coal, crude oil, wood, garbage and gasoline. These compounds are mainly emitted from exhaust fumes of vehicles, including automobiles, railways, ships, aircrafts, and other motor vehicles.

Polycyclic aromatic hydrocarbons can also be produced geologically, when organic sediments are chemically transformed into **fossil fuels** such as oil and coal. The rare minerals **idrialite**, **curtisite**, and **carpathite** consist almost entirely of polycyclic aromatic hydrocarbons, that originated from such sediments that were extracted, processed, separated, and deposited by very hot fluids. They may result from the incomplete combustion of organic matter in natural **wildfires**. **Perylene** can also be generated in **anaerobic sediments** from existing organic materials.

Fossil fuels are natural fuels formed in the geological past from the remains of living organisms

Idrialite is a rare hydrocarbon mineral and occurs as soft orthorhombic crystals. It is named after Idrija, town in Slovenia, where its occurrence was first described.

Curtisite is hydrocarbon $C_{24}H_{18}$ found at Skaggs Springs, California.

Carpathite is a rare hydrocarbon mineral.

SAQ 2

Fill in the following blanks:

- Polycyclic aromatic hydrocarbons are present in----- sources.
- _____ can also be generated in anaerobic sediments from existing organic material.
- Polycyclic aromatic hydrocarbons are emitted from exhaust fumes of _____.

9.4 PROPERTIES AND USES

Generally polycyclic aromatic hydrocarbons have high melting point, boiling point and low vapor pressure. These are nonpolar and **lipophilic** compounds. These compounds are hydrophobic and are generally insoluble in water. The larger members are also poorly soluble in organic solvents and in lipids. The chemical stability, low water solubility, and high absorption capacity of polycyclic aromatic hydrocarbons contribute greatly to their persistence in the environment.

Among the polycyclic aromatic hydrocarbons, naphthalene is a white crystalline solid. Naphthalene is a nonpolar compound and insoluble in polar solvents like water. Naphthalene is soluble in carbon tetrachloride, chloroform carbon disulfide, methanol, ethanol, diethylether benzene and toluene. Naphthalene is a solid that sublimates at standard atmospheric temperature with the sublimation point at around 355 K.

Naphthalene is used as an insecticide, in the form of naphthalene balls for protecting woolen clothings from insects. Polynuclear aromatic hydrocarbons are commonly used in pharmaceuticals, agricultural products, photographic products, thermosetting plastics, lubricating materials, and other chemical industries. These compounds are also used in manufacture of pigments, dyes, plastics and pesticides. NASA's **Spitzer Space Telescope** and **James Webb Telescope** include instruments for obtaining both images and spectra of light

Perylene or perilene occurs as a brown solid. It may be carcinogenic

Lipophilicity: is ability of a compound to dissolve in fats, oils, lipids, and non-polar solvents .

emitted by Polynuclear aromatic hydrocarbons associated with star formation. These images can trace the surface of star-forming clouds in our own galaxy or identify star forming galaxies in the distant universe.

Effect on Human health

Polycyclic aromatic hydrocarbons are carcinogenic in nature. Benzopyrene is the most common to cause cancer. Increased incidences of lung, skin and bladder cancers are associated with occupational exposure to polycyclic aromatic hydrocarbons. Long-term exposure to polycyclic aromatic hydrocarbons may cause eye cataracts or damage kidney and liver. Repeated skin contact to the naphthalene can result in redness and inflammation of the skin.

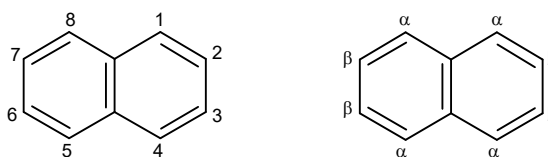
SAQ 3

Write "T" for true and "F" for false in the boxes for the following statements.

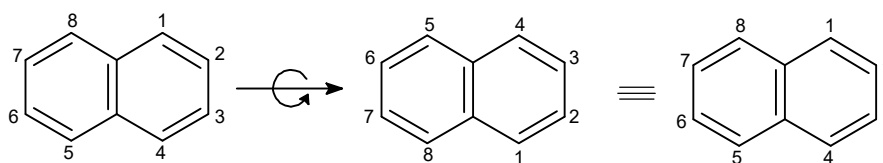
- i) Polycyclic aromatic hydrocarbons have lower melting point. ☐
- ii) Polycyclic aromatic hydrocarbons are polar in nature. ☐
- iii) Smaller members of Polycyclic aromatic hydrocarbons are soluble in water. ☐
- iv) Polycyclic aromatic hydrocarbons are carcinogenic in nature. ☐
- v) Repeated skin contact to the naphthalene can result in inflammation of the skin. ☐

9.5 NOMENCLATURE OF NAPHTHALENE AND ANTHRACENE DERIVATIVES

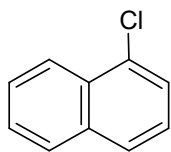
You may recall that in benzene the numbering starts at the position of a substituent, but in these compounds the numbering is fixed by convention and does not change with the position of a substituent. Various positions of naphthalene are numbered as shown below:



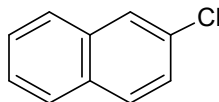
As indicated above we do not give any number to fused carbon atoms. If you rotate the molecule upside down you will notice that positions 1 and 4 are same and positions 5 and 8 are same. Similarly positions 2 and 3 are same and positions 6 and 7 are same.



In case of only one substitution, say chlorine, in naphthalene only two isomers are possible i.e. 1-chloronaphthalene (α -chloronaphthalene) and 2-chloronaphthalene (β -chloronaphthalene).

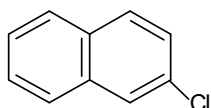


1-chloronaphthalene

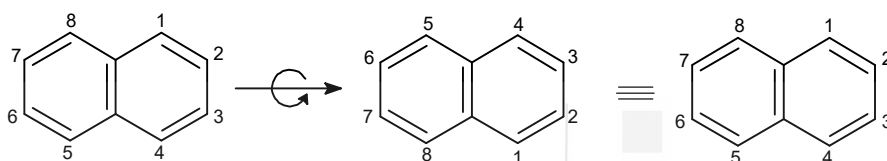


2-chloronaphthalene

Guess the name of the following compound.

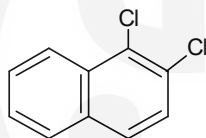


Can we call it 3-chloronaphthalene? No. As mentioned above, here position 2 and 3 are same.

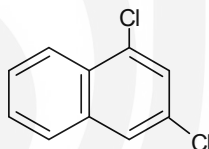


Actually it is 2-chloronaphthalene. 3-chloronaphthalene does not exist.

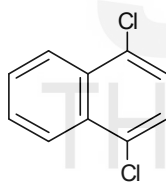
If the rings contains two or more identical substituents the prefixes di, tri, etc are used, e.g. dichloro or trichloro i.e.



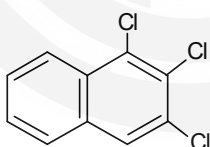
1,2-dichloronaphthalene



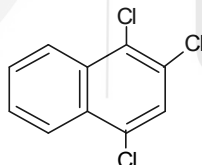
1,3-dichloronaphthalene



1,4-dichloronaphthalene

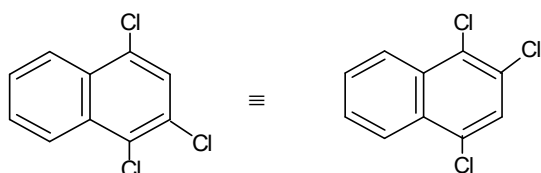


1,2,3-trichloronaphthalene



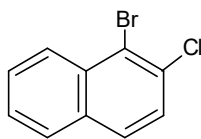
1,2,4-trichloronaphthalene

What name will you give to the following compound?

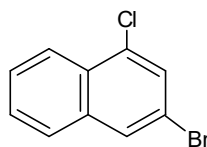


Can we call it 1,3,4-trichloronaphthalene? No. As mentioned above, here position 2 and 3 are same. Actually it is 1,2,4-trichloronaphthalene.

If more than one type of atoms or groups is attached, numbering of the compound will remain same but their names are arranged in alphabetical order, as shown below:

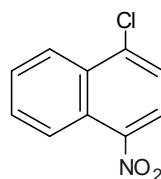


1-bromo-2-chloronaphthalene



2-bromo-1-chloronaphthalene

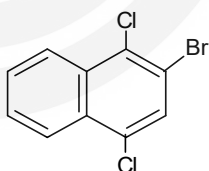
Now a question arises which is the 1-position in following compound? Will it be 1-chloro-4-nitronaphthalene or 4-chloro-1-nitronaphthalene? In such cases there is a IUPAC rule i.e.:



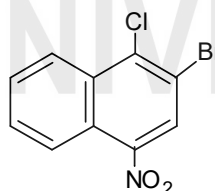
The priorities for selection of principal functional group are given below in the order of decreasing precedence. The order is: carboxylic acid, sulphonic acid, ester, acid anhydride, acyl halide, amide, nitrile, aldehyde, ketone, alcohol, thiol, amine, imine, alkyne, alkene, ethers, halides, nitro.

In this example nitro group comes after halogen (chlorine). Therefore, the name of this compound will be **1-chloro-4-nitronaphthalene** not 4-chloro-1-nitronaphthalene.

Similarly,

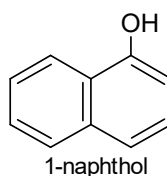


2-bromo-1,4-dichloronaphthalene



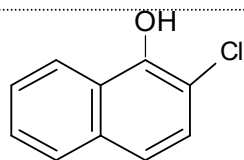
2-bromo-1-chloro-4-nitronaphthalene

Now take the example of –OH substituted naphthalene.



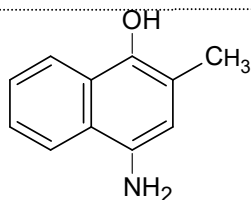
1-naphthol

According to IUPAC nomenclature the name of above compound is 1-naphthol. Here naphthol is considered as a parent hydrocarbon, when halogen or any other groups are substituted to naphthol, they are named as a prefix of naphthol. For example:



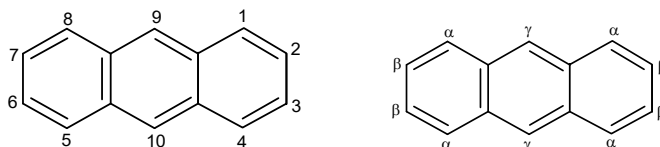
2-chloro-1-naphthol

or

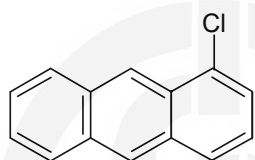


4-amino-2-methyl-1-naphthol

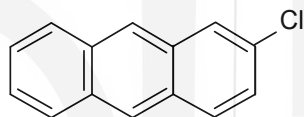
Now let us discuss nomenclature of anthracene. Various positions of anthracene are numbered as shown below:



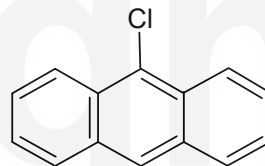
In case of only one substitution in anthracene, say chlorine, there is possibility of three isomers, i.e. 1-chloroanthracene, (α -chloroanthracene), 2-chloroanthracene (β -chloroanthracene), and 9-chloroanthracene (γ -chloroanthracene).



