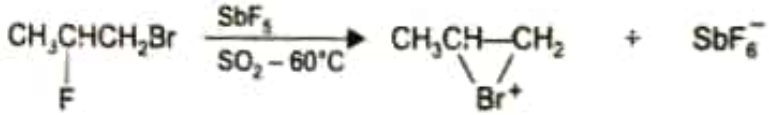
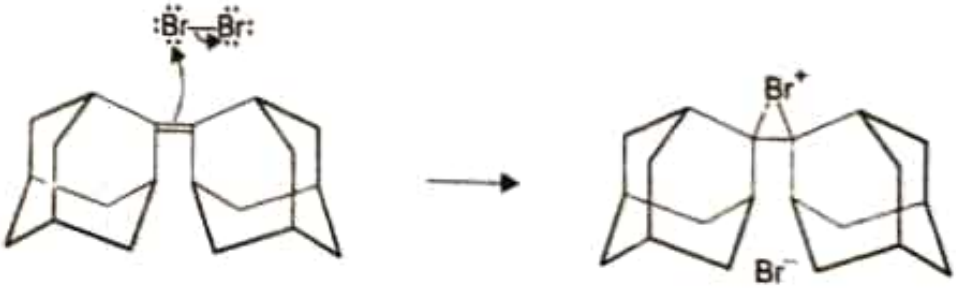
In several situations bromonium ions have been observed. Under superacid conditions 1-bromo-2-fluoropropane (Scheme 11.4) gives a cation, which infact is a bromonium ion related to propene as shown by NMR spectroscopy. The highly hindered alkene adamantylideneadamantane gives a bromonium ion (Scheme 11.5). An X-ray crystal structure determination on its derivative has shown the cyclic nature of the bromonium ion. In this case the bromonium ion is not attacked by Br^-, the attack is completely prevented by the steric hindrance offered to the backside approach of the bromide ion by the extremely bulky cage like structure.



SCHEME 11.4



SCHEME 11.5

Whether the intermediate is a halonium ion or an open carbocation the mechanism is termed Ad_E2 *i.e.*, electrophilic addition, bimolecular.

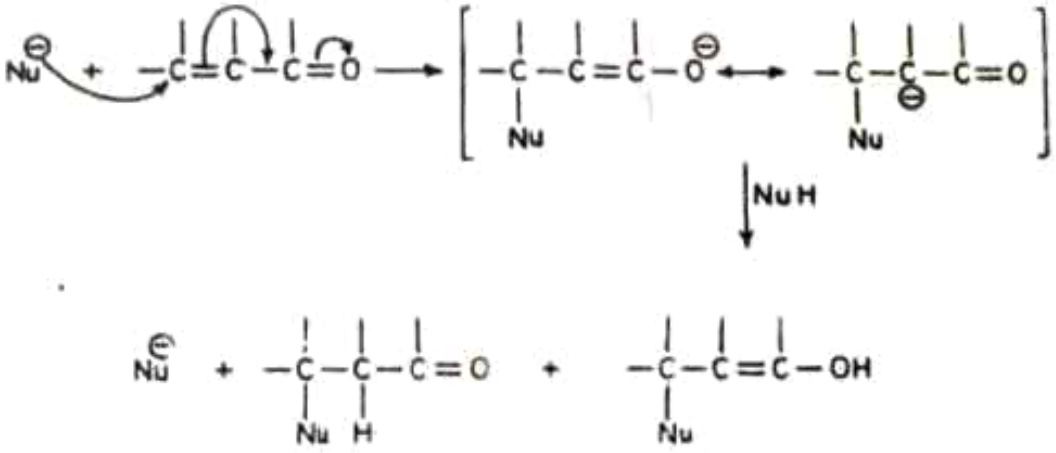
One may recall that allylic bromination (instead of addition) of an alkene is the reaction on treatment with NBS in CCl_4 in the presence of peroxides or light (see, Scheme 2.19, Problem 2.3). In summary, in a non-polar solvent and a very low concentration of bromine, the reaction is not addition of bromine but it reacts to substitute an allylic hydrogen atom. NBS provides a very low concentration of bromine by reacting with HBr. To understand the reason for allylic substitution at high temperature over addition a consideration of entropy changes is important. Addition of bromine combines two molecules into one, thus the reaction has a substantial negative entropy change (Sec. 4.4). However, at low temperature the $T\Delta S^\circ$ term in $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ is now not large to offset the favourable ΔH° term, at higher temperatures, the $T\Delta S^\circ$ term gains more significance, consequently ΔG° becomes more positive and the equilibrium becomes more unfavourable. (In the addition of bromine, the bromonium ion formation is a reversible step).

