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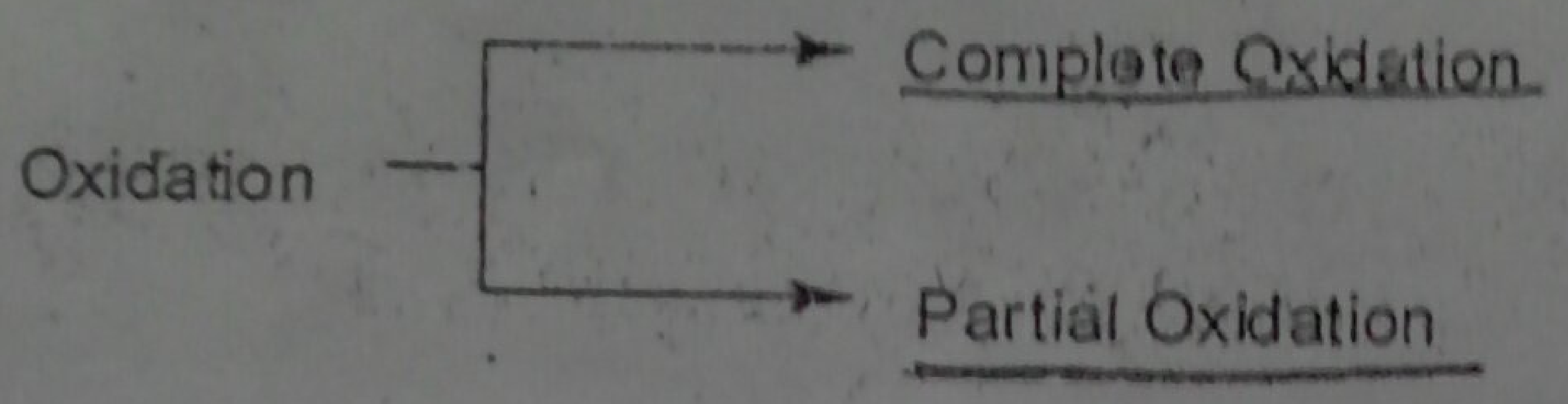
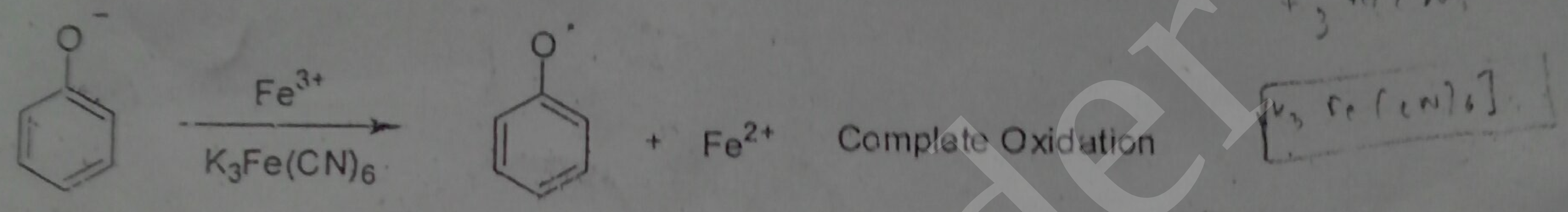
oxidation Reaction

98/25

Oxidation:- Oxidation may be defined as the loss of electron/addition of oxygen/removal of hydrogen. In an oxidation--reduction reaction, one compound loses electrons and one compound gains electrons. The compound that loses electrons is oxidized, and the one that gains electrons is reduced. One way to remember the difference between oxidation and reduction is with the phrase "LEO the lion says GER": *Loss of Electrons is Oxidation;Gain of Electrons is Reduction.* Oxidation is of two type:





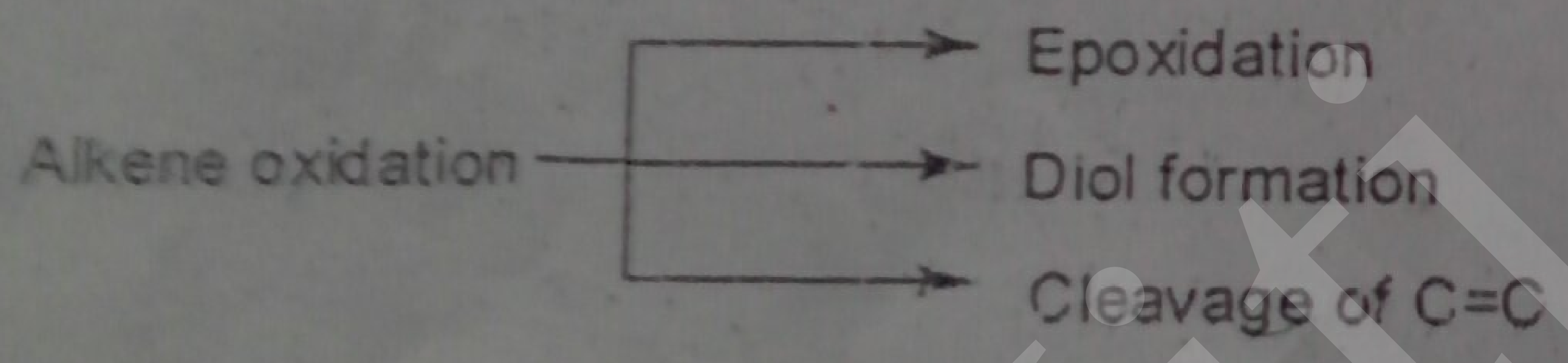
$\delta^+ \ \delta^-$

$CH_4 + Br_2 \longrightarrow CH_3\text{-}Br + HBr$ $\quad$ C-Br

Partial Oxidation

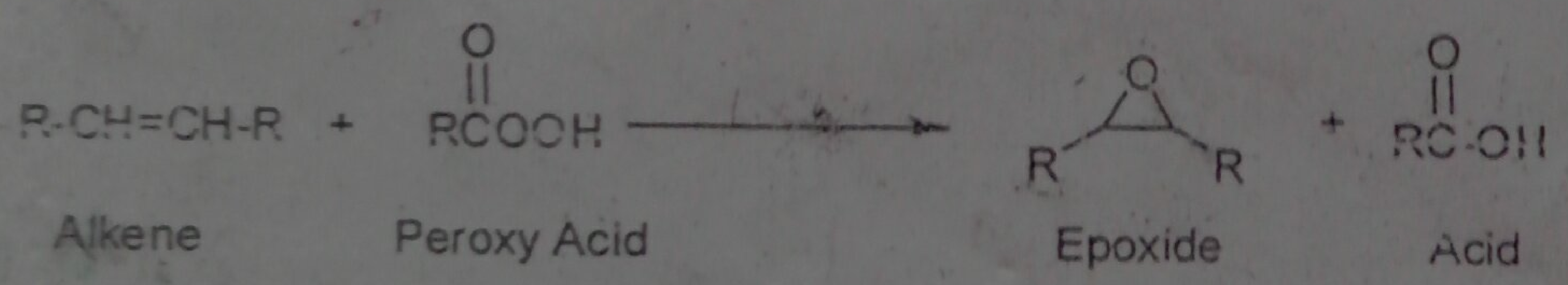
Oxidation of Hydrocarbons:-

Oxidation of Alkenes can be achieved at three levels.