1-chloroanthracene

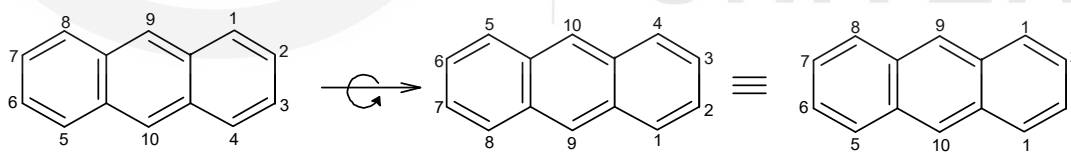


2-chloroanthracene



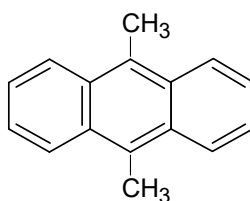
9-chloroanthracene

Like naphthalene, if you rotate the molecule of anthracene upside down you will notice that positions 1 and 4 are same, positions 5 and 8 are same and positions 9 and 10 are same. Similarly positions 2 and 3 are same and position 6 and 7 are same.



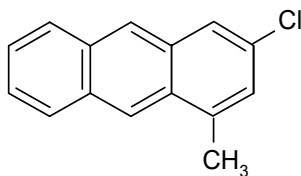
Like naphthalene, if the rings contains two or more identical substituents the prefixes di, tri, etc are used.

Now take the example of disubstituted anthracene:

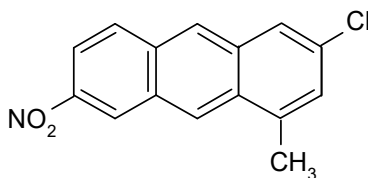


9,10-dimethylantracene

As mentioned above if more than one type of atoms or groups is attached to the anthracene their names are arranged in alphabetical order, as shown below:



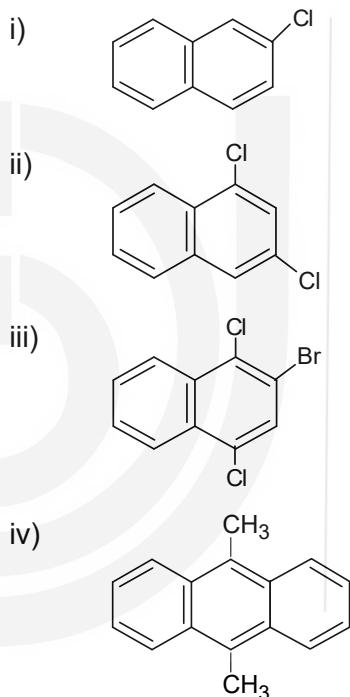
2-chloro-4-methylantracene



2-chloro-4-methyl-6-nitroanthracene

SAQ 4

Give IUPAC name of the following compounds.



9.6 AROMATICITY OF POLYNUCLEAR HYDROCARBONS

A hydrocarbon can be an aromatic compound if it follows the Huckel's Rule. Details of this rule you have studied in Unit 19 of Course BCHCT-133. Here we will only recall some important points of Huckel's Rule.

9.6.1 Huckel's Rule

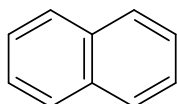
According to Hückel's Rule, a compound can be aromatic if it has the following distinct properties:

- a compound must contain $(4n + 2)$ π electrons, where “ n ” is any number i.e. 1,2,3,4,..... This means that only the ring with 2, 6, 10, 14,..... π electrons may be aromatic.
- the compound must be co-planar.

In this Unit we will take the examples of naphthalene and anthracene.

Naphthalene

How can we explain the aromaticity of naphthalene? The naphthalene has 10 π electrons.



No. of π -electrons = 10

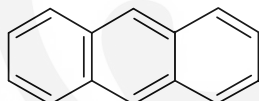
If $n = 2$

$4 \times 2 + 2 = 10$ π -electrons

Here, the Hückel's rule is followed. It has 10 π -electrons, which are required for a compound to be aromatic. All the carbon atoms of naphthalene are sp^2 hybridised and it is a planar molecule too. It is an excellent example of an aromatic system.

Similarly we can take the example of anthracene.

Anthracene



No. of π -electrons = 14

If $n = 3$

$4 \times 3 + 2 = 14$ π -electrons

Anthracene has 14 π -electrons (Hückel's no.) and all the carbon atoms of anthracene are sp^2 hybridised and it is a planar molecule. Therefore, it is also an aromatic compound.

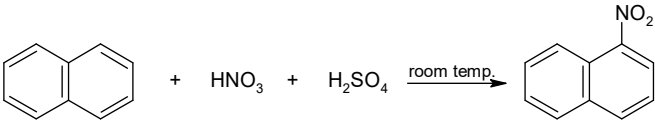
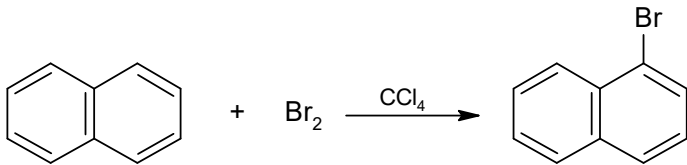
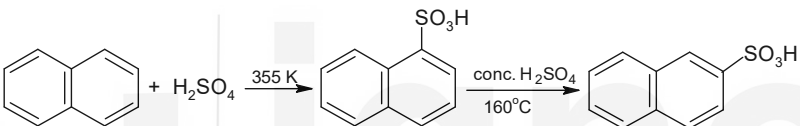
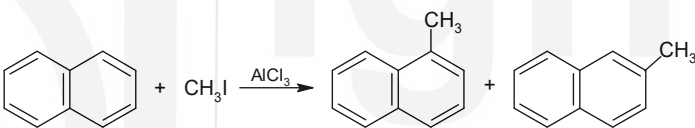
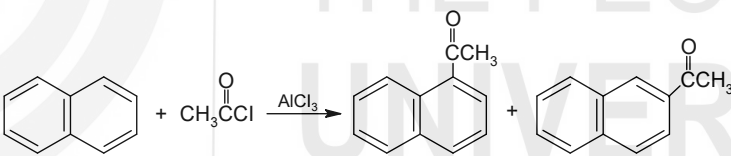
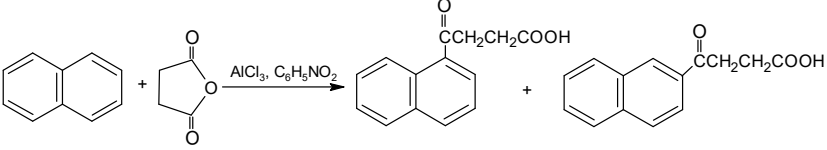
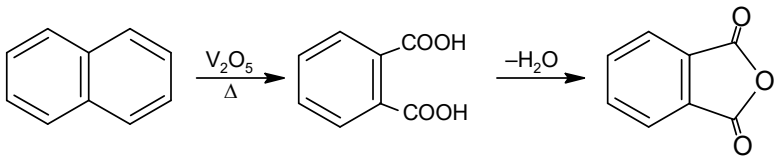
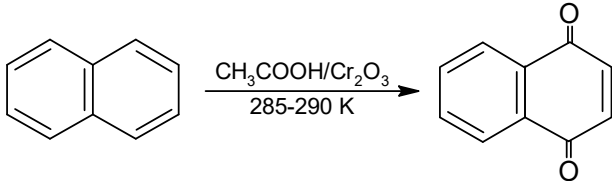
SAQ 5

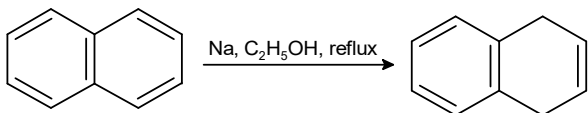
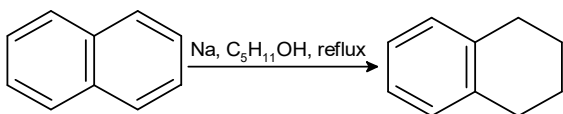
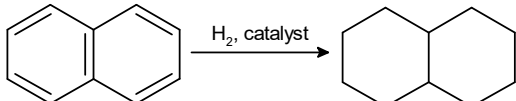
Anthracene is an aromatic compound. Explain.

9.7 REACTIONS OF NAPHTHALENE

Like, benzene, naphthalene undergoes usual electrophilic substitution reactions, oxidation and reduction. The naphthalene is more reactive towards these reactions than benzene. In this Unit we will concentrate mainly on reactions of naphthalene. Some important reactions of naphthalene are given in Table 9.1.

Table: 9.1 Reactions of Naphthalene

Sr. No.	Reactions
1.	Electrophilic substitution
a)	Nitration
	
b)	Halogenation
	
c)	Sulphonation
	
d)	Friedel-Crafts alkylation
	
e)	Friedel-Crafts acylation
i)	
ii)	
2.	Oxidation
a)	
b)	

3.	Reduction
a)	
b)	
c)	

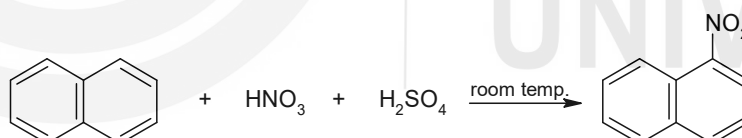
Let us discuss each reaction in little detail.

9.7.1 Electrophilic Substitution Reactions

Like benzene, polynuclear hydrocarbons also undergo electrophilic substitution reactions i.e. Nitration, Halogenation, Sulphonation, Friedel-Crafts alkylation and Friedel-Crafts acylation. The first substituent goes to 1-position (α -position); that means, the 1-position is more reactive than the 2-position (β -position). You can ask why it is so? We will explain this in section 9.7.2.

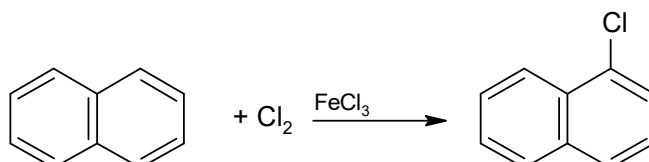
a) Nitration of Naphthalene

Nitration of naphthalene at room temperature occurs almost exclusively at 1-position, giving 1-nitronaphthalene. This reaction does not require any catalyst.



b) Halogenation of Naphthalene

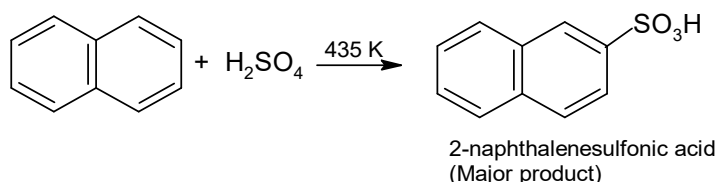
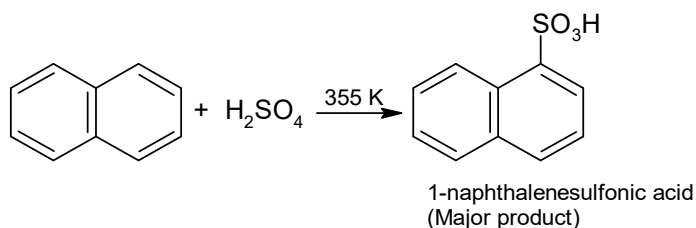
Chlorination and bromination of naphthalene in presence of FeCl_3 yield only one substituted product. 1-chloronaphthalene can form in presence of FeCl_3 . Bromination does not required any Lewis acid



c) Sulfonation of Naphthalene

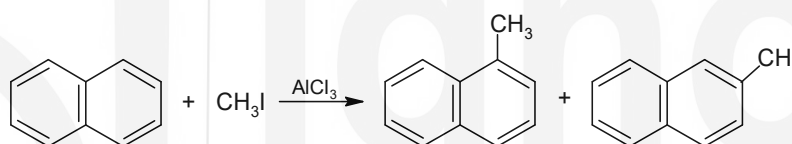
Reaction of naphthalene with sulfuric acid at 355 K, yields 1-naphthalenesulfonic acid as major product. If same reaction is carried out at a higher temperature (435K) it will give 2-naphthalenesulfonic acid as a major product. 1-naphthalenesulfonic acid is less stable than the 2-naphthalenesulfonic

acid because of repulsions between the $-\text{SO}_3\text{H}$ group and the hydrogen at 8-position.