Bridged ions

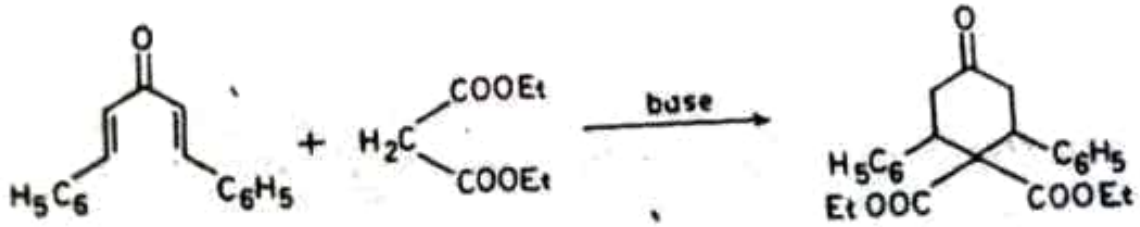
The term bridged ions is infact synonymous with nonclassical cations. A nonclassical carbocation involves three-center two electron bonding, a bromonium however, does not involve this. The term bridged ion as used here for a bromonium ion is thus ambiguous.

5.2.2 Addition to αβ-Unsaturated Carbonyl Compounds: The Michael Addition

The presence of the carbonyl group is responsible for the facile nucleophilic addition at the carbon-carbon double bond in αβ unsaturated aldehydes, ketones and esters. Nucleophilic attack at the β-carbon yields a stable anion which abstracts a proton from the solvent to produce either the keto or the enol form of the addition product. The enol form is usually less stable and so it is rapidly equilibrated to the more stable keto form.



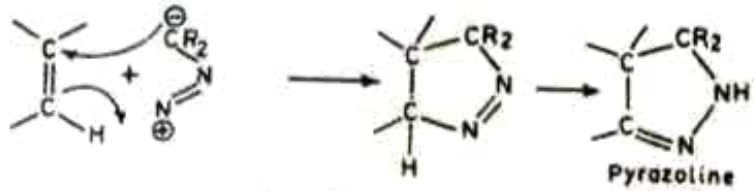
Probably the most important addition reaction of αβ-unsaturated carbonyl compounds is the nucleophilic addition of enolate anions to the carbon-carbon double bond. This process in which a new carbon-carbon bond is produced is called *Michael addition*. The αβ-unsaturated compounds used in this reaction include any unsaturated system having an electron-withdrawing group capable of stabilizing the intermediate anion. The enolate anions are commonly produced from malonic ester, ethyl cyanoacetate and ethyl acetoacetate. The mechanism of Michael addition, with ethyl malonate as the source of the nucleophile, may be depicted as above with $Nu^- = -CH(COOEt)_2$. Double Michael additions are often employed for synthesizing ring compounds.



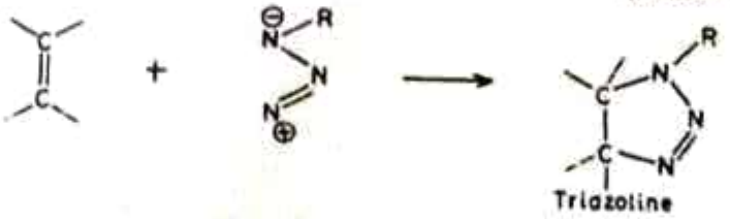
5.1.9 1,3-Dipolar Addition

This type of addition may be regarded as a [2+3] cycloaddition which provides a versatile method for synthesizing five-membered heterocyclic compounds by the addition of a 1,3-dipolar compound to a double bond. The generalized equation may be written as follows:

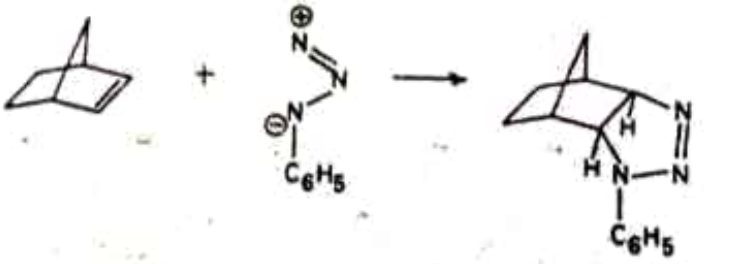
X has only six electrons in the outer shell and Z has at least one pair of unshared electrons, e.g., diazoalkanes, alkyl azides and azoxy compounds. All these compounds add to the double bond forming various heterocyclic compounds. Carbon-carbon triple bond may also undergo 1,3-dipolar addition.



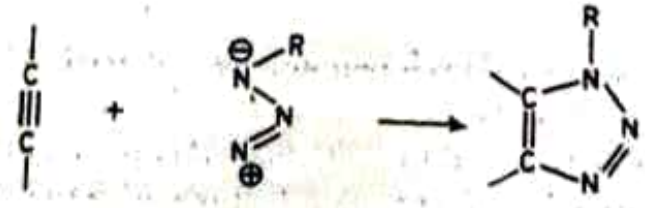
Pyrazoline



Triazoline



Phenyltriazoline



Triazole

Formation of molozonide (XVII) as discussed earlier may be regarded as an example of 1,3-dipolar addition.

A convenient method for lengthening a carbon chain by three is based on 1,3-dipolar addition of a keto carbene to a ketene.