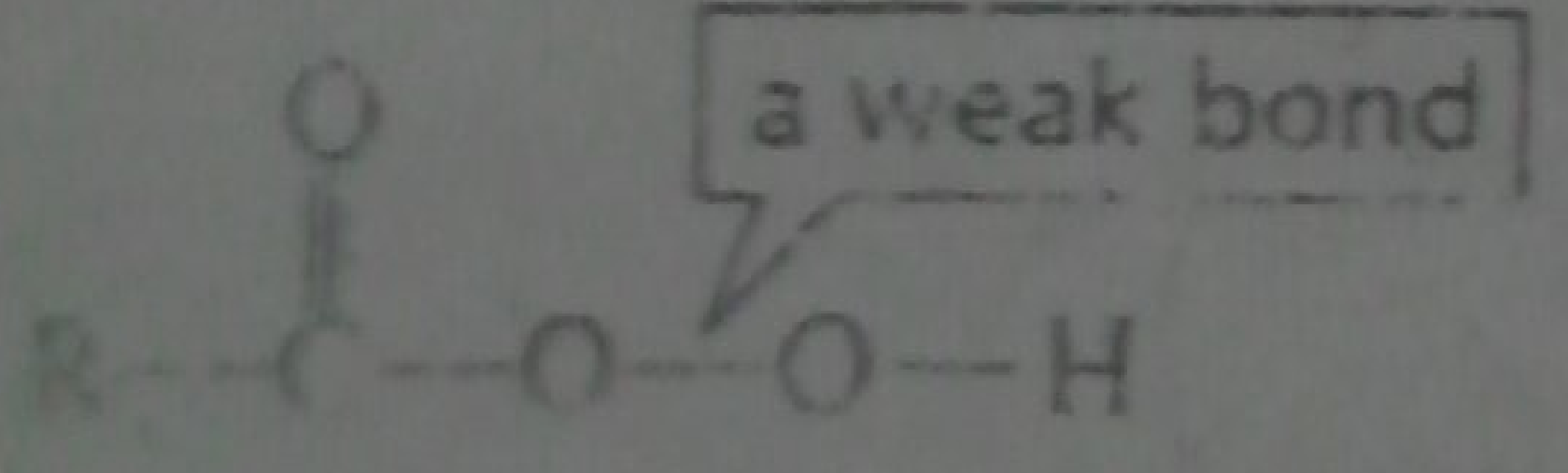


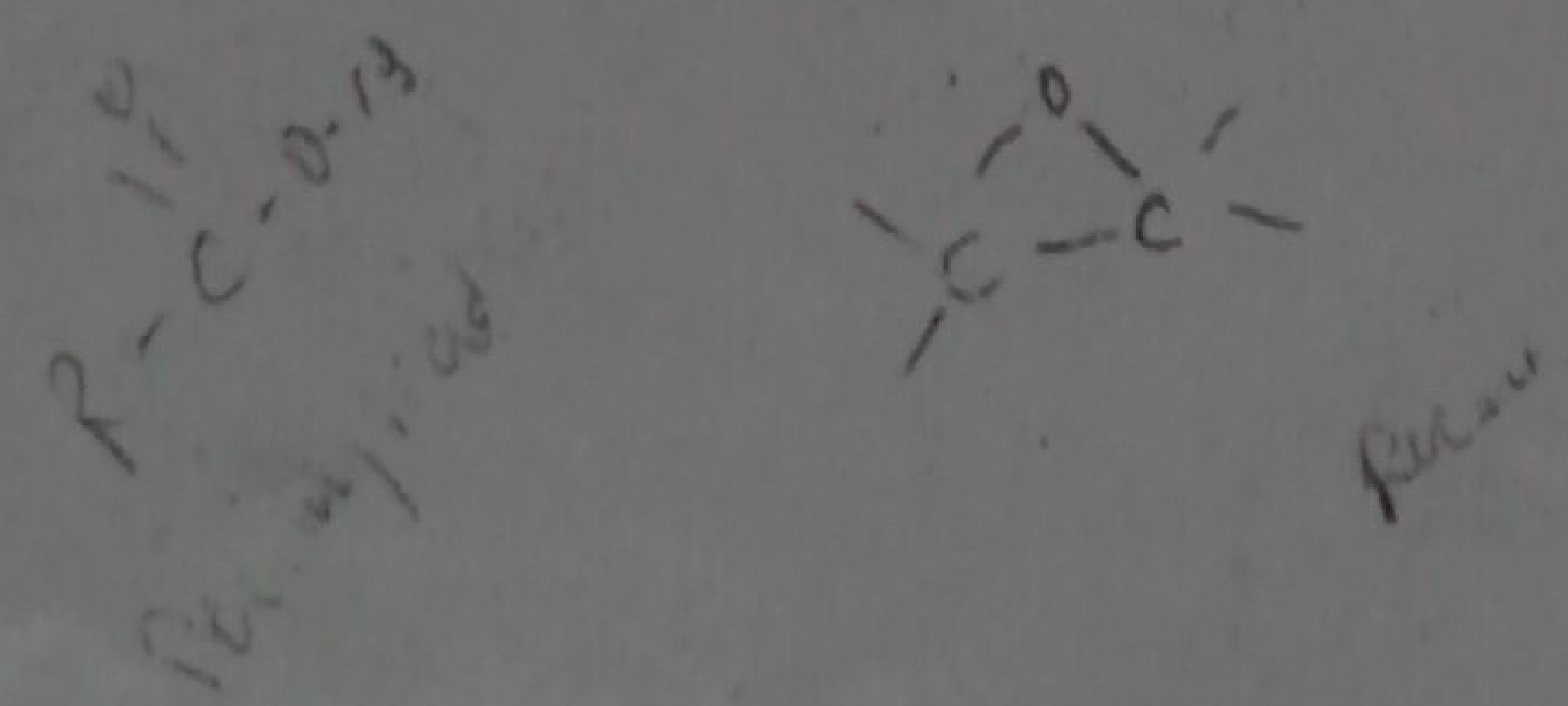
Oxidation of Alkenes with Peroxyacids: Epoxidation

An alkene can be oxidized to an epoxide by a peroxyacid. The overall reaction involves the transfer of an oxygen atom from the peroxyacid to the alkene.

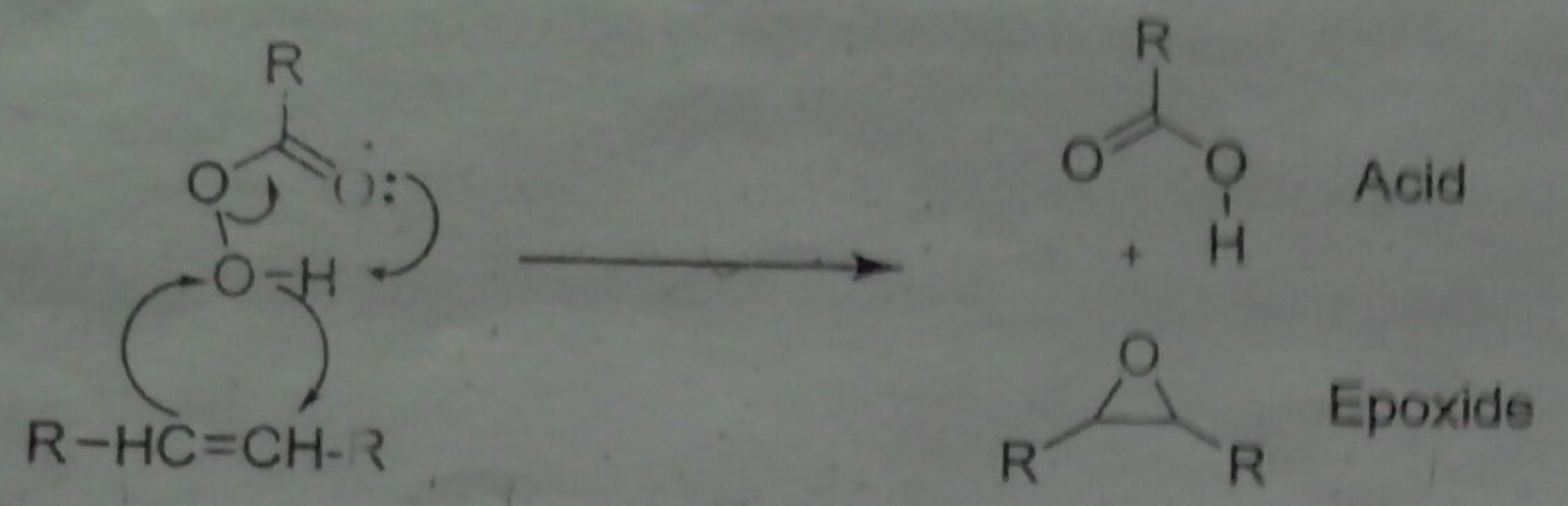


Recall that an O-O bond is weak and easily broken.





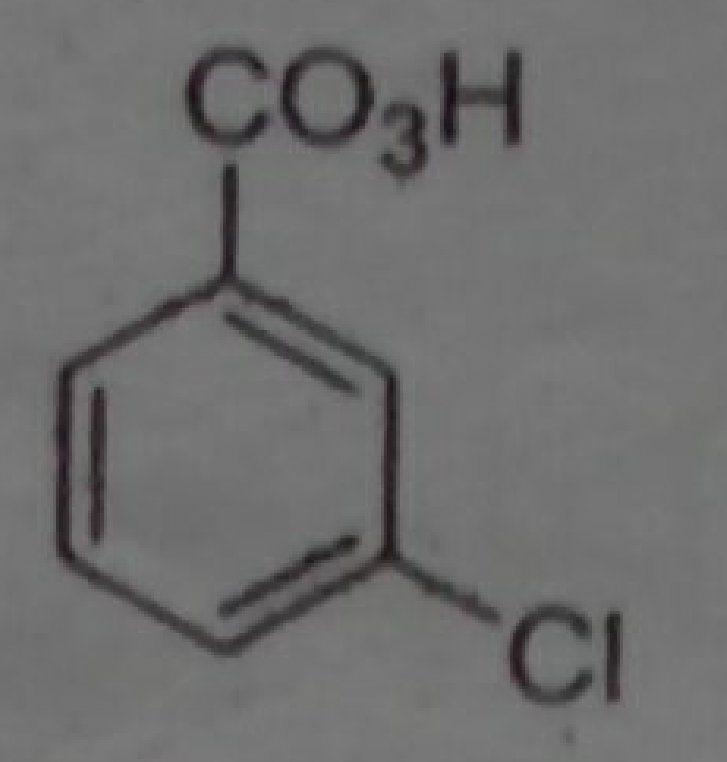
Mechanism for epoxidation of an alkene:- When an alkene is treated with a peroxyacid, electrophilic attack of peroxy acid on double bond take place. Therefore electron releasing group on double bond should increase the rate of epoxidation.



So the reactivity order is $R_2C=CR_2 > RCH=CHR > R_2C=CH_2 > RCH=CH_2 > CH_2=CH_2$

Peracid has the deficiency of electron, so electron withdrawing group on peracid should increase the rate of epoxidation.