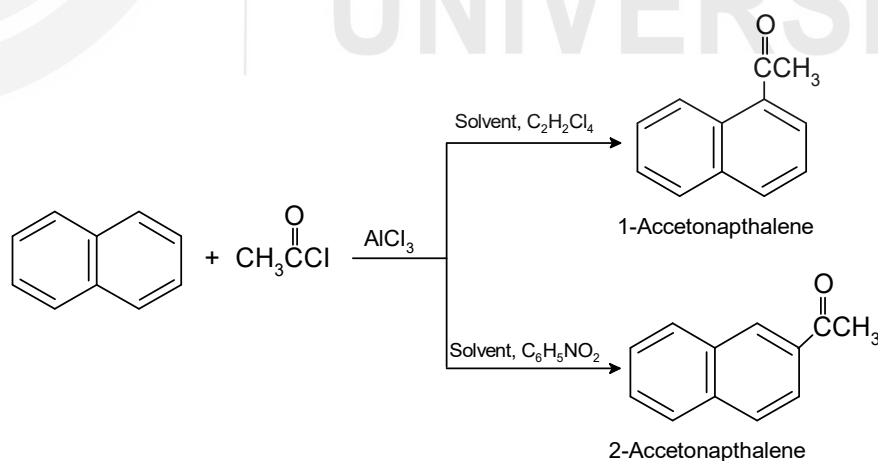
d) Friedel-Crafts Alkylation

Reaction of naphthalene with alkyl halide in presence of AlCl_3 gives two different isomers i.e. 1-methylnaphthalene and 2-methylnaphthalene. The percentage of the two products depends on the size of the reagent.



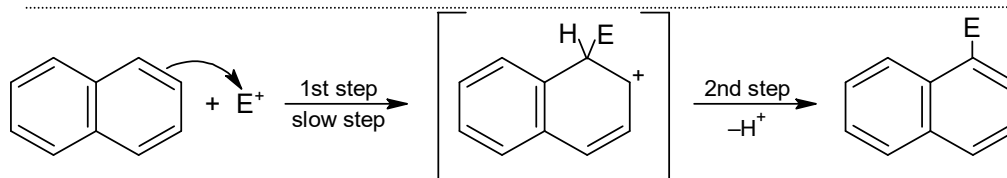
e) Friedel-Crafts Acylation

Naphthalene undergoes Friedel-Crafts acylation in the presence of acetyl chloride and aluminium chloride to give 1-acetonaphthalene and 2-acetonaphthalene. The orientation of substitution depends on the solvent used, as shown below:



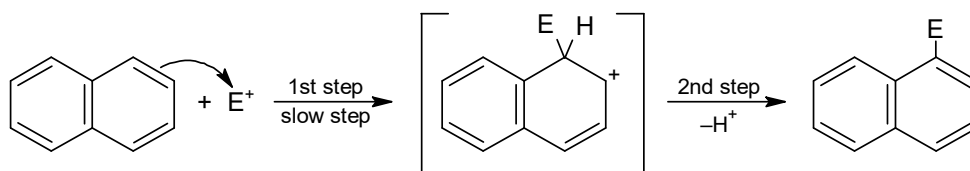
9.7.2 Mechanism of Electrophilic Substitution Reactions of Naphthalene:

Polynuclear aromatic hydrocarbons are more reactive towards electrophilic attack than benzene. The mechanism for electrophilic substitution of naphthalene is similar to that of electrophilic substitution of benzene.

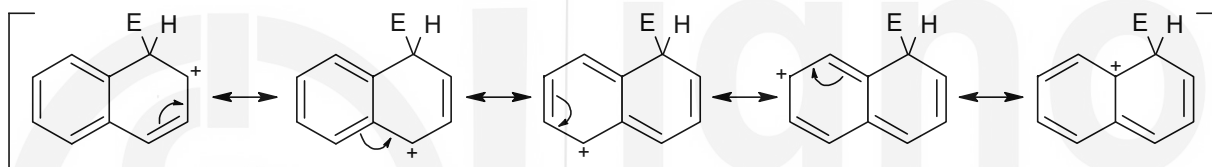


The first substituent goes to 1-position (α -position); that means, the 1-position is more reactive than the 2-position (β -position). You can ask why it is so? To understand this, let us examine the resonance structures of the two intermediate carbocations resulting from the respective attacks.

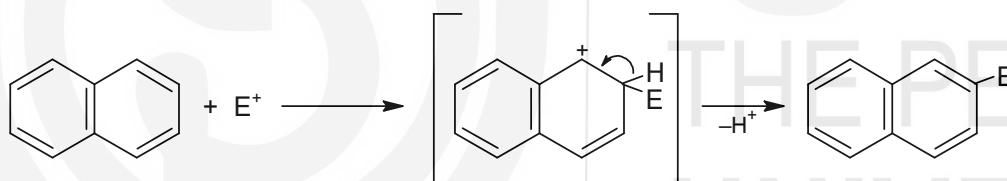
Substitution at 1-Position



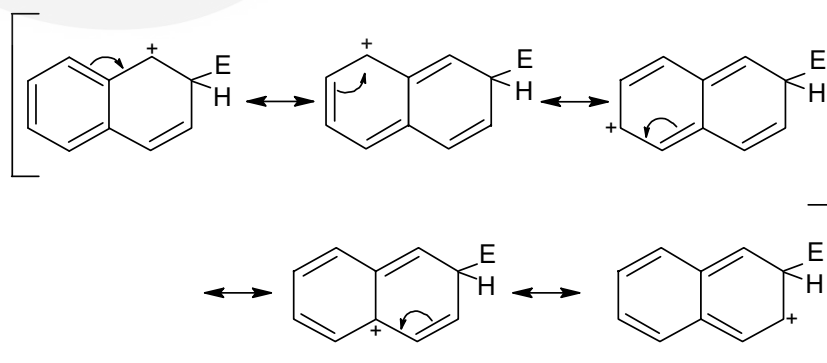
Following are the Resonance structures of carbocation formed during attack of electrophile on 1-carbon.



Substitution at 2-Position



Following are the Resonance structures of carbocation formed during attack of electrophile on 2-carbon.

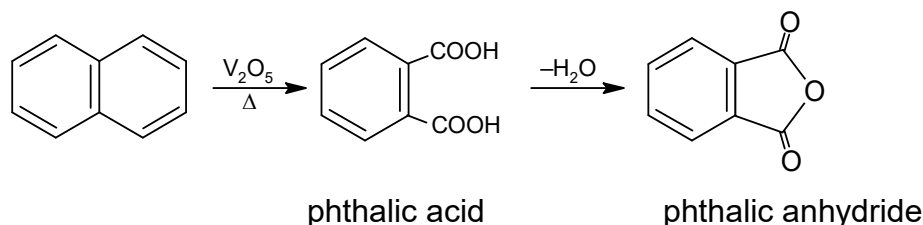


In both cases, the positive charge can be distributed to five different positions, but these carbocations are not equivalent in energy. In the first case, the first two structures have their benzenoid ring intact and are consequently more stable than the remaining three structures. In the second case, only one resonance structure has a benzenoid ring intact. The resulting resonance hybrid has higher energy in the second case than in the first case. The intermediate carbocation in the first case is more stabilised by resonance, and its transition state is of lower

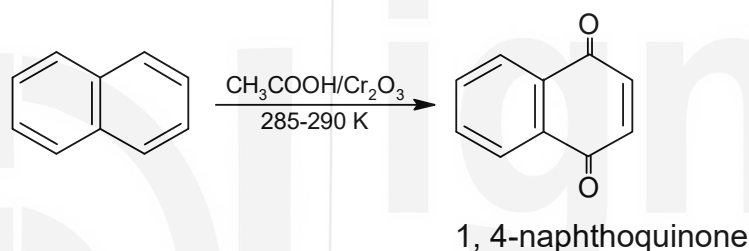
energy. For this reason the intermediate in the first case is formed faster and hence 1-position is more reactive.

9.7.3 Oxidation of Naphthalene

Benzene is not easily oxidised however naphthalene can be easily oxidised to products in which aromaticity is retained. For example Phthalic anhydride, which has commercial importance, can be synthesis by oxidation of naphthalene in good yield. This reaction probably proceeds through the formation of phthalic acid.

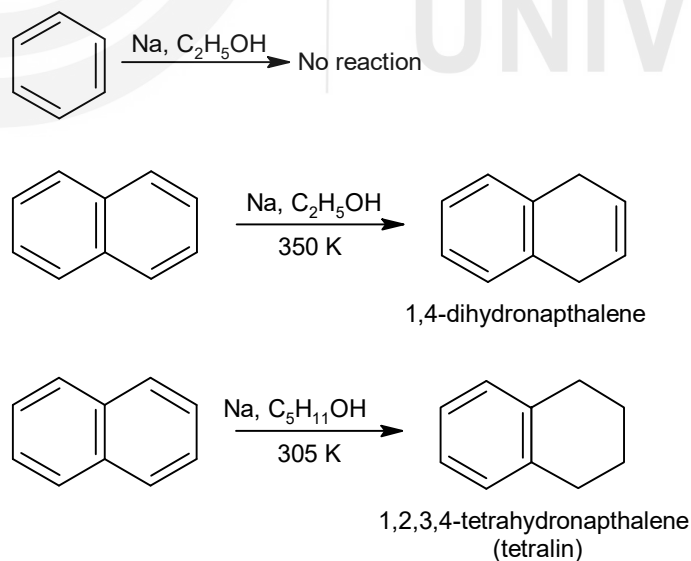


Under controlled conditions, naphthalene is oxidized to 1,4-naphthoquinone, but the yield is usually low.

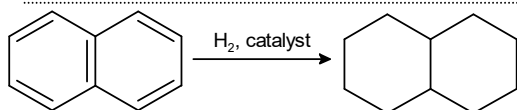


9.7.4 Reduction of Naphthalene

Unlike benzene, naphthalene can be partially hydrogenated by reducing agents. Naphthalene can be reduced with sodium and ethanol.