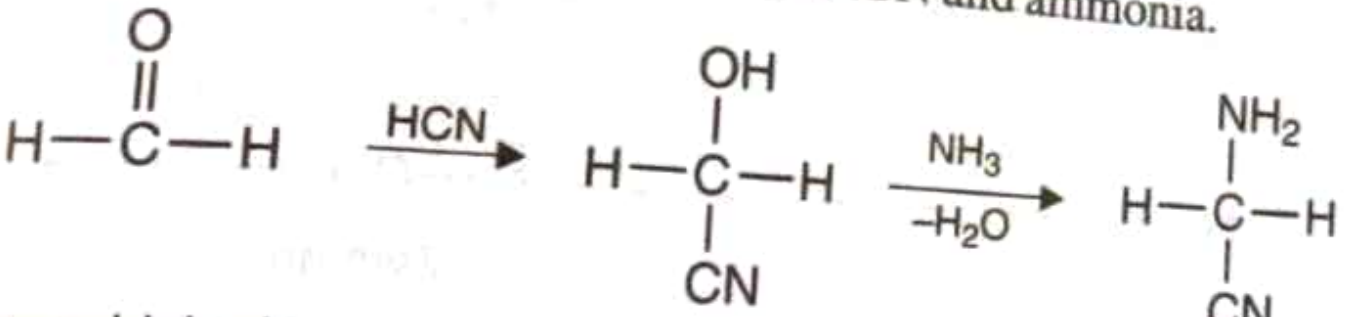
CH_3COOH ⟶ $HCl + Cl—CH_2COOH$ ⟶ $H_2N—CH_2COO^-NH_4^+$ ⟶ $H_2N—CH_2COOH$

Acetic acid — Glycine (Aminoacetic acid)

monia ; (*iii*) Ammonium salt

(2) **By Strecker Synthesis.** This involves two steps :

Step 1. An aldehyde is treated with a mixture of HCN and ammonia.



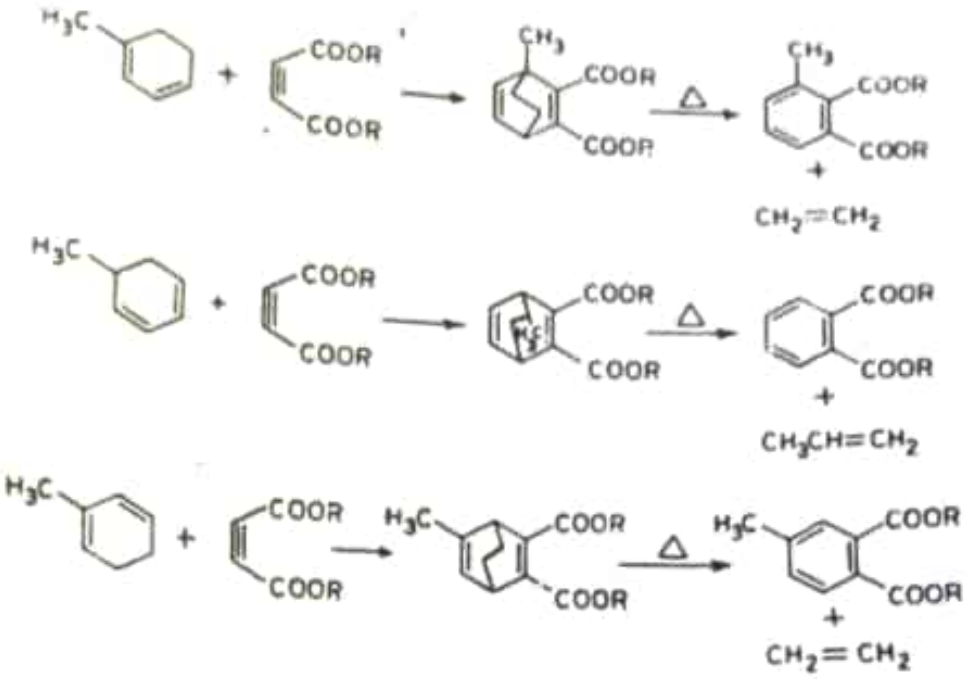
Formaldehyde — α-Amino nitrile

Step 2. α-Amino nitrile is hydrolysed.

$H_2N—CH_2—CN \xrightarrow{H^+/H_2O} H_2N—CH_2—COOH$

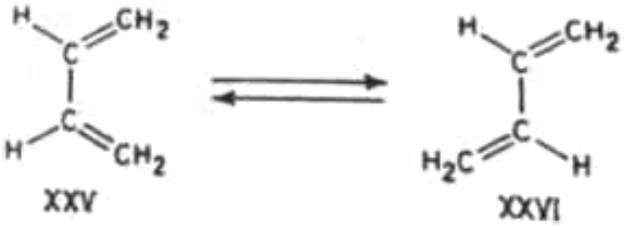
α-Amino nitrile — Glycine

(3) **By Gabriel Phthalimide Synthesis.** This involves the treatment of potassium phthalimide an ester of a α-halo acid followed by hydrolysis.



By identifying the phthalic esters through hydrolysis, and pyrolysis to the corresponding phthalic anhydride, the structures of the homoannular cyclohexadienes are very conveniently determined.