$CF_3CO_3H > CH_3CO_3H$ and

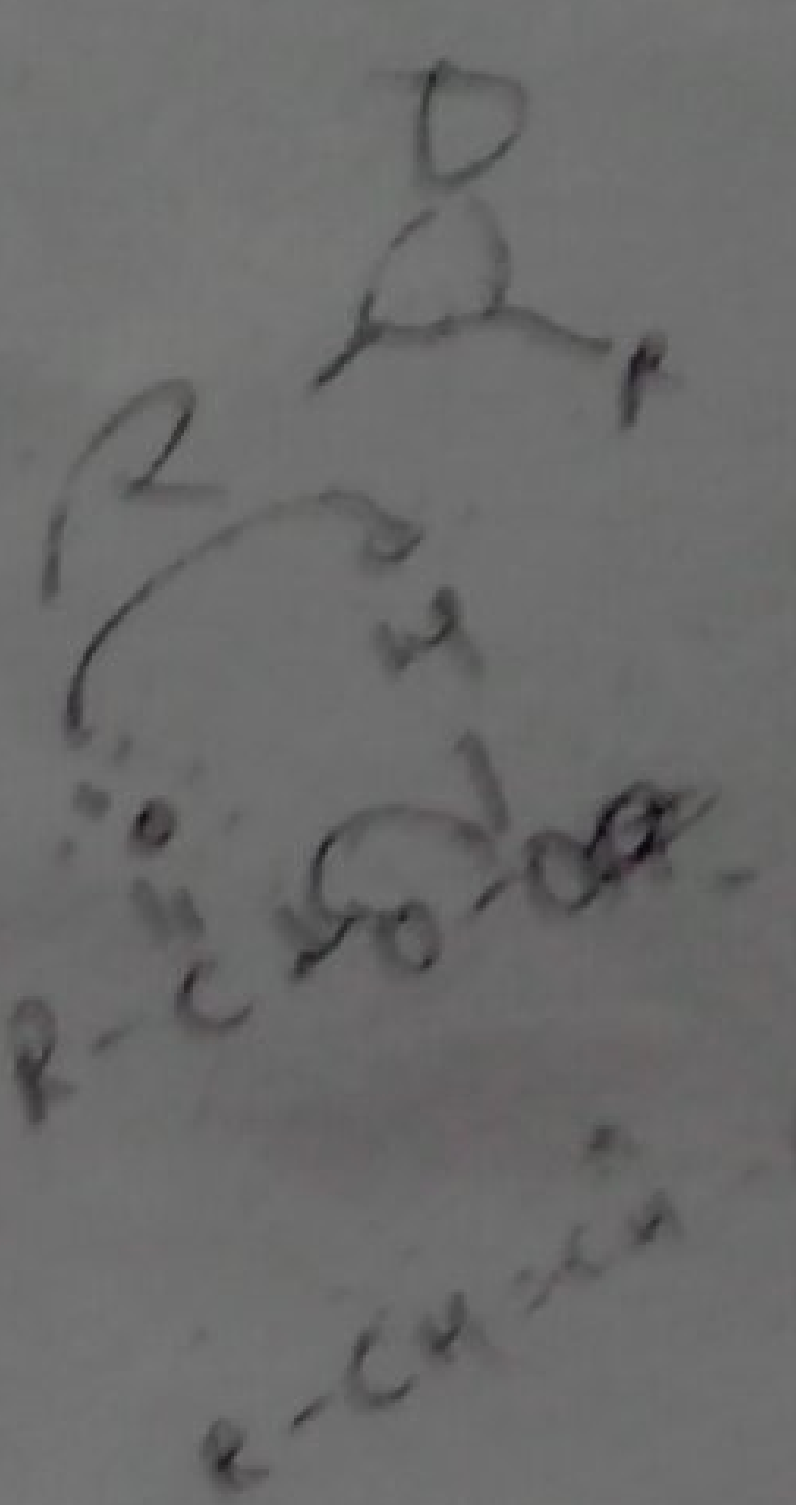


meta-Chloro Per Benzoic Acid
(m-CPBA)

>

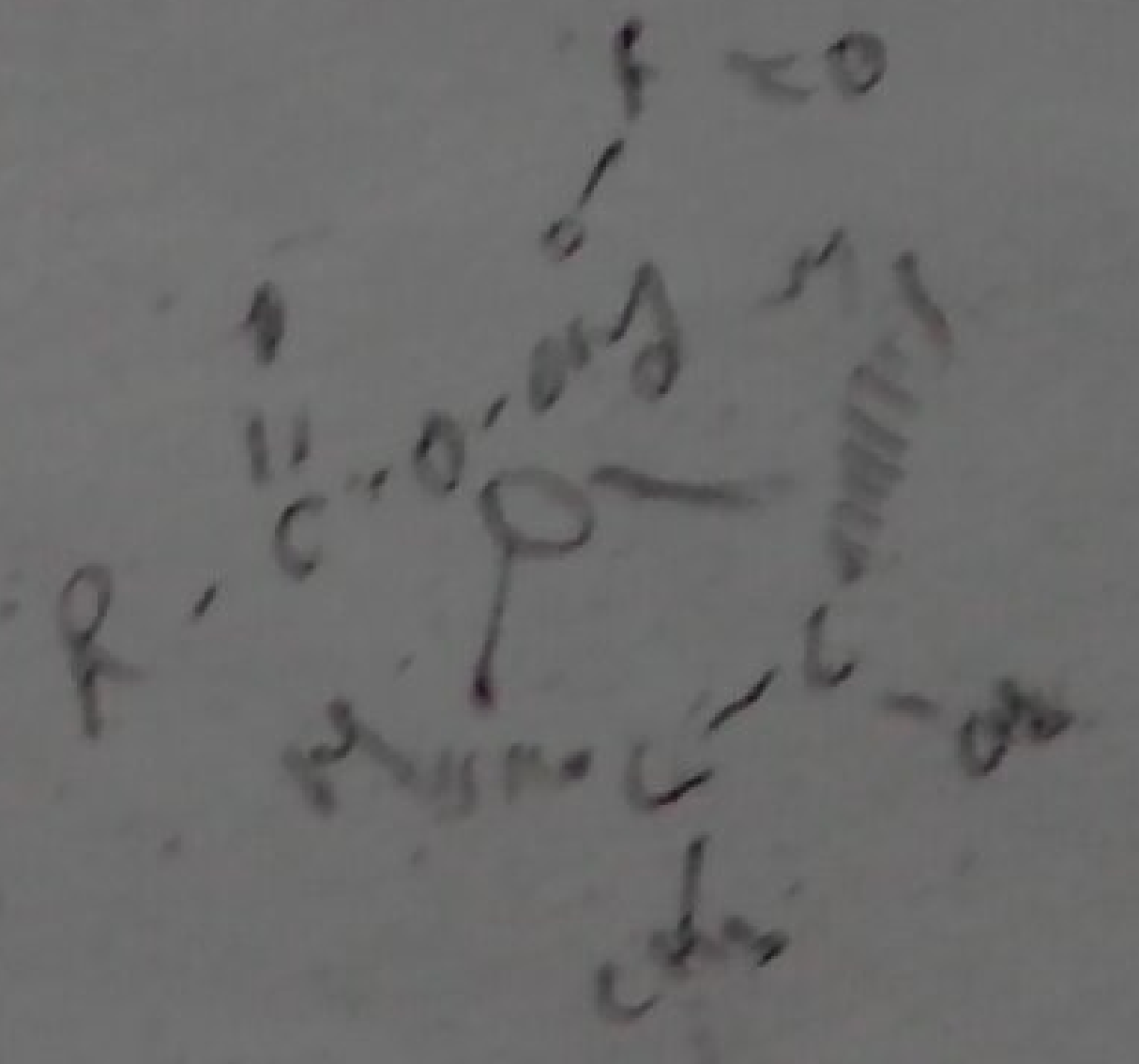
Per Benzoic Acid

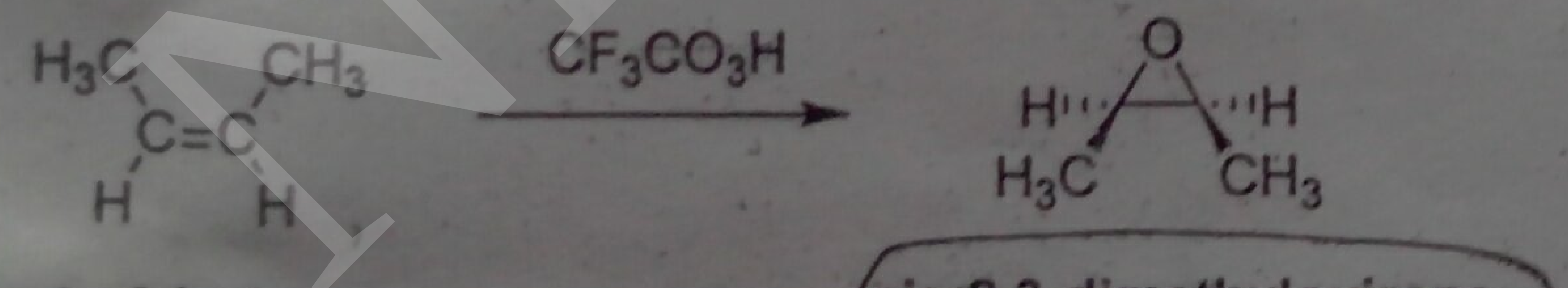
benzoic acid



Characteristics of the reaction:

1. **Stereospecific:** The addition of oxygen from peroxyacid to an alkene is a stereospecific reaction. Because the reaction is concerted, the C-C bond cannot rotate, so there is no opportunity for the relative positions of the groups bonded to the sp^2 carbons of the alkene to change. Therefore, a cis alkene forms a cis epoxide. Similarly, a trans alkene forms a trans epoxide.

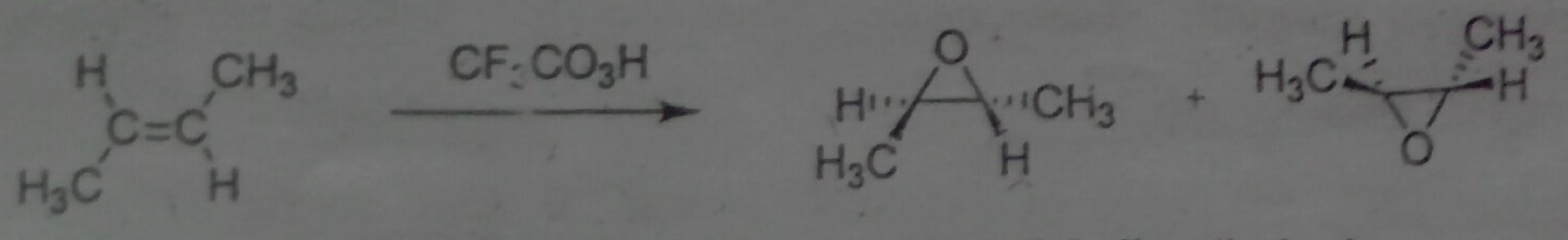




cis-2-butene

cis-2,3-dimethyloxirane

Because the oxygen can add from the top or the bottom of the plane containing the double bond, *trans*-2-butene forms a pair of enantiomers.