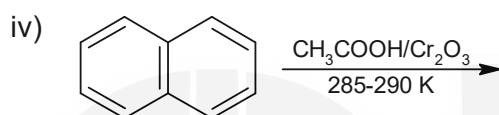
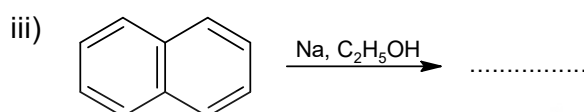
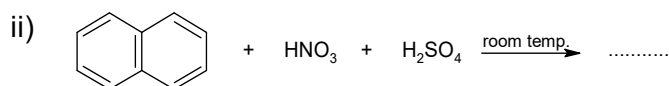
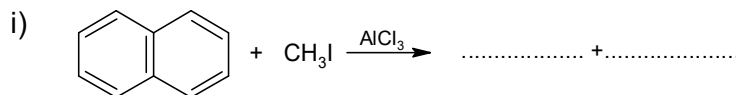
The decahydronaphthalene (decalin) is obtained by complete hydrogenation of naphthalene only by vigorous catalytic hydrogenation.



decahydronaphthalene (decalin)

SAQ 6

Give the product of the following reactions.



9.8 SUMMARY

In this unit we have explained to you the following points:

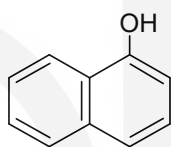
- Polynuclear aromatic hydrocarbon (PAHs) is an assembly of more than one benzene ring in the molecule. One is isolated benzenoid hydrocarbon and the other is condensed or fused benzenoid hydrocarbons.
- PAHs are present in natural sources such as, coal, crude oil, wood, garbage and gasoline.
- PAHs are emitted from exhaust fumes of vehicles.
- Generally PAHs have high melting point, boiling point and low vapor pressure.
- PAHs are nonpolar and lipophilic.
- PAHs are commonly used in pharmaceuticals, agricultural products and photographic products.
- NASA's **Spitzer Space Telescope** and **James Webb Telescope** include instruments for obtaining both images and spectra of light emitted by polynuclear aromatic hydrocarbon associated with star formation.
- The numbering of these compounds is fixed by convention and does not change with the position of a substituent.
- PAHs follow Hückel's Rule and hence are aromatic.

- Like, benzene, naphthalene undergoes usual electrophilic substitution reactions, oxidation and reduction.
- Naphthalene is generally white crystalline solid with the sublimation point at around 355 K.
- Naphthalene is a nonpolar compound and insoluble in polar solvents like water. Naphthalene is soluble in carbon tetrachloride, chloroform, carbon disulfide, methanol, ethanol, diethylether benzene and toluene.

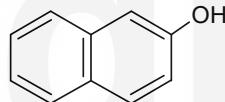
9.9 TERMINAL QUESTIONS

1. What are isolated benzenoid hydrocarbons? Give an example.
2. Give the numbering of anthracene
3. What is Hückel's Rule?
4. Draw the resonance structure of carbocation formed during nitration at 1-carbon of naphthalene.
5. Give the IUPAC name of the following compounds.

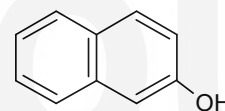
a)



b)



c)



9.10 ANSWERS

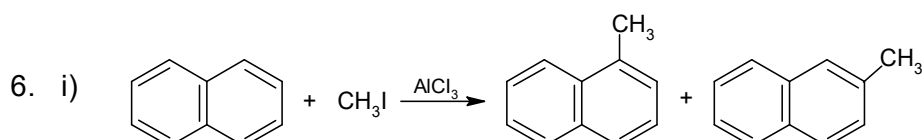
Self Assessment Questions

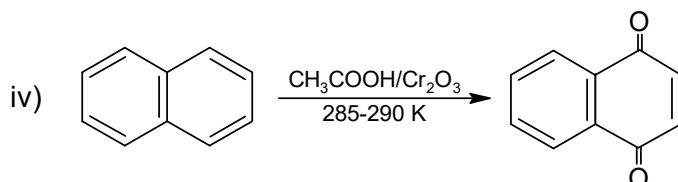
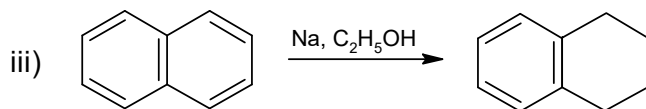
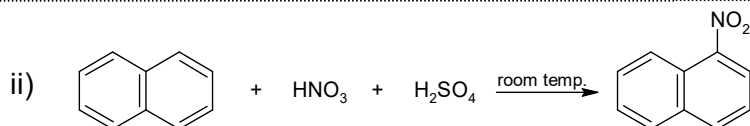
1. There are two types of polynuclear aromatic hydrocarbons, i.e. i) isolated benzenoid hydrocarbons and ii) condensed or fused benzenoid hydrocarbons.
2. i) natural; ii) Perylene; iii) vehicles
3. i) F; ii) F; iii) F; iv) T and v) T
4. i) 2-Chloronaphthalene; ii) 1,3-dichloronaphthalene; iii) 2-bromo-1,4-dichloronaphthalene; iv) 9,10-dimethylantracene
5. No. of π -electrons = 14

If $n = 3$

$4 \times 3 + 2 = 14$ π -electrons.

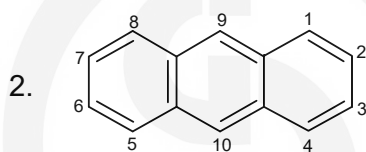
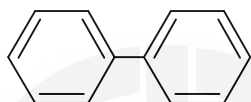
Since 14 is Hückel's no, it is an aromatic compound.



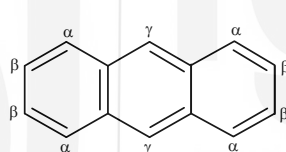


Terminal Questions

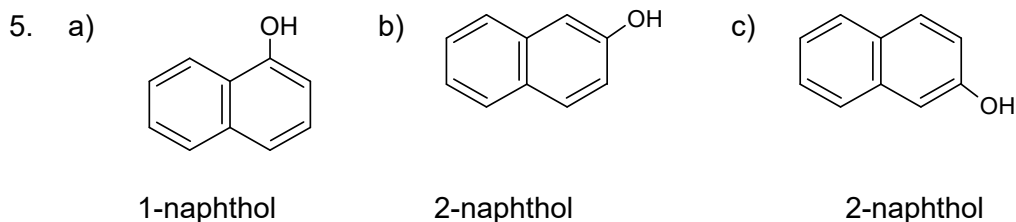
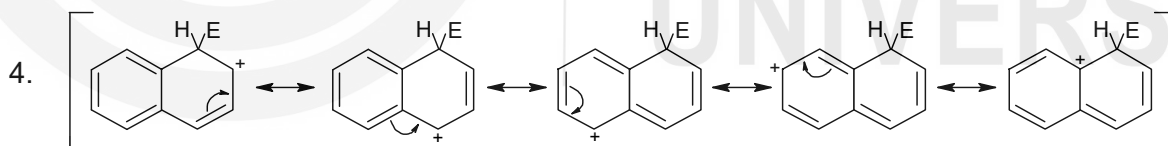
1. In isolated systems, two or more rings are joined to each other directly or through carbon chain. Example



or



3. According to Huckel's rule, a compound must contain $(4n + 2)$ π electrons, where n is any number i.e. 1,2,3,4..... This means that only the ring with 2, 6, 10, 14,..... π electrons may be aromatic



HETEROCYCLIC COMPOUNDS

Structure

10.1	Introduction	Reactions of Five-Membered Heterocyclic Compounds
	Expected Learning Outcomes	
10.2	Heterocyclic Compounds- An Introduction	10.6 Six-Membered Heterocyclic Compounds
10.3	Nomenclature	Source of Pyridine
10.4	Properties of Heterocyclic Compounds	Preparation of Pyridine
10.5	Five-Membered Heterocyclic Compounds	Basic Character of Pyridine
	Source	Reactions of Pyridine
	Preparation	10.7 Summary
	Basic Character of Pyrrole	10.8 Terminal Questions
		10.9 Answers

10.1 INTRODUCTION

Hetero cyclic aromatic compounds are very important class of organic chemistry. So far our study of the cyclic systems was restricted to compounds in which the ring contains only carbon atoms. In this unit, we will study about hetero aromatic compounds. After brief introduction of heterocyclic compounds, we will discuss the nomenclature of heterocyclic aromatic compounds. Then we will briefly study their structure and sources. In the next section we will explain some important methods for preparation of five membered heterocyclic compounds followed by explanation for basic character of pyrrole. We will also study their important reactions like; electrophilic substitution, reduction, Diels-Alder and ring expansion reactions. In the last section we will discuss the chemistry of six membered heterocyclic compound, pyridine.

Expected Learning Outcomes

After studying this unit and having the experiments performed, you should be able to:

- ❖ write down the name of some heterocyclic compounds
- ❖ list the natural sources of furan, pyrrole, thiophene and pyridine

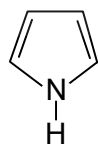
- ❖ discuss the basic properties of heterocyclic compounds
- ❖ list the different methods for the preparation of furan, pyrrole, thiophene and pyridine, and
- ❖ explain the chemical properties of these compounds

10.2 HETEROCYCLIC COMPOUNDS- AN INTRODUCTION

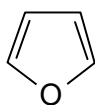
Our study of the cyclic systems upto this point was restricted to compounds in which the ring contains only carbon atoms. (Remember hydrogen atoms are not part of the ring). Such compounds are called **homocyclic** compounds. Here we will study another type of compounds called **heterocyclic compounds**. Rings that contain, in addition to carbon, atoms of other elements in the ring are called **heterocyclic compounds**. In other words, we can say that the ring of *homocyclic* compounds contain only carbon atoms and the ring of heterocyclic compounds contain at least one atom other than carbon atoms. The hetero atoms that occur most frequently in heterocyclic rings are nitrogen, sulphur and oxygen. The rings in heterocyclic compounds may be saturated or unsaturated. Unsaturated heterocyclic systems may be aromatic or nonaromatic. Among aromatic heterocycles, five and six-membered heterocyclic rings are most common.

For example, the pyrrole ring is the basic unit of the porphyrin system, in chlorophyll and hemoglobin. From this unit, we can have some idea of the importance as well as the complexity of heterocyclic systems.

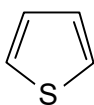
There are many types of heterocyclic aromatic compounds but we will focus our study only on five membered heterocyclic aromatic hydrocarbons, **Pyrrole, Furan, and Thiophene** and a six membered heterocyclic aromatic compound **Pyridine**.



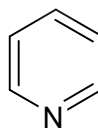
Pyrrole



Furan



Thiophene



Pyridine

SAQ 1

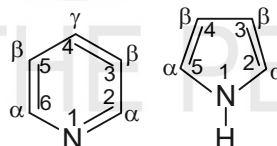
Fill in the following blanks:

- The rings which contains only carbon atoms are called ----- compounds.
- In pyrrole----- is the hetero atom.
- Pyrrole ring is the basic unit of the ----- system.