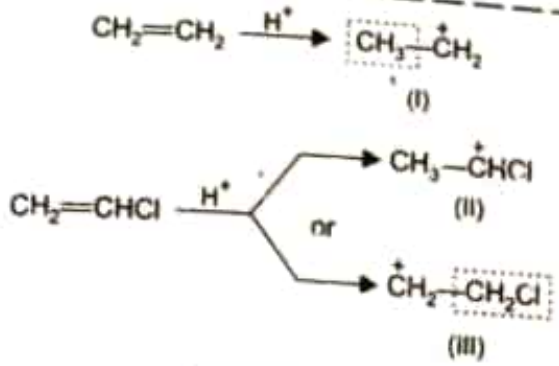
Success of the Diels-Alder reaction depends upon the geometric arrangement about a single bond of the diene component; in other words, the diene must have a *s-cis* conformation. Since the energy barrier for the interconversion of *s-cis* (XXV) and *s-trans* (XXVI) acyclic dienes is very low (5 kcal/mole), the reaction proceeds well with the latter dienes as well because of the equilibrium between the two conformational structures, even though *s-trans* is thermodynamically more stable.



XXV XXVI

Cyclic dienes such as 1,3-cyclopentadiene are fixed in the *s-cis* conformation and are especially reactive.

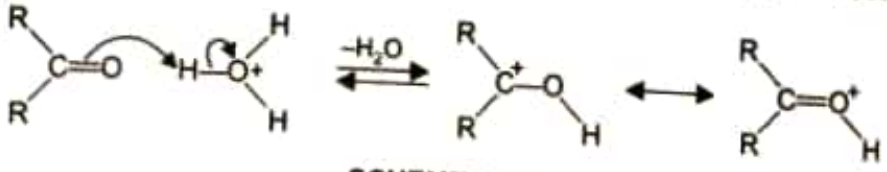
The Diels-Alder reaction usually does not appear to involve ionic or free radical intermediates and is remarkably insensitive to the presence or absence of solvents and catalysts. There is simultaneous making and breaking of several bonds through a transition state in which all first order changes occur on a closed curve. It is an example of [4+2] cycloaddition and we shall discuss its mechanism in Chapter 14.



SCHEME 11.1c

$\overset{+}{C}H_2$—CH_2Cl. Thus vinyl chloride reacts at a slower rate than ethylene but orients in the same way as propylene.

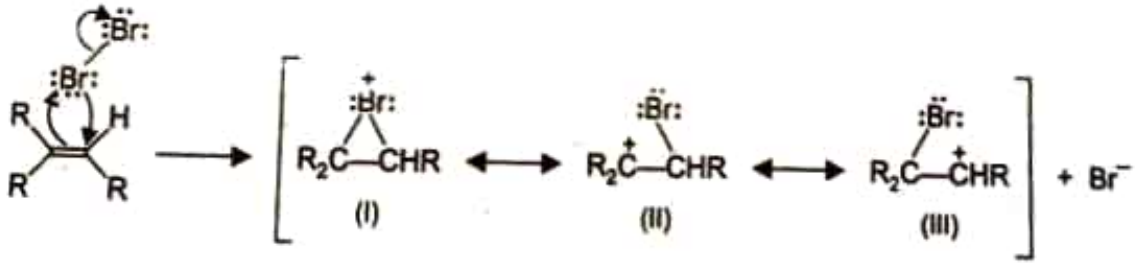
The carbonyl group gets protonated to give a delocalized cation. This reversible reaction is the first step of several acid catalysed reactions on carbonyl compounds (Scheme 11.1*d*).



SCHEME 11.1d

(B) Addition of Halogens

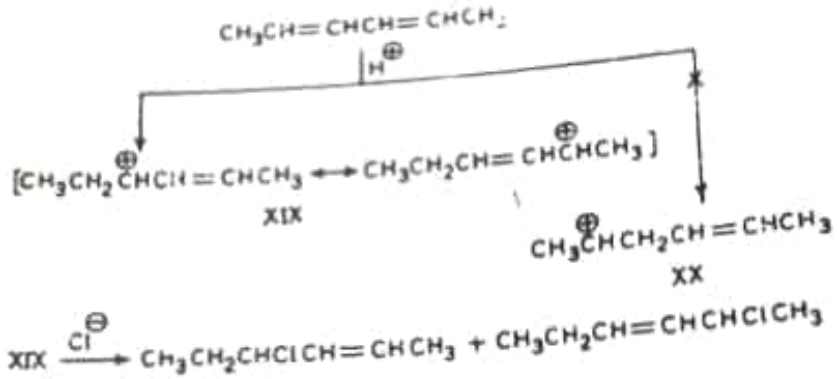
Chlorinations and brominations of alkenes are electrophilic additions and involve a discrete positively charged intermediate which may be a bridged cyclic halonium ion (*e.g.*, bromonium ion I, Scheme 11.2) or a carbocation. This positively charged intermediate is formed after the addition of Br^+ to the alkene (see, also Scheme 4.23).