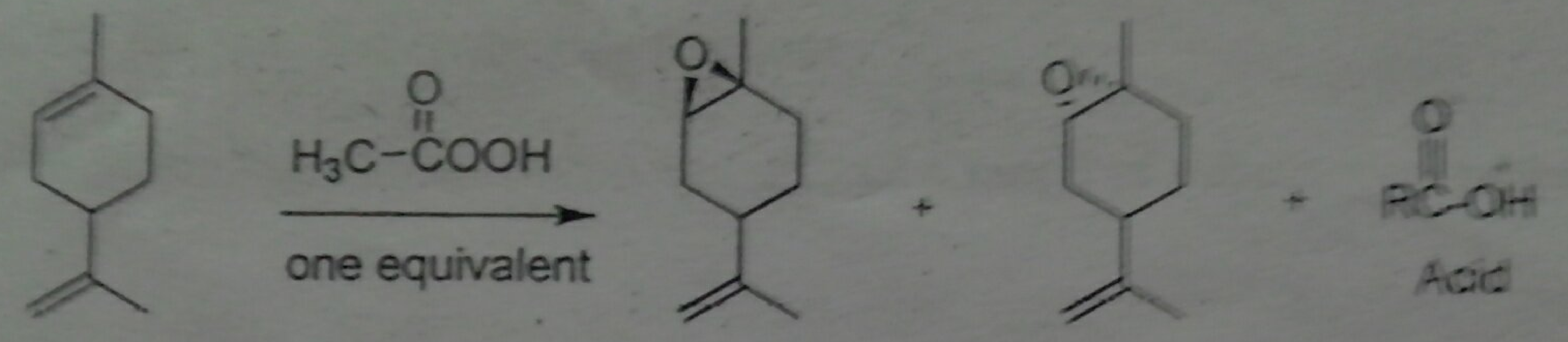
trans-2-butene

trans-2,3-dimethyloxirane

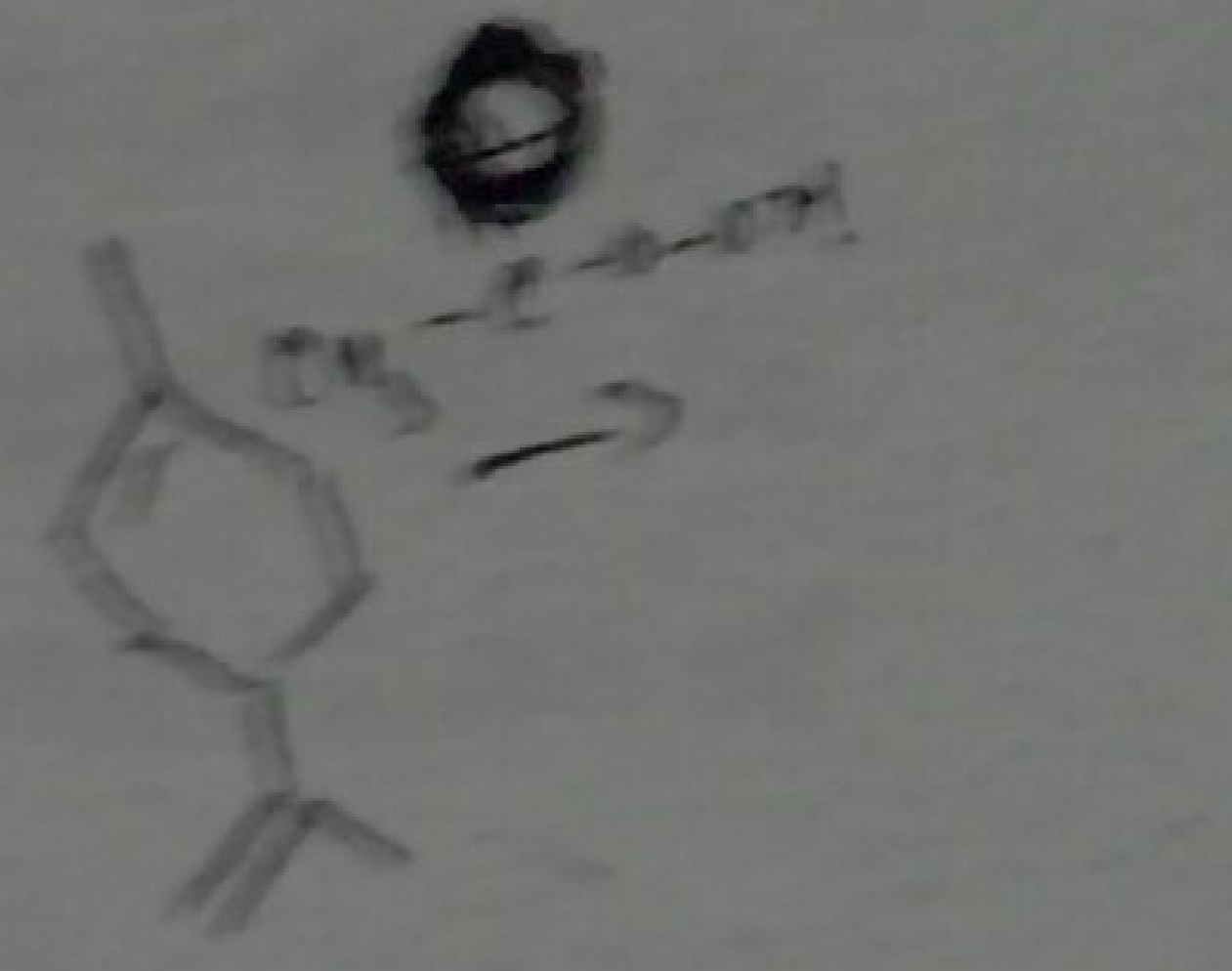
$cF_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}O\text{-}O\text{-}H$

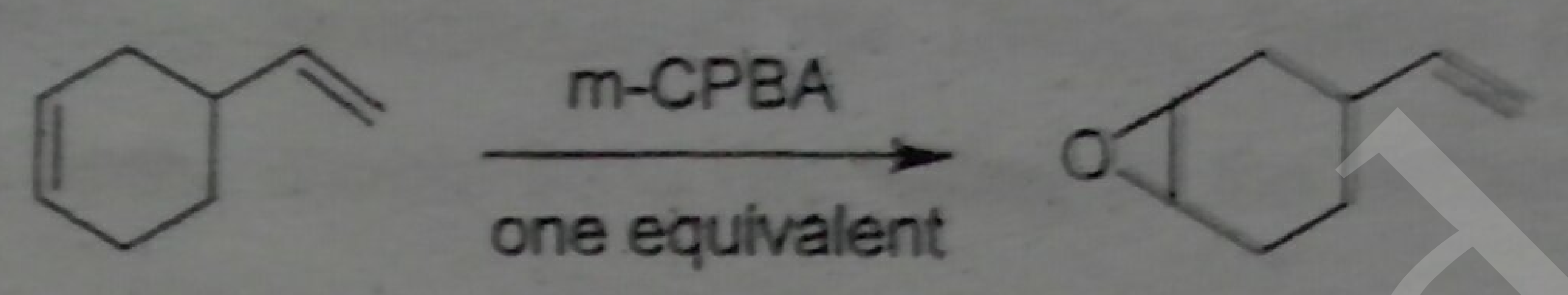
2. Regioselective:- Increasing the electron density of the double bond increases the rate of epoxidation because it makes the double bond more nucleophilic. Alkyl substituents increase the electron density of the double bond. Therefore, if a diene is treated with only one equivalent of peroxyacid to react with one of the double bonds, it will be the most substituted double bond that is epoxidized.

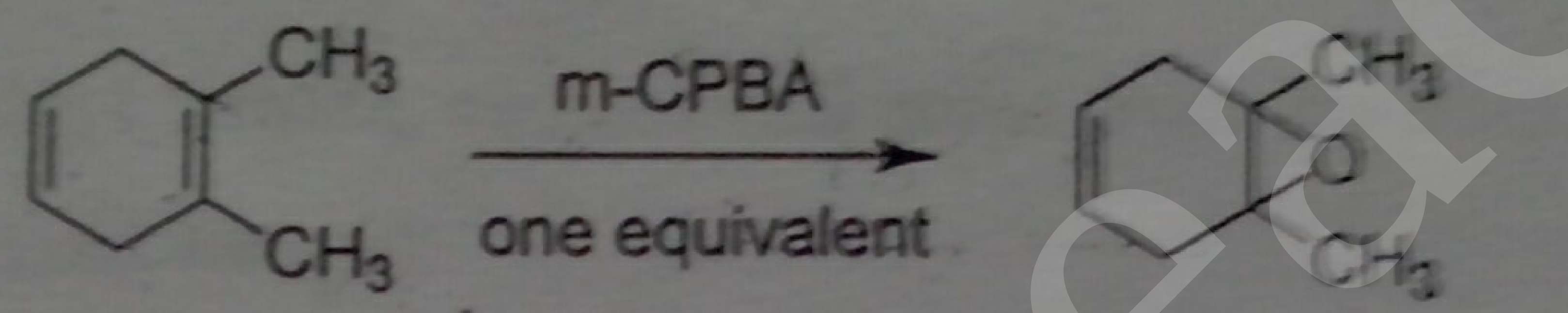
In short, it is regioselective for the more electron-rich double bond when more than one is present, e.g.