10.3 NOMENCLATURE

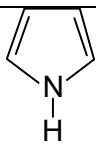
In this section, we shall discuss some of the rules adopted by IUPAC for naming heterocyclic compounds. The size of the ring as well as the numbers, kind and position of the hetero atom are specified by this system using a suitable prefix or suffix according to a set of rules given below:

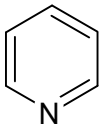
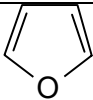
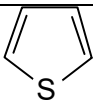
- i) The names of monocyclic compounds are derived by a prefix indicating the nature of the hetero-atom present, e.g. oxygen, oxa; sulphur, thia; nitrogen, aza. It may be noted that when the name contains two vowels and are in a sequence, then 'a' of the prefix is omitted.
- ii) If the ring contains two or more identical hetero-atoms, the prefixes di, tri, etc. are used, e.g. dioxo, triaza. If the hetero atoms are different, oxygen takes precedence over sulphur and sulphur over nitrogen.
- iii) The size of a five- and six-membered ring is indicated by the ending part, ole and ine, respectively.
- iv) In monocyclic compounds, containing only one hetero atom, numbering starts with the hetero atom and proceeds in such a way that substituent gets the lowest numbered position and the, numbering proceeds counter clockwise around the ring. In common names, Greek letters may also be used to designate ring position. The carbon adjacent to the hetero atom is the α -carbon, the next atom is β -carbon and then γ -carbon, for example.



- v) If the hetero atoms are different, then numbering starts at the atom cited first according to the rule in (ii) and proceeds round the ring in order of precedence.
- vi) The state of hydrogenation is indicated by the prefix dihydro, tetrahydro, etc or by prefixing the name of the parent unsaturated compound with the symbol H preceded by a number indicating the position of saturation.

Table 10.1 : Naming of the five- and six- membered heterocyclic compounds

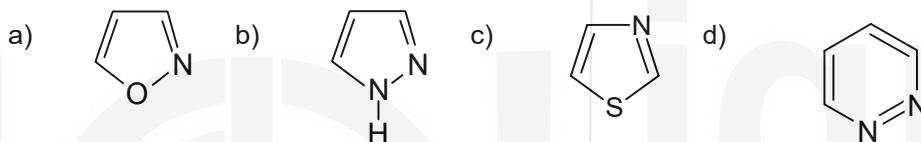
Name of the Hetero atom	Ring size	Beginning of the name	End part of the name	Example
Nitrogen	5	aza	ole	aza + ole =azole, 

	6	aza	ine	Aza + ine = azine,	
Oxygen	5	oxa	ole	Oxa + ole = oxole,	
Sulphur	5	thia	ole	Thia + ole = thiole	

The common names of azole, azine, oxole and thiole are pyrrole, pyridine, furan and thiophene, respectively.

SAQ 2

Give the IUPAC name of the following compounds.



10.4 USES AND PROPERTIES OF HETEROCYCLIC COMPOUNDS

Heterocyclic compounds have a wide range of application. They are mainly used in pharmaceutical preparations, because, it is possible to expand the available drug-like chemical space and drive more effective drug discovery programs using them. In addition to this, they are used in agrochemicals and as veterinary products. They are used as starting materials in the synthesis of other heterocyclic compounds. They also find applications as sanitizers, developers, antioxidants, corrosion inhibitors, copolymers, dye stuff etc. The application of heterocycles provides a useful tool for modification of solubility, polarity, and hydrogen bonding capacity of biologically active agents. In the biological world, heterocyclic compounds are of wide occurrence and are often of critical physiological importance. Thus chlorophyll, the green pigment of leaves which catalyses photosynthesis is based on a heterocyclic framework. The same is true of haemin, which gives the red colour to our blood and functions as an oxygen carrier. Heterocyclic compounds form the sites of reaction in many enzymes and coenzymes. Heredity comes down, ultimately to the particular sequence of attachment of half a dozen heterocyclic rings to the long chains of nucleic acids

Most of them are highly flammable, weakly alkaline, water-miscible liquid with a distinctive unpleasant fish-like smell.

10.5 FIVE-MEMBERED HETEROCYCLIC COMPOUNDS

The three simplest five membered heterocyclic compounds containing a hetero atom are furan (oxole), pyrrole (azole) and thiophene (thiole). By looking at the structure of these compounds, you may say that they should have properties like those of conjugated dienes. But these compounds do not show any such properties. Rather these compounds are found to undergo electrophilic substitution reactions such as nitration, sulphonation, halogenation and the Friedel-Crafts reaction with considerable ease. Thus, these compounds evidently have aromatic character. The heats of combustion of these compounds are less than that of benzene $150.5 \text{ kJ mol}^{-1}$. The values are as follows: 66.8 kJ mol^{-1} for furan, 87.8 kJ mol^{-1} for pyrrole and $121.2 \text{ kJ mol}^{-1}$ for thiophene.

In fact pyrrole, furan and thiophene are aromatic. These heterocycles are also planar pentagons consisting of sp^2 hybridised carbon atoms (Fig.10.1). Of the six π electrons required as per Huckel's rule for aromaticity the double account for four and the lone pair on the heteroatom for the remaining two.

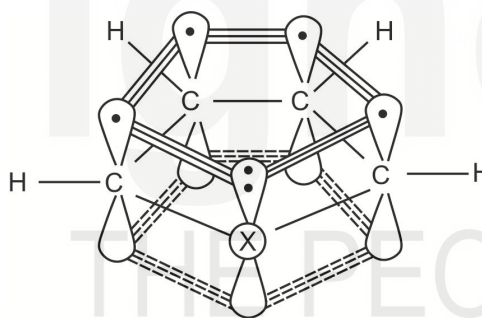


Fig. 10.1: Orbital picture of Five-membered heterocycles $X=O$, or $N-H$

10.5.1 Source

Bone Oil:

Product obtained by the destructive distillation of bones. It is a dark oily evil-smelling liquid.

Shale Oil:

Petroleum extracted from a kind of rock, known as shale. This rock is rich in hydrocarbons: Shale is subjected to destructive distillation where by the oil is released.

Pyrrole occurs in coal-tar and bone oil. It may be isolated from bone oil by washing the bone oil with dilute alkali to remove acidic substances, then with acid to remove strongly basic substances and finally by fractionating. Furan is extracted from coal tar and wood, especially pine-wood.

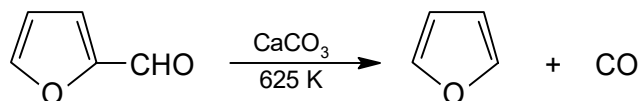
Thiophene occurs in coal tar and shale oil. Its boiling point (355 K) is close to that of benzene and hence it is difficult to separate from the benzene fraction, obtained from coal tar. Thiophene can be sulphonated more readily than benzene, and this property is used to separate the two compounds by repeatedly shaking benzene (from coal-tar) with cold concentrated sulphuric acid, so that water-soluble thiophenesulphonic acid is formed. When thiophenesulphonic acid is boiled with dilute hydrochloric acid or heated with steam. The $-\text{SO}_3\text{H}$ group is replaced by hydrogen to give thiophene

10.5.2 Preparation

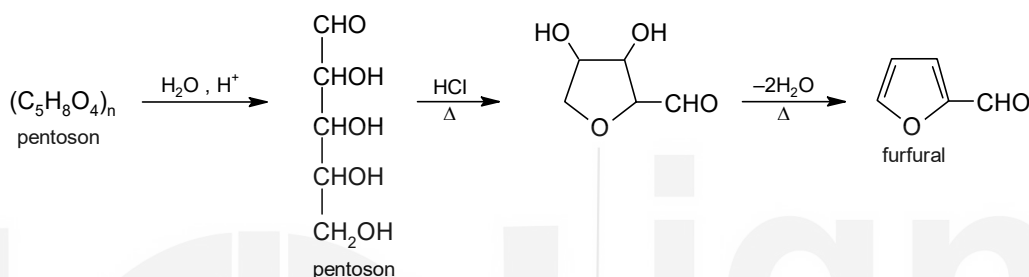
As mentioned above, although pyrrole, furan and thiophene can be obtained from natural sources, the quantities are too small to fulfill our demands. The

following methods for large scale preparation of these compounds are, therefore, important

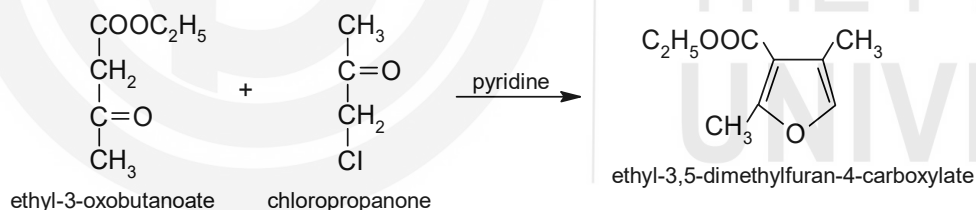
- i) Furan is synthesised readily by decarbonylation (elimination of the CO group) of furfural



Furfural production is an interesting example of the use of industrial waste products. The hulls of rice and oats contain polymeric carbohydrates known as pentosans. Pentoses obtained from the polymeric material undergo subsequent dehydration and cyclisation to yield furfural.

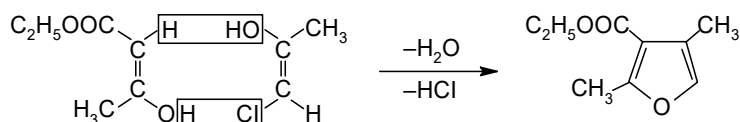


- ii) An important method for laboratory preparation of substituted furans is the Fiest Benary synthesis in which a β -keto ester and a α -haloketone are reacted in presence of pyridine. For example, the enol form of ethyl 3-oxobutanoate (ethyl acetoacetate) and chloropropanone (chloroacetone) react as shown below to give ethyl 3,5-dimethylfuran-4-carboxylate.

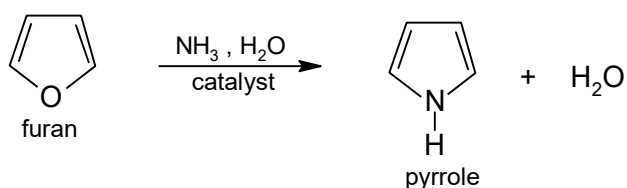


You can see that in many of the synthesis procedures, it is probable that ketonic compounds react through enol form.

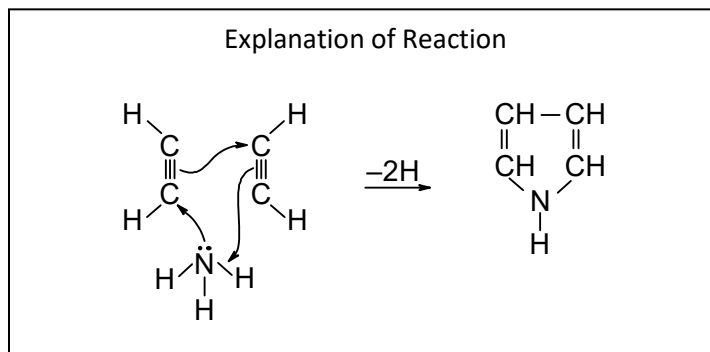
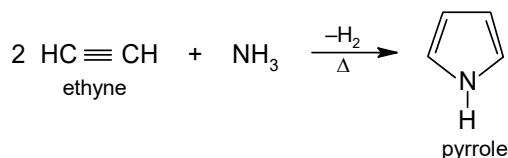
Explanation of the Reaction



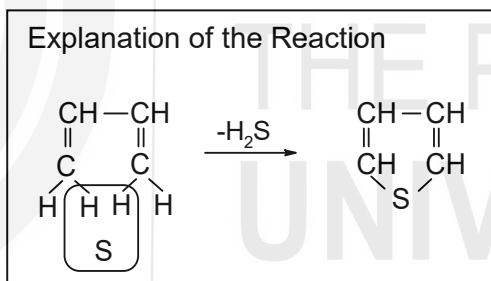
- iii) Pyrrole is commercially produced from furan, ammonia and steam using alumina as catalyst at 675 K.