SCHEME 11.2

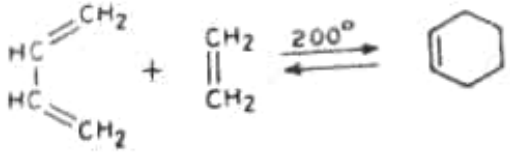
The bridged bromonium ion is best represented by the hybrid (Scheme 11.2) where a tertiary carbocation (II) is a far more important contributor to the hybrid than the secondary carbocation (III, Scheme 11.2). Consequently the carbon with an alkyl substituent(s) will be more electrophilic. The regioselectivity is explained on this stability feature and the addition of bromine to propylene in water (water competes with bromide ion as the nucleophile) gives in addition to dibromo compound, 1-bromo-2-hydroxypropane as the major product than 2-bromo-1-hydroxypropane (Scheme 11.2*a*). Thus regioselectivity of addition of BrOH to an unsymmetrical olefin is explained on the charge distribution within the delocalized reactive intermediate (bromonium ion) (See, Scheme 11.2). In fact the three membered ring of the

Allylic carbonium ions are unusually stable and hence are formed preferentially. For example, treatment of 2, 4-hexadiene with HCl yields products derived from the allylic carbonium ion (XIX) rather than the alternative carbonium ion (XX) although in both the structures, the positive charge is located on a secondary carbon atom.

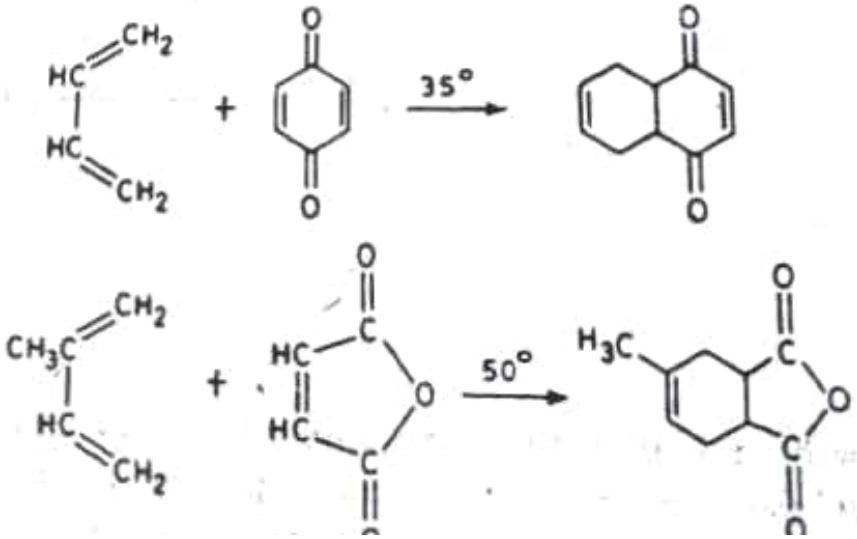


5.1.8 Diels-Alder Reaction

The familiar Diels-Alder reaction involves the formation of a six-membered ring by the 1,4-addition of an alkene (called a dienophile) to a conjugated diene.

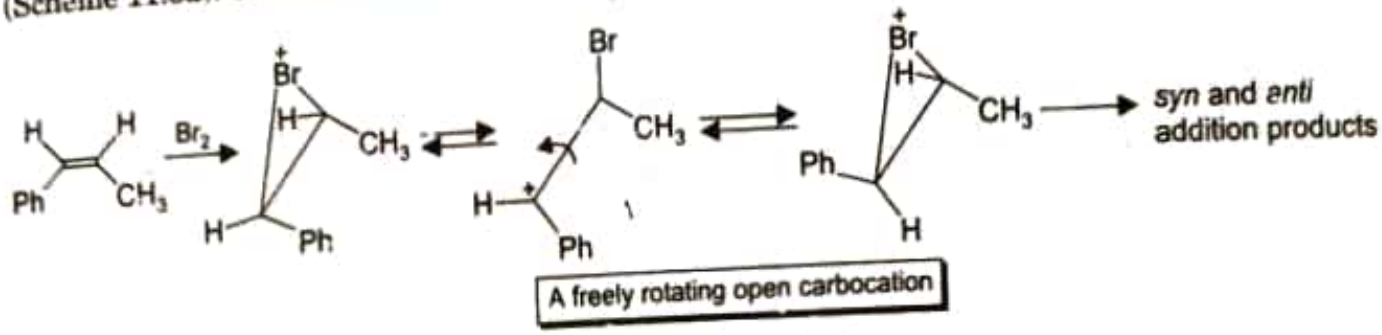


The reaction proceeds faster when the dienophile has electron-withdrawing substituents such as —COOH, —COOR, —CHO, —NO_2 and —CN. On the other hand, reaction rates rise with increasing electron supply in the diene; 1,3- butadiene, for instance, is less reactive than its mono-, di- and trimethyl derivatives. Many such reactions take place under relatively milder conditions.



positively charged bridged bromonium ion and in the second step the nucleophile, Br^- adds to the face away from the bridging group to give the overall *anti* addition.