Limonene

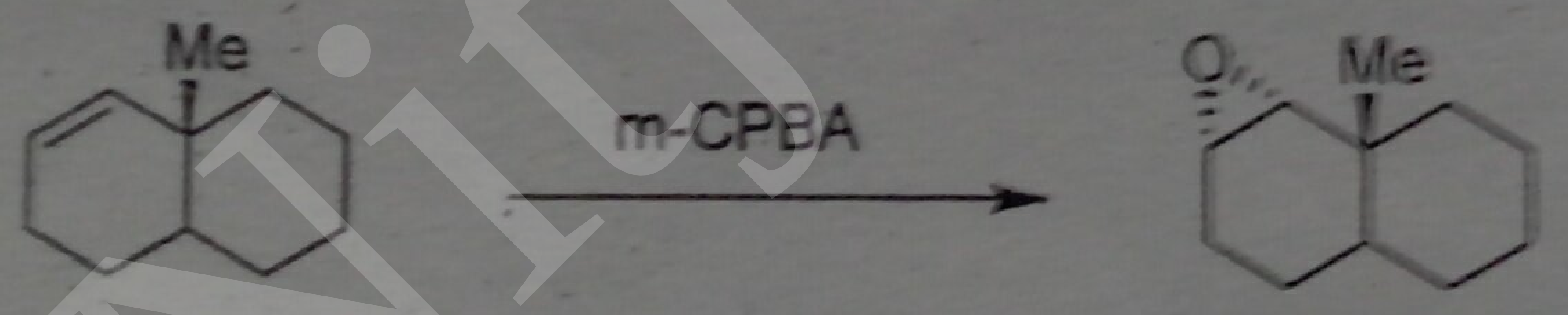


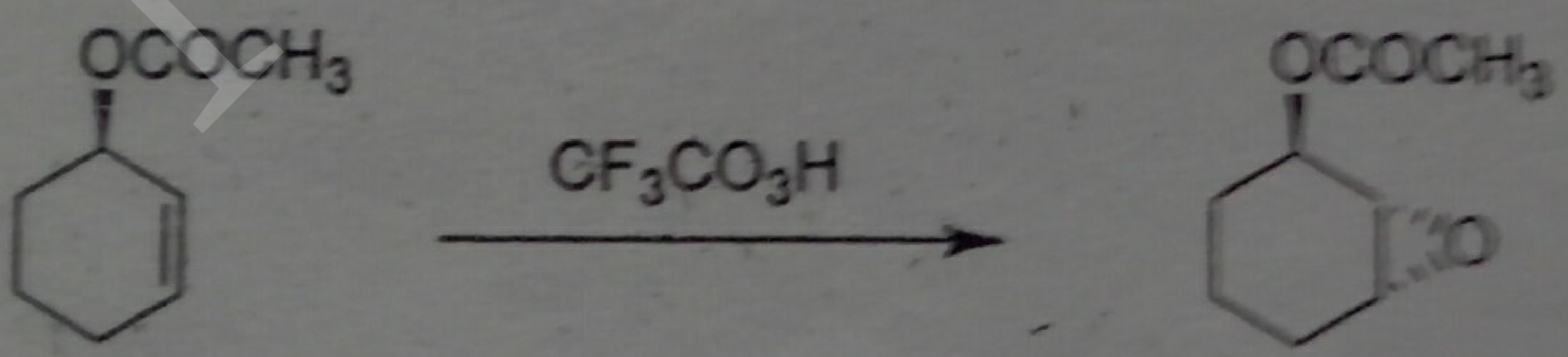




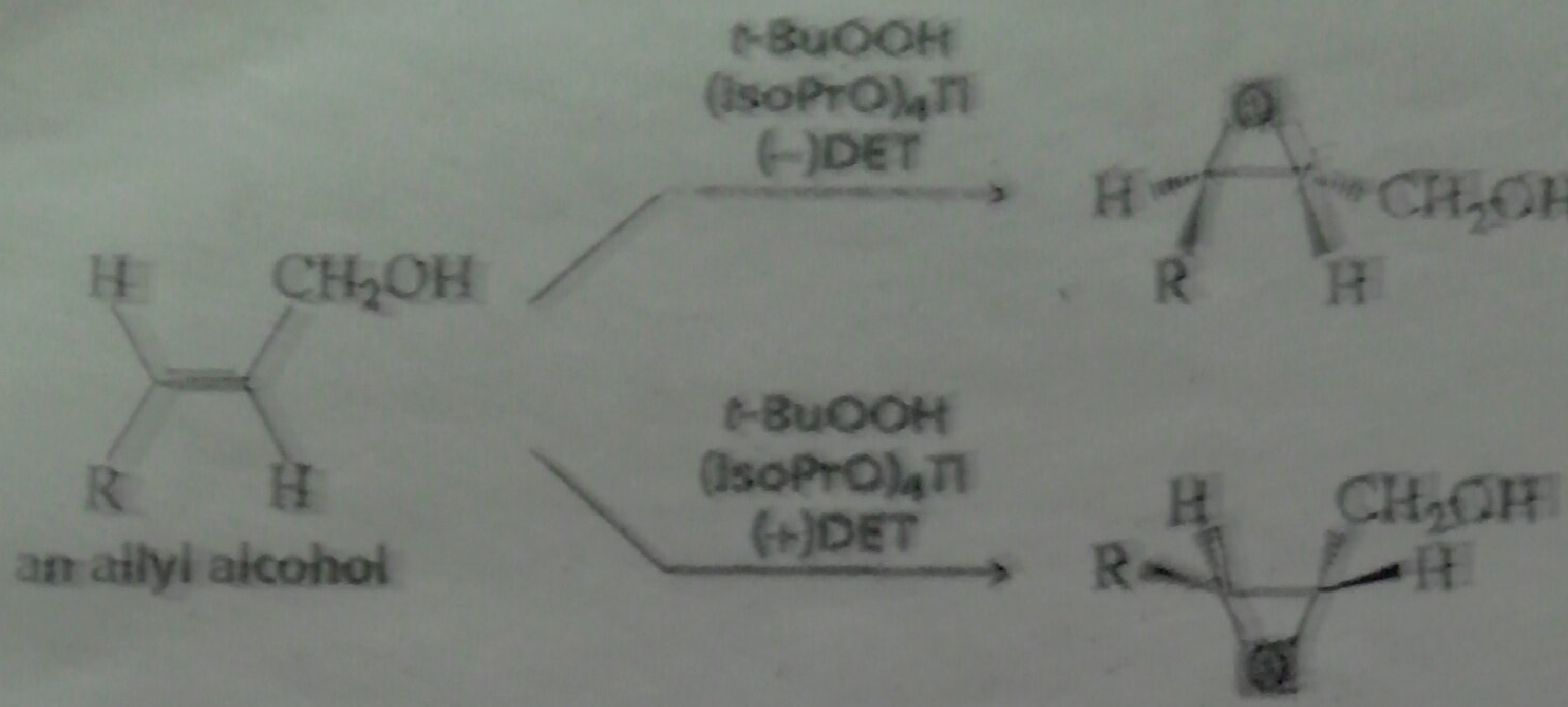
Both enantiomer

3, In case of cyclic alkenes, the addition of oxygen take place on the double bond from the less hindered side.





Sharpless Epoxidation: An enantiomerically pure epoxide of an allylic alcohol can be prepared by treating the alcohol with *tert*-butyl hydroperoxide, titanium isopropoxide, and enantiomerically pure diethyl tartrate (DET). The structure of the epoxide depends on the enantiomer of diethyl tartrate used. K. Barry Sharpless received the 2001 Nobel Prize in chemistry for his work on chirally catalyzed oxidation reactions.

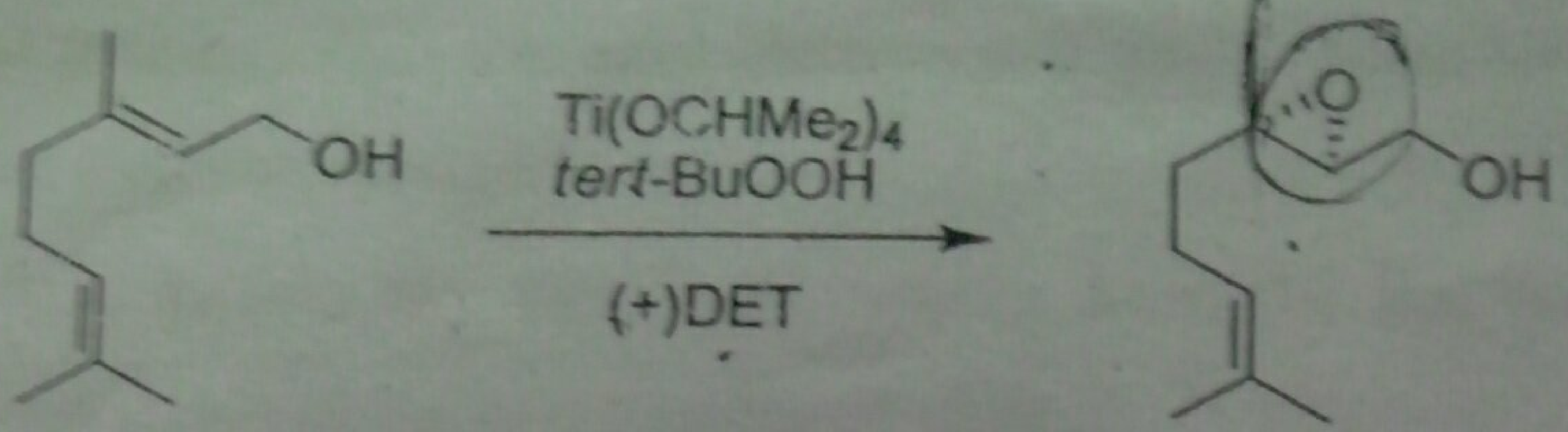


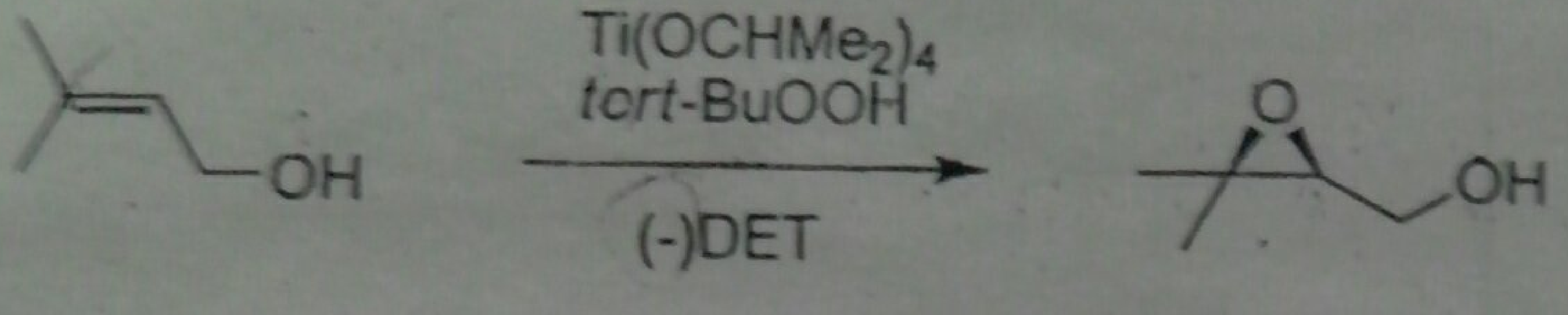
The beauty of the reaction lies in the two features:

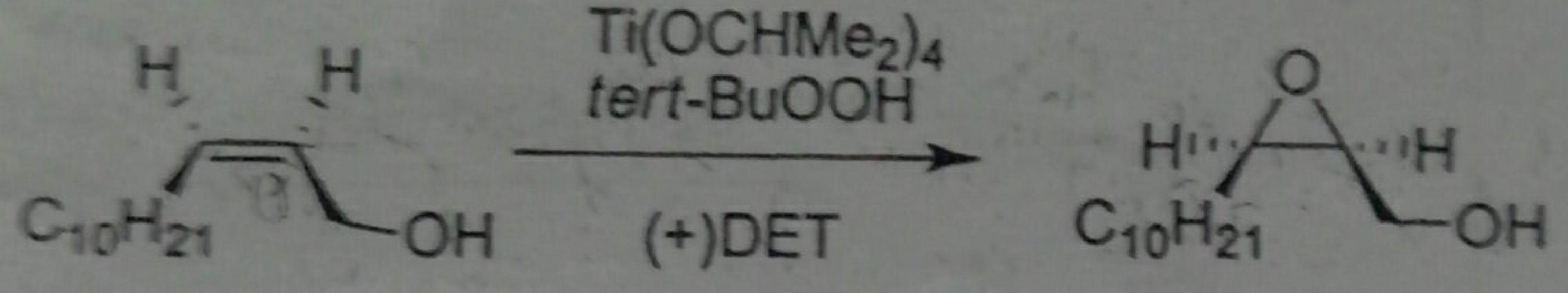
1) Uniformly high asymmetric induction throughout a range of substitution pattern of allylic alcohols.