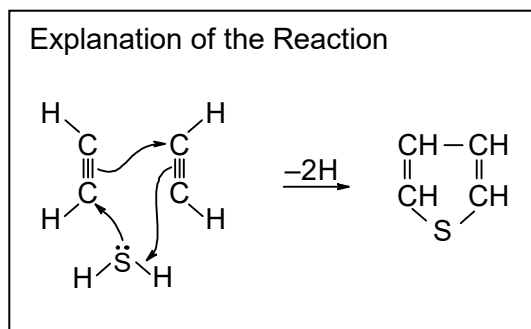
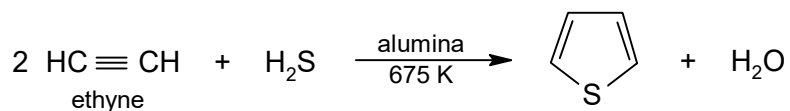
- iv) Pyrrole is also produced when a mixture of ethyne and ammonia is passed through a red hot tube



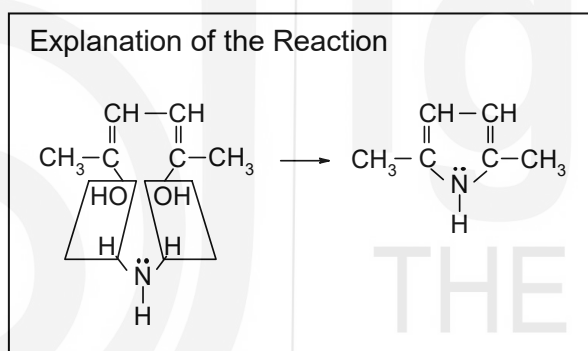
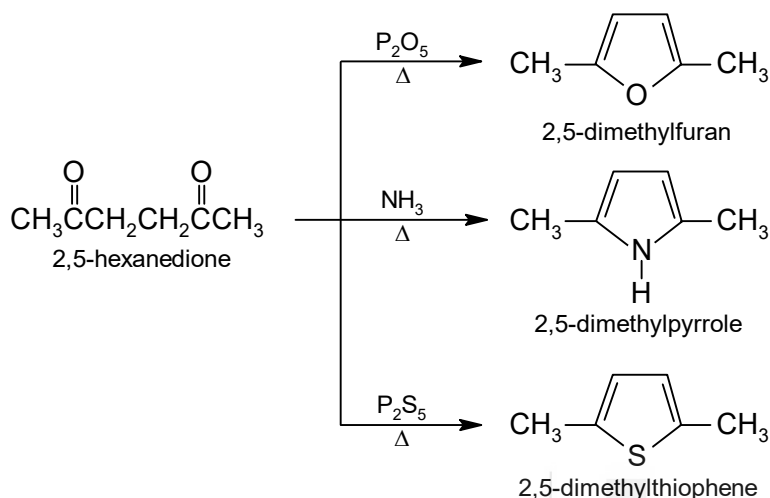
- v) Thiophene is produced from C4 hydrocarbons such as butane, butene or butadiene. Butadiene formed initially through-dehydrogenation of butane or butene by sulphur at 875 K is the probable precursor of thiophene.



- vi) Thiophene is also produced commercially by passing a mixture of ethyne and H₂S over heated alumina.



vii) 1, 4-Dicarbonyl compounds are useful starting materials for the synthesis of these heterocycles. If the dicarbonyl compound is heated with a dehydrating agent, e.g., P_2O_5 , a furan derivative is formed. If heated with a source of nitrogen or sulphur, substituted pyrrole or thiophene is formed. These reactions are also known as Paul-Knorr methods.



10.5.3 Basic Character of Pyrrole

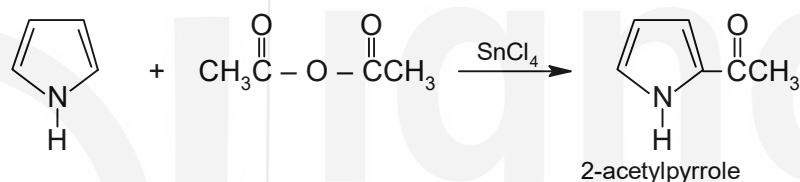
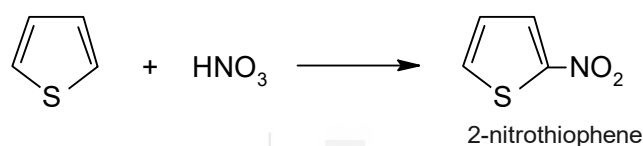
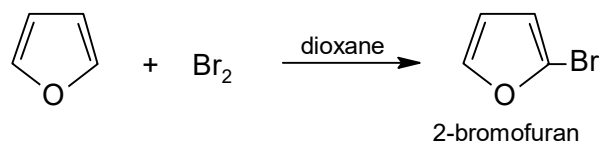
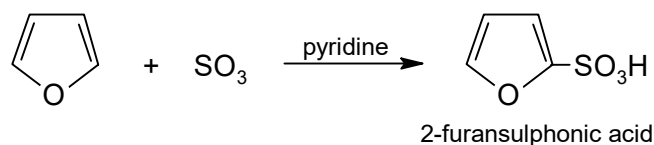
A lone pair of electrons on nitrogen is responsible for the basicity of nitrogen compounds. Pyrrole also has a lone pair of electrons on nitrogen and therefore it, also acts as a base but it is a very weak base (K_b 2.5×10^{-14}). The reason for the weak basic character of pyrrole is that the lone pair of electrons on nitrogen is involved in the formation of the delocalised molecular orbitals and is not readily available for the formation of a new bond with hydrogen. Furthermore, if a hydrogen is added to the nitrogen atom (through reaction with an acid), the resulting structure ceases to be aromatic. This makes the pyrrole cation extremely unstable. This is responsible for the absence of any significant basicity in pyrrole.

10.5.4 Reaction of Five-Membered Heterocyclic Compounds

Five membered heterocyclic compounds undergo electrophilic substitution reduction, Diels-Alder and ring expansion reactions.

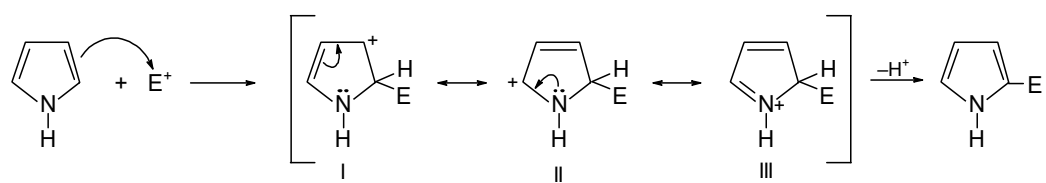
i) Electrophilic Substitution Reaction

Like other aromatic compounds pyrrole, furan and thiophene commonly undergo electrophilic substitution reactions such as nitration, sulphonation, halogenation and Friedel Crafts acylation. Pyrrole is more reactive than furan and thiophene in electrophilic substitution reactions. Few important reactions are discussed below:

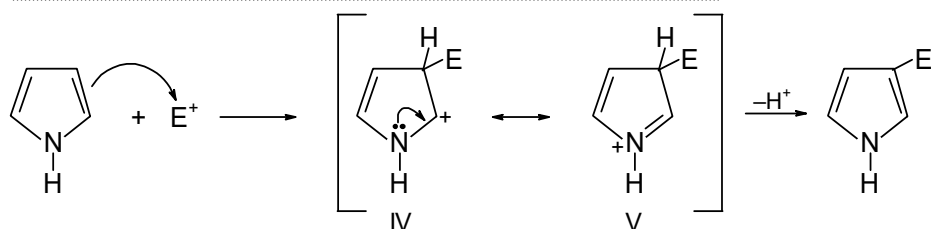


The attack of the electrophile in these heterocycles usually occurs at the C-2 (or α) position i.e., next to the hetero atom. In Unit 9 you have studied that you could account for orientation on the following basis: the controlling step is the attachment of electrophilic reagent to the aromatic ring, which takes place in such a way as to yield the most stable carbocation intermediate. Let us apply this approach to the reactions of pyrrole. Attack at position 2 of pyrrole yields a carbocation that is a resonance hybrid of three structures, i.e., I, II and III whereas attack at position 3 would yield carbocation which is a hybrid of only two structures, i.e., IV and V. **The extra resonance stabilization of carbocation provided by structure III**, in case of attack at position 2 makes positive charge at this 'position more stable. Thus, the attack at position 2 is favoured. Orientation of substitution in furan and thiophene can be accounted for in the same way.

Attack at C-2



Attack at C-3

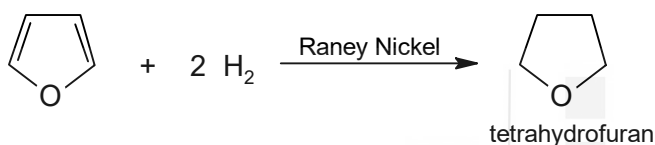


SAQ 3

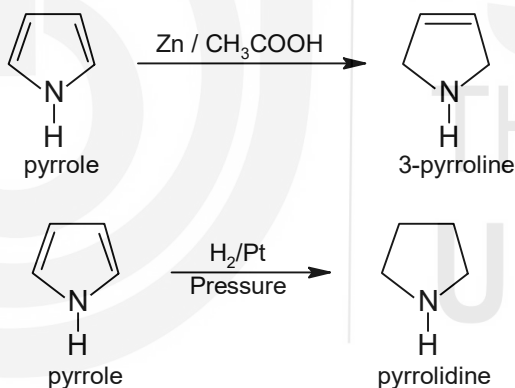
The attack of the electrophile in pyrrole is usually occurs at the C-2 (or α) position. Explain

ii) Reduction

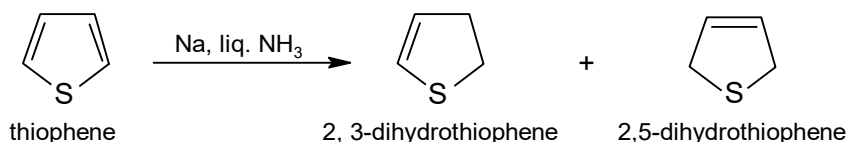
Tetrahydrofuran (THF) which is an industrially important solvent, results on catalytic reduction of furan over Raney Nickel catalyst



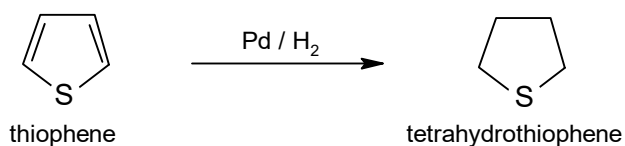
Mild reduction of pyrrole with zinc and ethanoic acid yields 3-pyrroline (2,5-dihydro pyrrole). Catalytic reduction completely hydrogenates the ring system yielding pyrrolidine