When the alkene has phenyl group on the double bond, the selectivity becomes less and both *anti* and *syn* adducts are formed. This is so, because now the positive charge in the intermediate is delocalized on the aromatic ring (Scheme 11.3*a*). The presence of a phenyl group, therefore, provides sufficient stabilization to allow carbocation formation (Scheme 11.2). This situation reduces the strength of bromine bridging and allows rotation to occur as shown (Scheme 11.3*a*). The freely rotating open carbocation would give both *syn* as well as *anti* addition



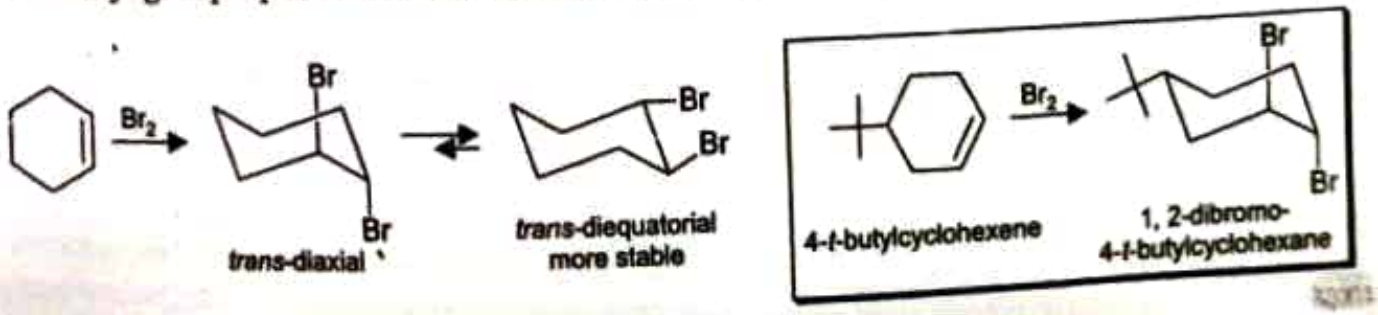
SCHEME 11.3a

products. Thus *syn* and *anti* addition is observed with both *Z*-1-phenylpropene (Scheme 11.3*a*) as well as with *E*-1-phenylpropene

ADDITION OF HALOGENS TO ALKENES

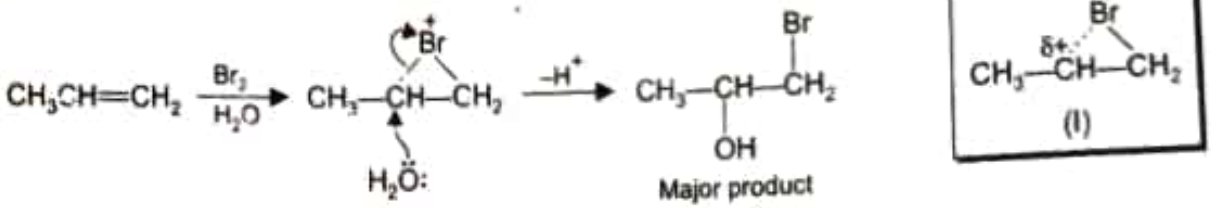
A weakly bridged bromonium ion can lead to the loss of stereospecificity during halogen addtion. The unconjugated alkenes involved in strong bridging leading to predominant anti-stereospecificity. The presence of a phenyl group on the double bond generates a cationic character at the benzylic site leading to the formation of more syn addition. Chlorine has a smaller size and lesser polarizability than bromine, consequently chloronium ion is far less bridged. Thus overall bromination gives more pronounced anti addition than chlorination.

Cyclohexene and its derivatives add chlorine and bromine to yield *trans* diaxial product since only axial positions on adjacent carbons in a cyclohexane are *anti* and coplanar. The initial *trans* diaxial product undergoes a conformational change and is in equilibrium with the more stable *trans* diequatorial conformation (Scheme 11.3*b*). When a *t*-butyl group is introduced on the cyclohexene ring, then the molecule exists almost exclusively in a conformation in which the *t*-butyl group is equatorial. Thus when 4*t*-butylcyclohexene is brominated, the product has *t*-butyl group equatorial with bromine atoms in the axial positions in the favoured product.



SCHEME 11.3b

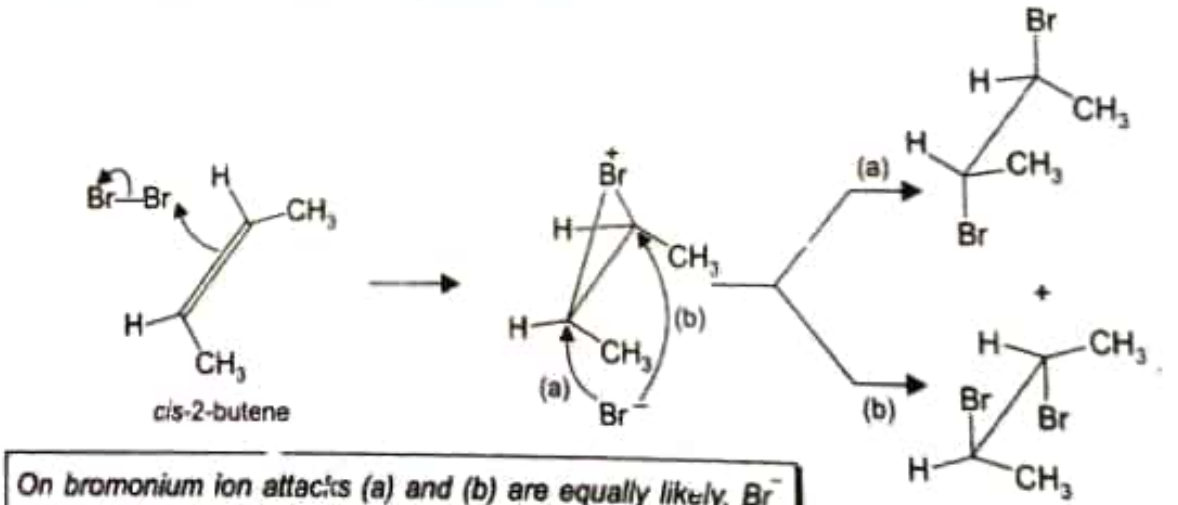
halonium ion is symmetrical provided the original double bond is symmetrical. Greater stabilization of the 2° carbocation makes the bridged bromonium ion infact an unsymmetrical species (I, Scheme 11.2*a*).