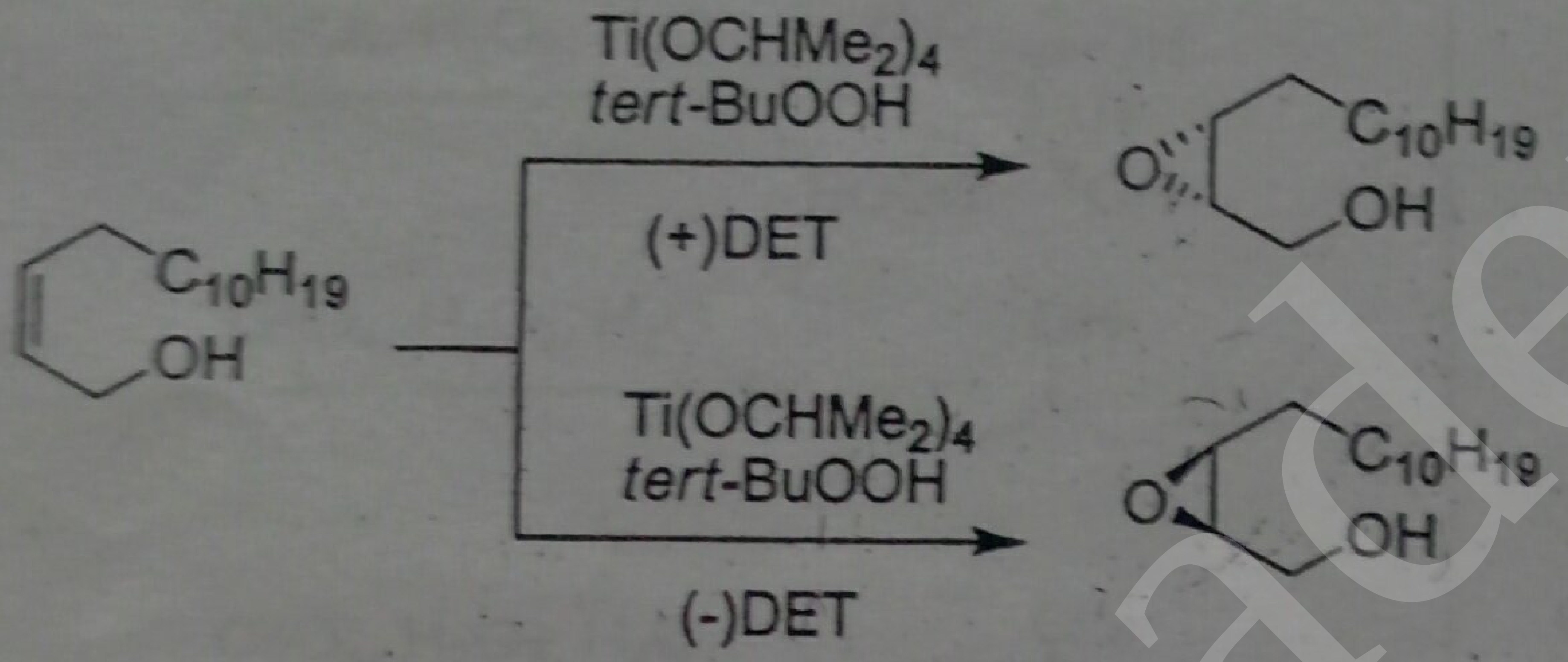
2) The absolute configuration of the epoxide produced can be predicted. This control depends upon the use of a particular enantiomer of the Diethyl Tartrate (DET). Oxygen will be delivered from the face of the double bond depending on the tartrate used and regardless of the substituents.

- If used D(-) diethyl tartrate, oxygen will come from the front side and will be shown with dark line (solid wedge).
- If used L(+) diethyl tartrate, oxygen will come from the back side and will be shown with dashed line.







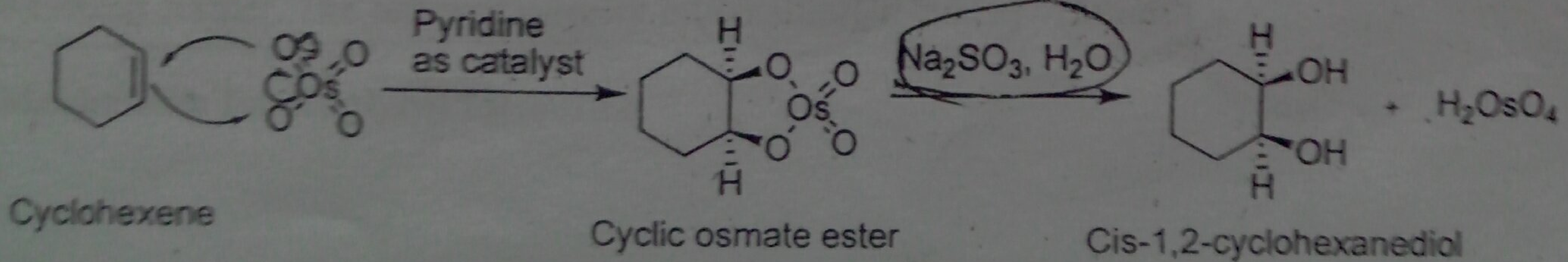


Hydroxylation of Alkenes

An alkene can be oxidized to a cis-1,2-diol either by potassium permanganate ($KMnO_4$) in a cold basic solution or by osmium tetroxide (OsO_4). A cisidiol is formed and a diol is also called a glycol. The OH groups are on adjacent carbons in 1,2-diols, so 1,2-diols are also known as vicinal diols or vicinal glycols.

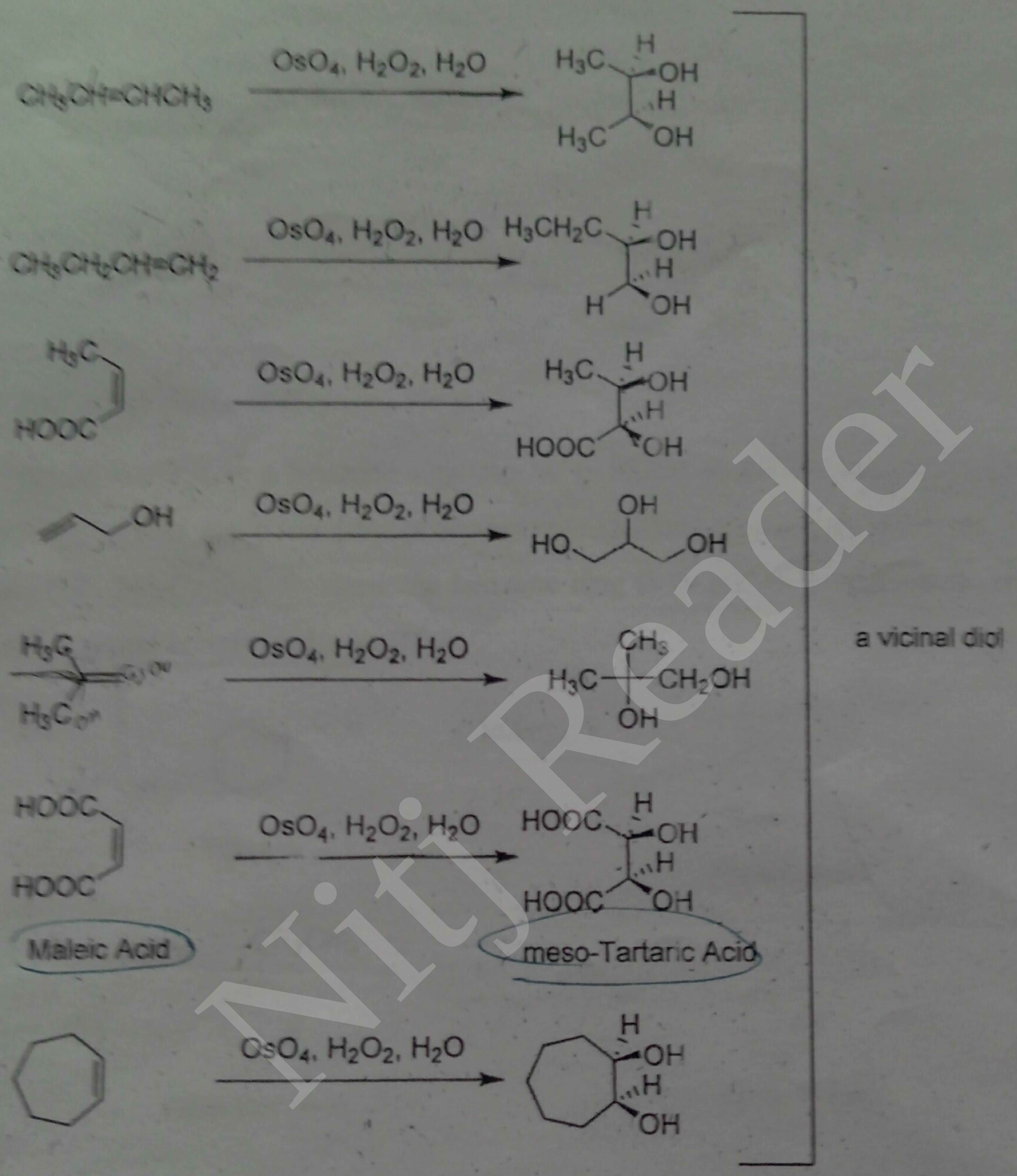
1. Osmium tetroxide (OsO_4). Both OsO_4 and $KMnO_4$ form a cyclic intermediate when they react with an alkene. The reactions occur because manganese and osmium are in a highly positive oxidation state and, therefore, attract electrons. Formation of the cyclic intermediate is a syn addition because both oxygens are delivered to the same side of the double bond. Therefore, the oxidation reaction is stereospecific—a cis cycloalkene forms only a cis diol.