Birch reduction (sodium in liquid ammonia) is used to obtain 2,3-dihydrothiophene and 2,5-dihydrothiophene

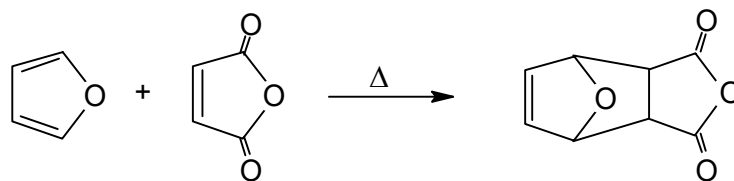


Tetrahydrothiophene is the product when large amount of palladium is used as catalyst

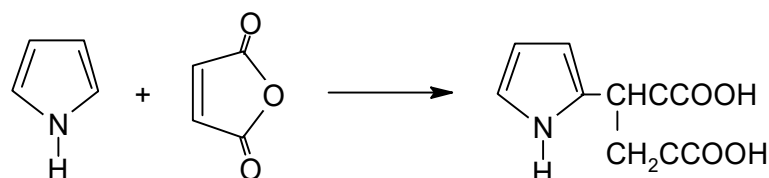


iii) Diels-Alder Reaction

Furan has sufficient diene character to undergo Diels-Alder reaction with maleic anhydride to form an addition product



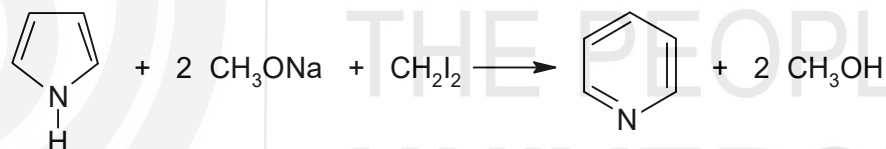
Pyrrole does not undergo Diels-Alder reaction on treatment with maleic anhydride. Rather a substitution product is obtained.



Thiophene does not undergo Diels-Alder reaction or substitution reaction with maleic anhydride

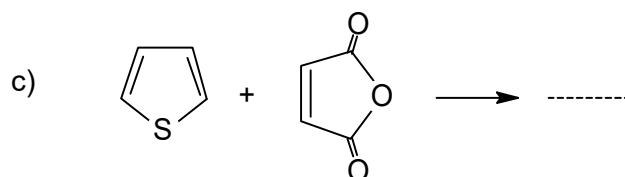
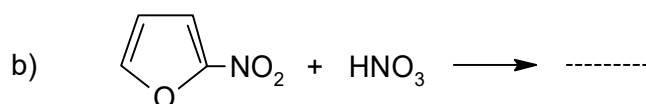
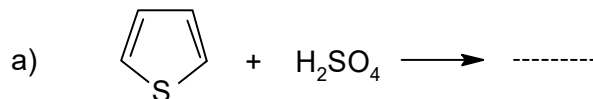
iv) Ring. Expansion Reaction

Pyrrole undergoes ring expansion forming pyridine when treated with sodium methoxide and diiodomethane.



SAQ 4

Predict the product of the following reactions:



10.6 SIX-MEMBERED HETEROCYCLIC COMPOUND: PYRIDINE

Of the six membered aromatic heterocyclic compounds only nitrogen containing heterocycles are known. Pyridine is the simplest six membered stable aromatic compounds. So in this unit, we shall study only pyridine.

Pyridine contains a six membered ring consisting of five carbon atoms and one nitrogen atom. The structure of pyridine has close resemblance to that of benzene. The molecule is planar with bond angles of 120° . All the five carbon atoms and the nitrogen atom are sp^2 hybridised. Each of the five carbon atoms and the nitrogen atom use their sp^2 orbital in forming bonds. Note that the lone pair of electrons in nitrogen atom is responsible for the basic character of pyridine. The six electrons in the unhybridised orbitals of carbon and nitrogen atoms are responsible for the formation of three double bonds (Fig. 10.2).

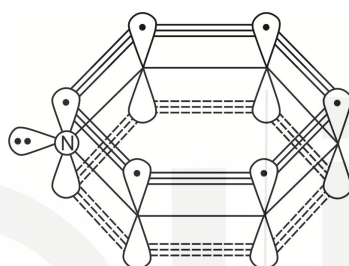


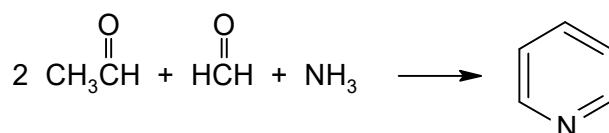
Fig. 10.2: Orbital picture of pyridine

10.6.1 Source of Pyridine

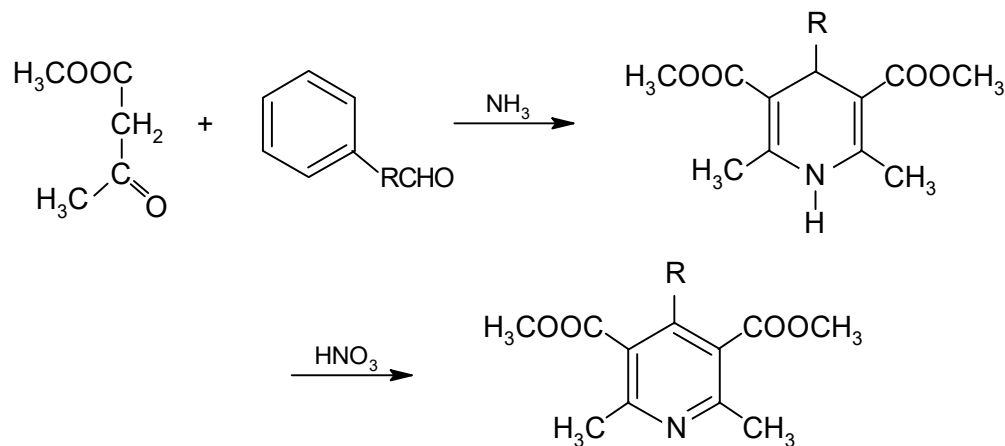
Pyridine occurs in the light oil fraction of coal tar and in bone oil, and is a decomposition product of several alkaloids. Pyridine is obtained from light oil by treating it with dilute sulphuric acid. This dissolves pyridine and other basic substances. This solution is neutralised with sodium hydroxide and the liquid is repeatedly fractionated to get pyridine.

10.6.2 Preparation of Pyridine

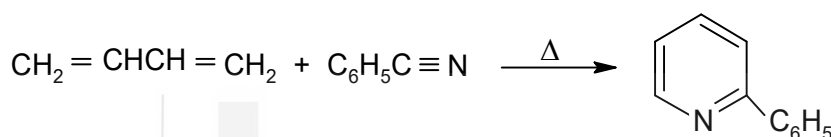
- i) Pyridine is produced on a commercial scale by condensation of methanal and ethanal in the presence of ammonia



- ii) The substituted pyridine is usually produced in the laboratory by the Hantzsch synthesis in which two moles of a β -keto ester combine with an aldehyde in presence of ammonia. The dihydropyridine produced initially is readily oxidised to aromatic product.



- iii) Diels-Alder reaction is also used for the preparation of substituted pyridine using benzonitrile as the dienophile.



10.6.3 Basic of Pyridine

Pyridine is a base with $K_b = 2.3 \times 10^{-9}$. The N is sp^2 hybridized and therefore has free a pair of electrons in a sp^2 orbital which is available for sharing by a proton. In contrast to this, pyrrole ($K_b = 2.5 \times 10^{-14}$) does not have a pair of free electrons and can accept a proton only at the expense of its aromatic character. Hence, pyridine is more basic than pyrrole.

Pyridine is, however, far less basic than the alkyl amines ($K_b = 10^{-14}$). This is so because the sp^2 hybridised nitrogen atom in pyridine is more electron attracting than the sp^3 hybridised nitrogen atom in aliphatic amines. Consequently, the lone pair is more tightly held in pyridine as compared to aliphatic amines and so is less available for prolongation.

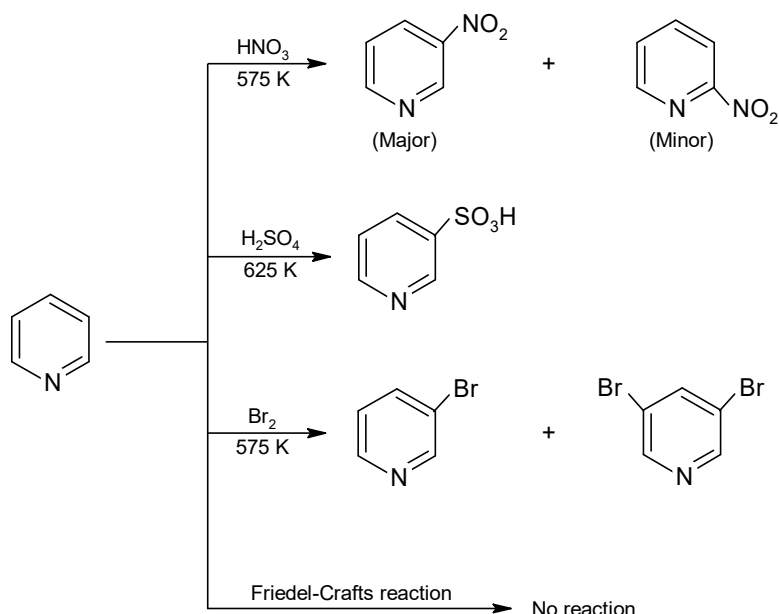
10.6.4 Reaction of Pyridine

Pyridine undergoes electrophilic and nucleophilic substitution reactions.

i) Electrophilic Substitution

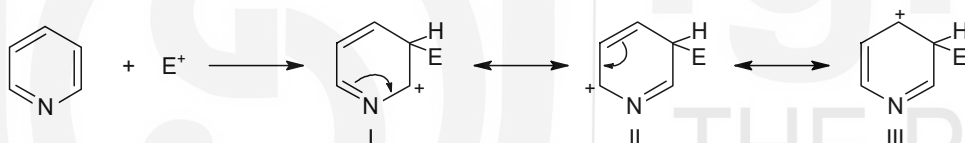
The pyridine ring is deactivated for electrophilic substitution as the electronegative nitrogen atom tends to attract the ring electrons towards itself. This effect is enhanced by protonation which occurs under the acidic reaction conditions.

It undergoes nitration, sulphonation and halogenation only under very vigorous conditions and that these too in very poor yield. It does not undergo Friedel-Crafts reaction at all.

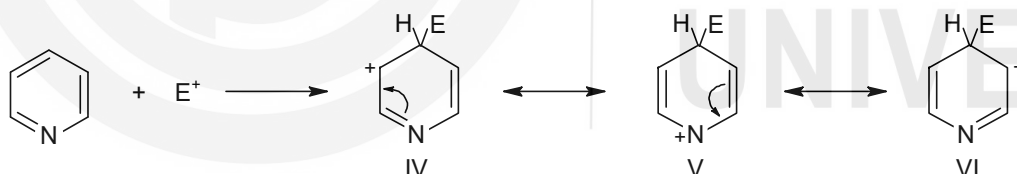


The substitution occurs chiefly at the 3- (or β -) position as the transition state leading to substitution at this position is energetically more favourable. The positively charged intermediate formed due to attack at 3-position is stabilised by three resonance structures, I to III.