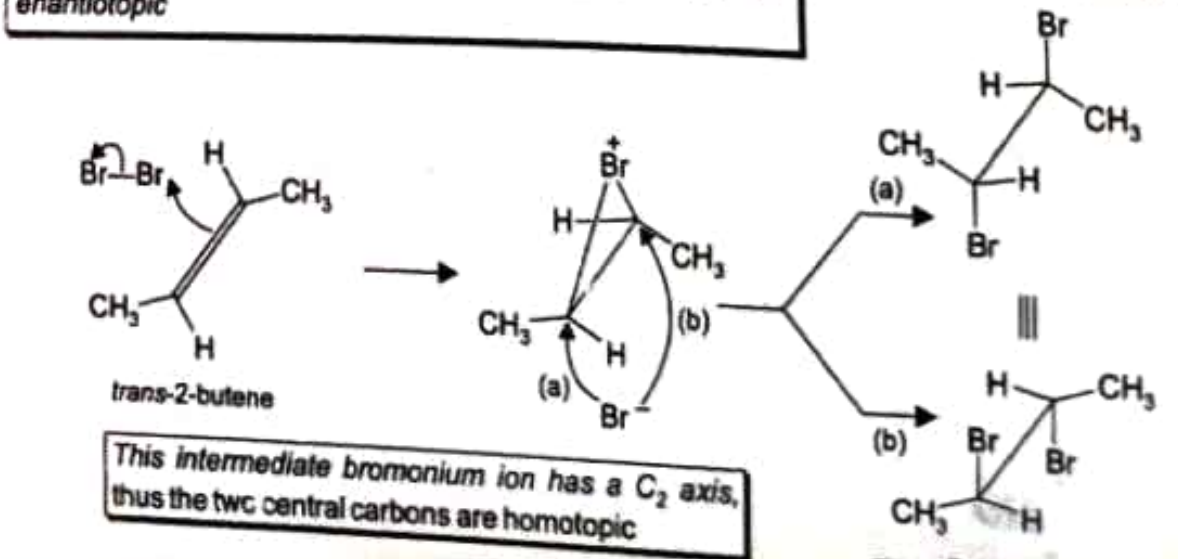
SCHEME 11.2a

The formation of a bromonium ion intermediate ensures the formation of *anti* product. The bridging will prevent free rotation around the C—C bond which will ensure the formation of a mixture of diastereomers. Note that the opening of the cyclic bromonium ion is an S_N2 reaction in which the incoming nucleophile attacks on the opposite side of the leaving group. Moreover, when bridging is strong, the *anti* product is formed as a major or exclusive product.

The *anti*-addition of bromine is observed for alkenes which do not have substituent groups that would stabilize a carbocation intermediate (Scheme 11.2). Thus, addition of bromine to *cis*- and *trans*-2-butene is stereospecific (Scheme 11.3). The first step is the formation of a



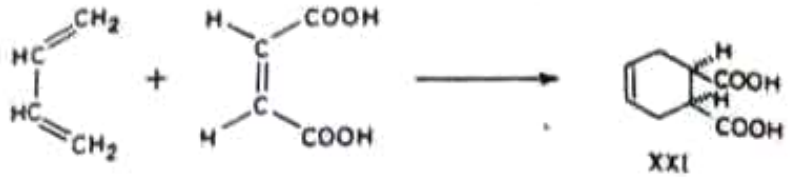
On bromonium ion attacks (a) and (b) are equally likely, Br^- attacks the bottom face (S_N2 reactivity). The bromonium ion has a mirror plane thus the two central carbons are enantiotopic



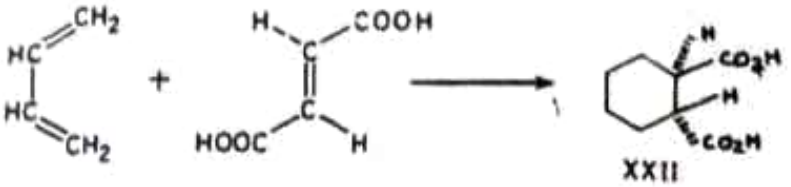
This intermediate bromonium ion has a C_2 axis, thus the two central carbons are homotopic

SCHEME 11.3

These reactions show an extremely high degree of stereospecificity, for whereas maleic acid gives *cis* acid (XXI) fumaric acid yields the *trans* isomer (XXII), both by *cis* addition.