Mechanism for cis glycol formation



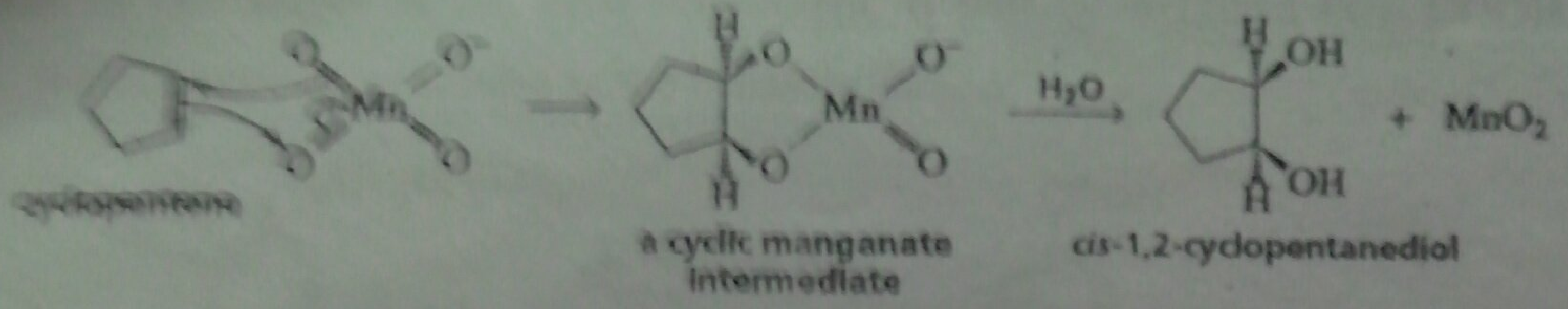
Characterstics:

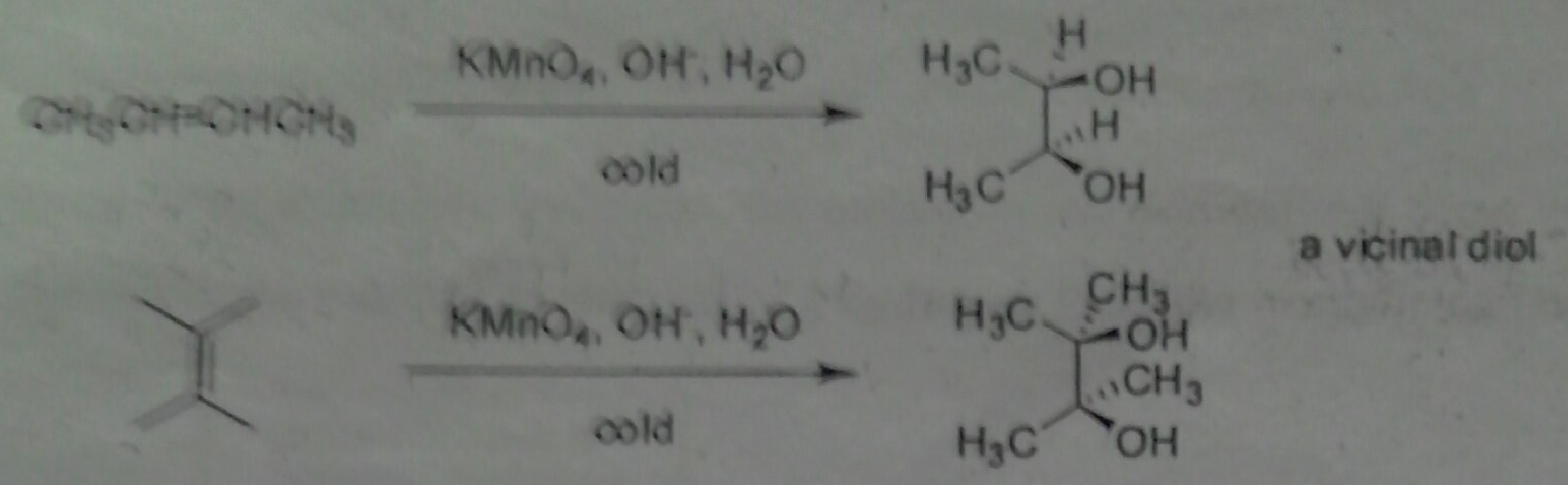
- Regioselective: It reacts with the most electron rich double bond when more than one is present. So that it can be used regioselectively.
- Stereoselective: It attacks the rigid cyclic systems from the less hindered side, thereby yielding the more stable of the two possible cis-diols.



Potassium permanganate ($KMnO_4$): If we want to stop the reaction at diol stage, the solution of potassium permanganate must be basic, and the oxidation must be carried out at room temperature or below. If the solution is heated or if it is acidic, the cis-diol will be oxidized further. The order of priority is Alkaline > Neutral > Acidic.