Attack at C_3



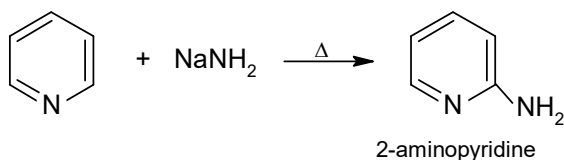
Attack at C_4



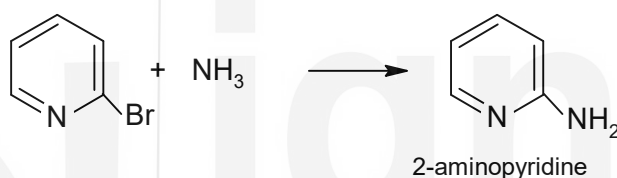
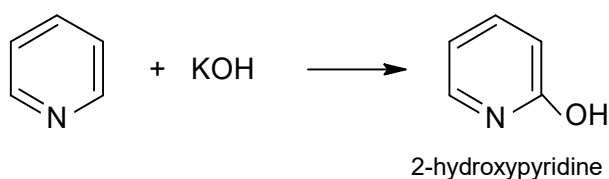
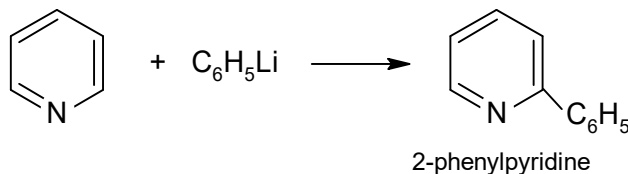
If the electrophile attacks at 4-position it results in positive species which can be represented by three resonance structures, IV to VI. In one resonance structure (V), the positive charge is at the electronegative nitrogen atom. This which increases the energy of the transition state. As a result, attack at 4-position is especially slow. No such structure is possible when the electrophile attacks 3-position. Therefore electrophilic substitution occurs predominantly at 3-position. Attack at 2-position resembles attack at the 4-position just as *ortho* attack resembles *para* attack in the benzene series.

ii) Nucleophilic Substitution

Because of the presence of the electron withdrawing nitrogen atom, the reactivity of pyridine towards nucleophilic substitution is so great that even the powerfully basic hydride ion (H^-) can be displaced by the amide anion as shown in the following reaction.

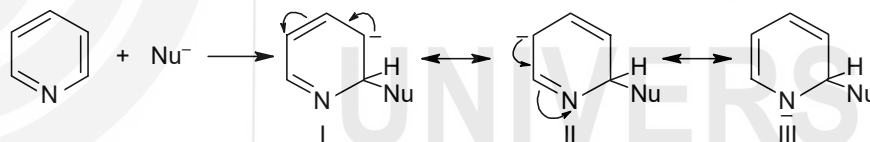


Other typical nucleophilic reactions of pyridine are:

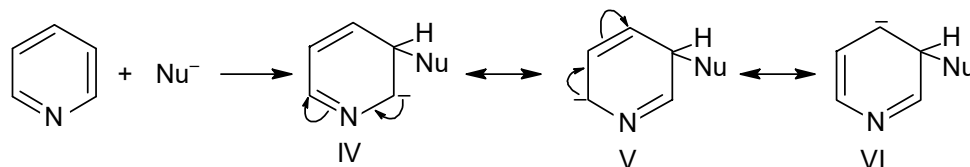


We have illustrated nucleophilic substitution at 2-position only, although such substitution takes place to a large extent at 2- and 4-positions and not at 3-position. This can be explained through the following structures.

Attack at C_2



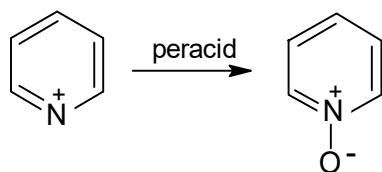
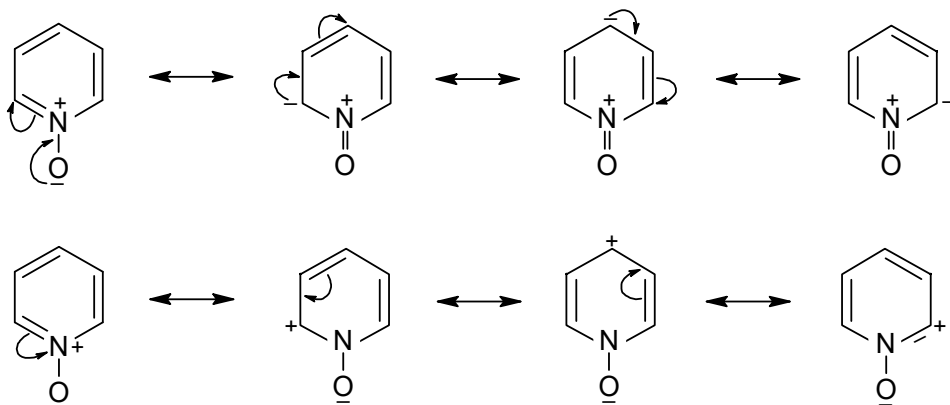
Attack at C_3



The attack of the nucleophile at 2-position gives rise to resonance structure III in which the negative charge resides on the electronegative nitrogen atom; this is energetically favourable. We can apply similar arguments for the nucleophilic attack at 4-position. No such resonance structure arises when nucleophile attacks at 3-position. Thus the attack, of the nucleophile occurs selectively on 2- and 4-positions of the pyridine ring.

iii) N-Oxides

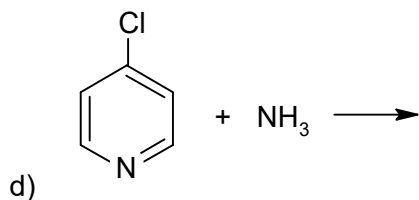
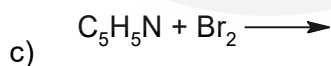
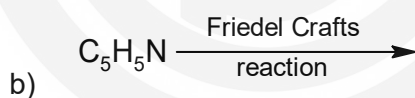
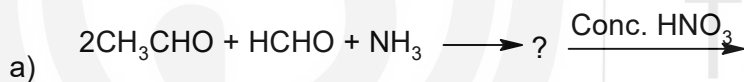
Pyridine when treated with peracids such as perethanoic acid or perbenzoic acid is converted into pyridine N-oxide. It can be depicted as a resonance hybrid of the following structures.

**Mechanism**

In some of the above structures, there is a decrease in electron density at various ring positions while in the others there is an increase in electron density. Thus pyridine N-oxides have been found to be more reactive towards both electrophilic and nucleophilic reagents than pyridine itself.

SAQ 5

Predict the product(s) of the following reactions.

**10.7 SUMMARY**

- Furan, pyrrole, thiophene and pyridine are important heterocycles.
- Heterocyclic compounds are mainly used in pharmaceuticals preparation.
- In addition to this they used in agrochemicals and as veterinary products.

- They are used as vehicles in the synthesis of other organic compounds. They also find applications as sanitizers, developers, antioxidants, as corrosion.
- Heterocyclic compounds generally occur in coal tar and bone oils.
- Pyrrole acts as a weak base, its K_b value being 2.5×10^{-14} . Pyridine is a stronger base ($K_b = 22.5 \times 10^{-9}$) than pyrrole but much weaker than aliphatic amines.
- Five-membered heterocyclic compounds can be prepared by the Paal-Knorr method and some other methods.
- Five membered heterocyclic compounds undergo electrophilic substitution reduction and ring expansion reactions.
- Pyridine can be prepared by Hantzsch synthesis, Diels-Alder reaction and by condensation of methanal, ethanal and ammonia.
- Pyridine undergoes electrophilic substitution as well as nucleophilic substitution reaction.
- Electrophilic substitution occurs predominantly at 3-position and nucleophilic substitution occurs predominantly at 2- and 4-positions of the pyridine ring.

10.8 TERMINAL QUESTIONS

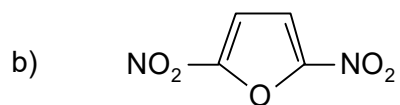
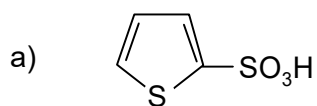
- 1) Arrange the following compounds in the increasing order of the basic strength. Pyridine, pyrrole and aliphatic amine
- 2) Write the structure for the product(s) obtained on treating furan with (a) maleic anhydride (b) catalytic reduction (c) $\text{CH}_3\text{COO}^-\text{NO}_2^+$; (d) SO_3 , pyridine.
- 3) Give the resonance structures for the intermediate in the reaction where electrophile E^+ attacks on 2-position of pyridine.

10.9 ANSWERS

Self-Assessment Questions

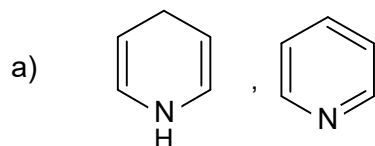
- 1) a) homocyclic, b) nitrogen, c) porphyrin
- 2) a) 1,2-Oxazole b) 1,2-Diazole c) 1,3-Thiazole
d) 1, 2-Diazine
- 3) Attack at position 2 of pyrrole yields a carbocation that is a hybrid of three structures, i.e., I, II and III whereas attack at position 3 yields carbocation which is a hybrid of only two structures, i.e., IV and V. The extra resonance stabilisation of carbocation in case of attack at position 2 makes positive charge at this position more stable (sec. 10.5.4).

4)

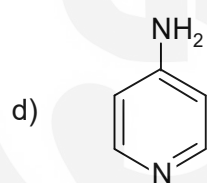
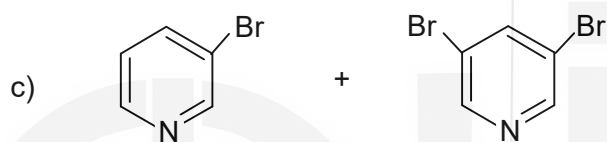


c) No reaction

5)



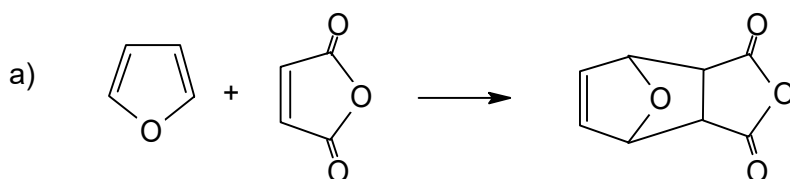
b) No reaction



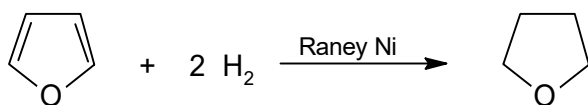
Terminal Questions

1) Aliphatic amine > pyridine > pyrrole

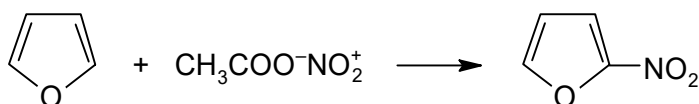
2)



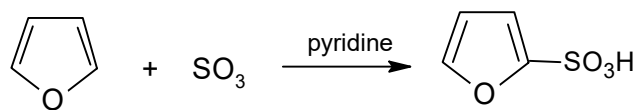
b)



c)



d)



3)