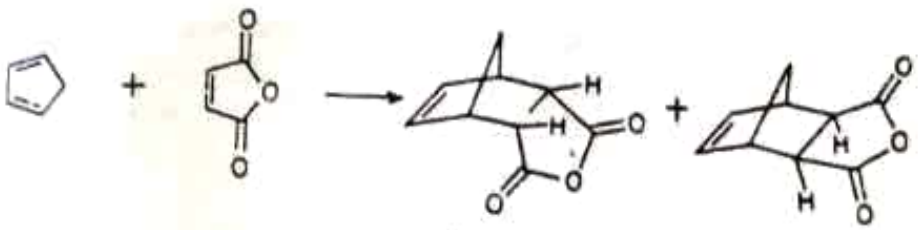


XXI



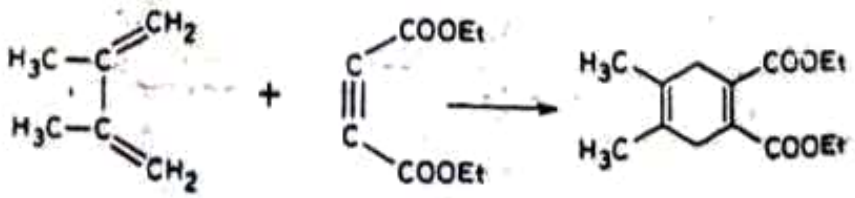
XXII

When cyclic dienes are used the *endo* adduct (XXIII) is favoured over the *exo* (XXIV).



XXIII XXIV

A carbon-carbon triple bond may also participate in the reaction.

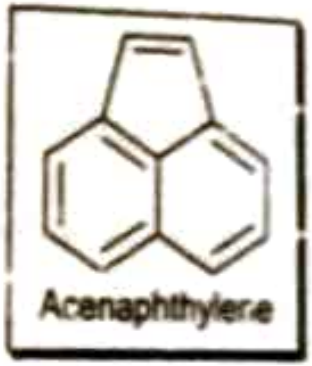


This reaction has been employed in determining the structures of substituted homoannular cyclohexadienes. For example, the structures of the following isomers of methylcyclohexadienes can be determined.

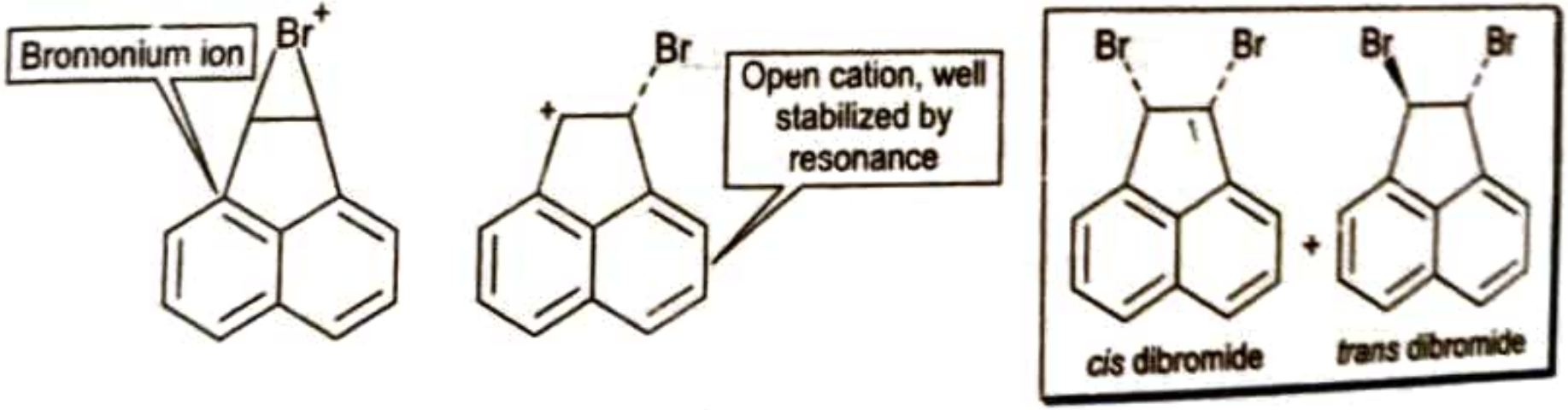
EXERCISE 11.3

Why acenaphthylene (Scheme 11.5a) on reaction with bromine gives the expected trans dibromide (anti addition) alongwith a large amount of cis dibromide (syn addition).

ANSWER. *Due to the formation of a resonance stabilized open carbocation. S_N2 reaction on cyclic bromonium ion will give only the trans product, while the open cation will give both cis and trans products (Scheme 11.5b)*



SCHEME 11.5a



SCHEME 11.5b

(C) Addition of Hydrogen Halides to Alkenes

The first aspect of mechanism of addition of hydrogen halides to alkenes is the observed regioselectivity controlled by Markovnikov rule *i.e.*, the relative ability of the carbon atoms to [illegible] complicated when a free