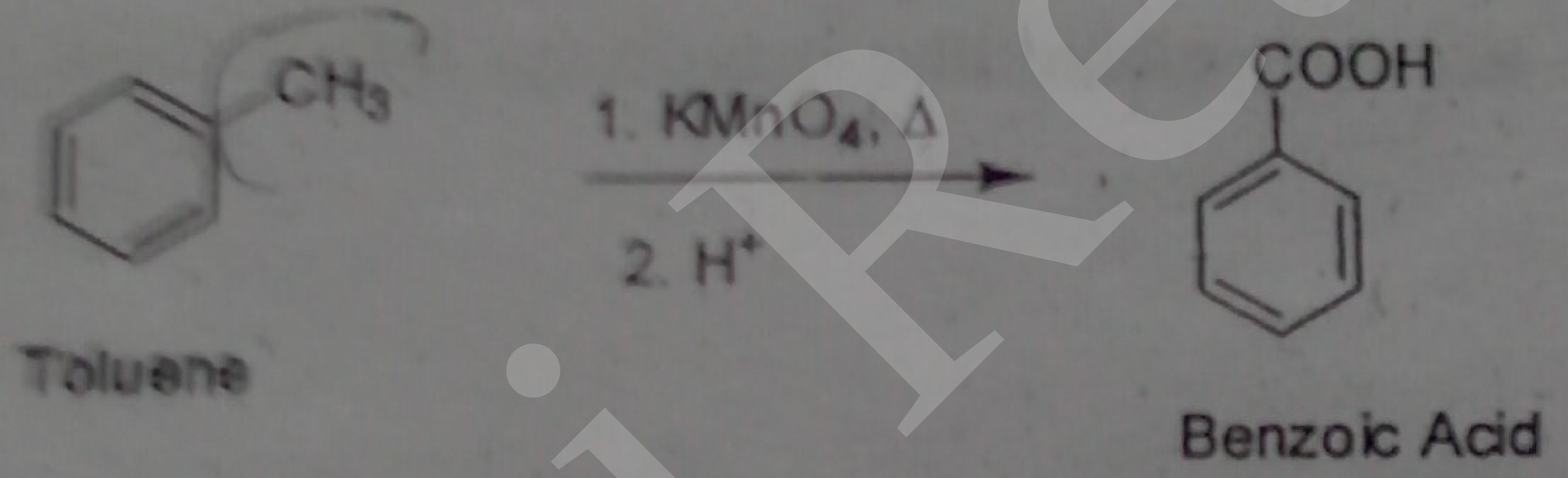
Mechanism for cis glycol formation

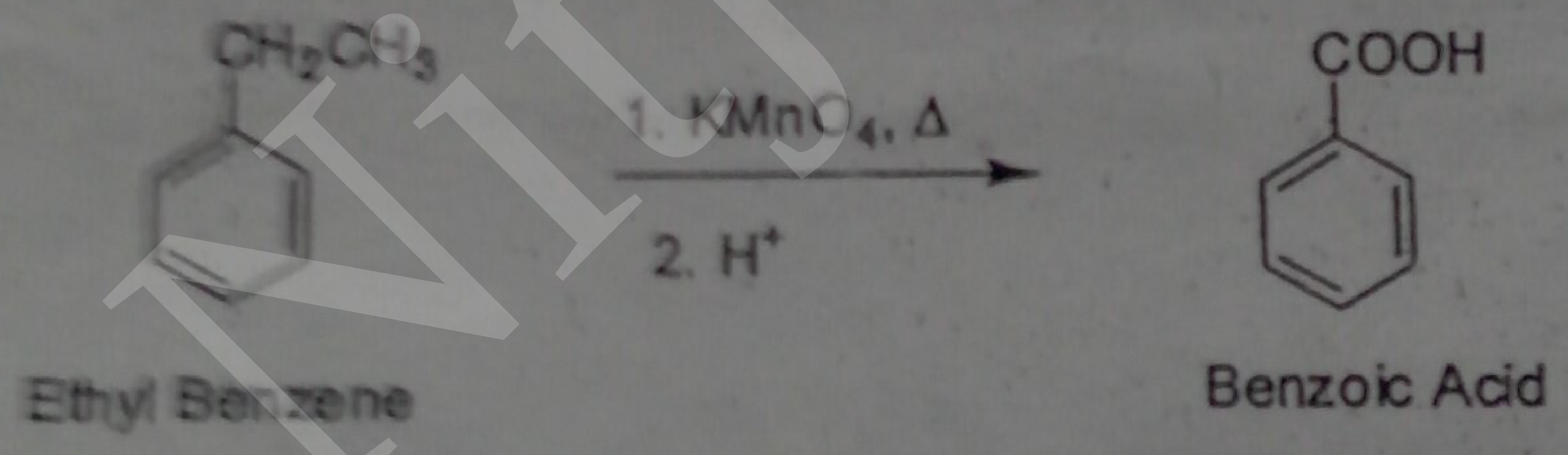


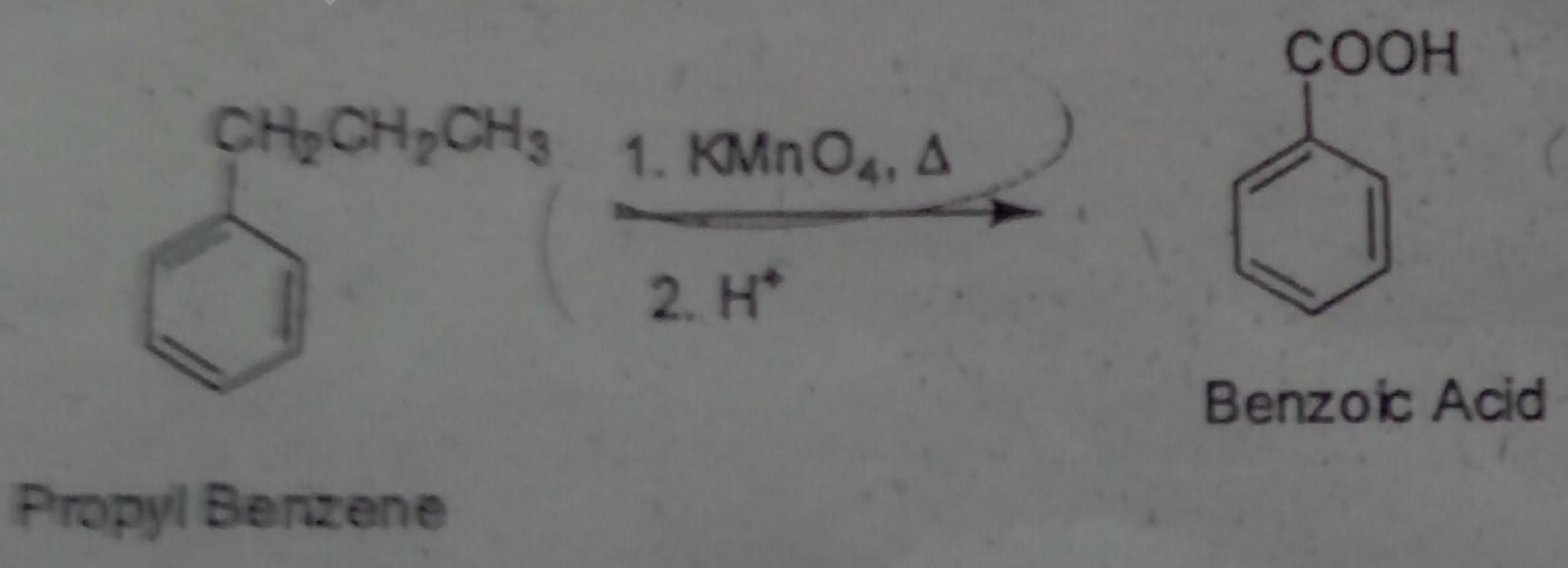


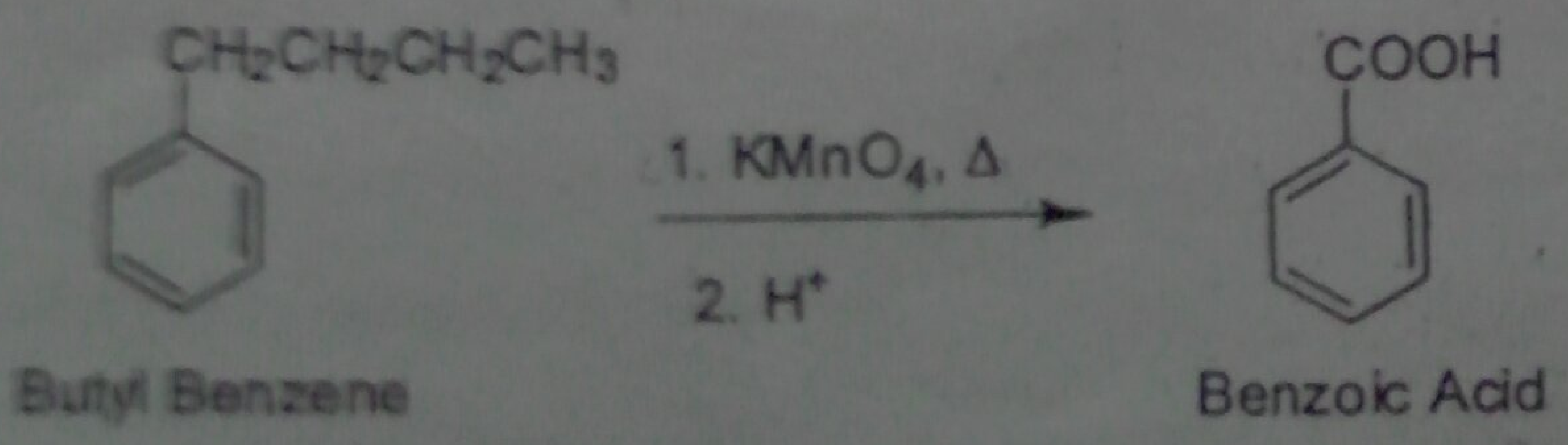
Oxidation of alkyl chain of Benzene ring:

An alkyl group bonded to a benzene ring can be oxidized to a carboxyl group. Commonly used oxidizing agents are potassium permanganate ($KMnO_4$) or acidic solutions of sodium dichromate (H^+, $Na_2Cr_2O_7$). Because the benzene ring is so stable, it will not be oxidized—only the alkyl group is oxidized.

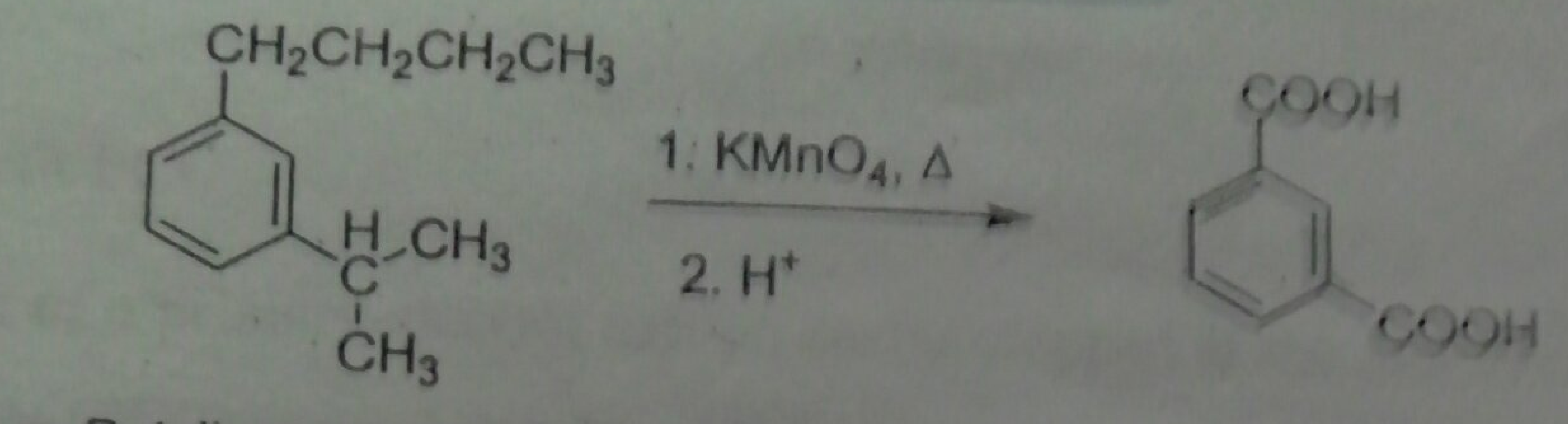








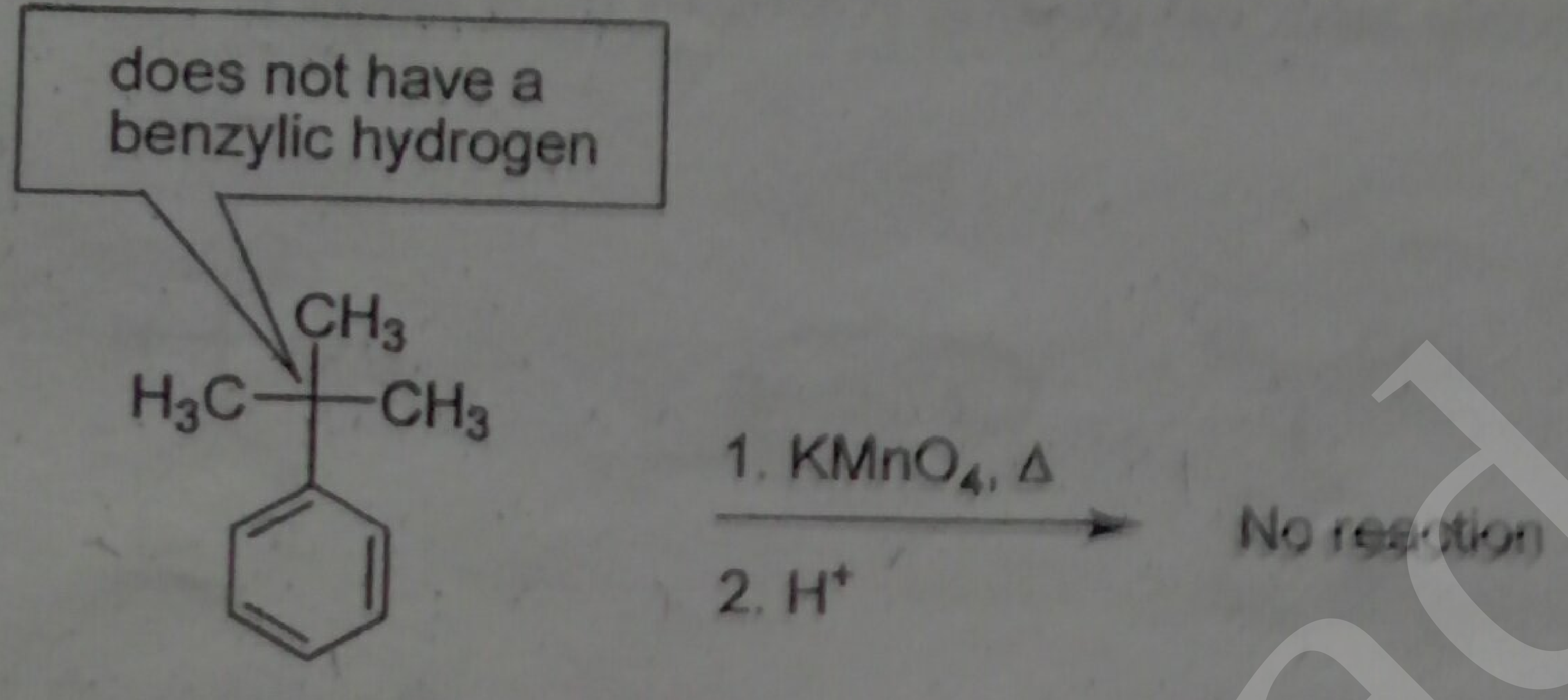
Regardless of the length of the alkyl substituent, it will be oxidized to a COOH group, provided that a hydrogen is bonded to the benzylic carbon.



m-Butylisopropyl Benzene

m-Benzenedicarboxylic Acid

If the alkyl group lacks a benzylic hydrogen, the oxidation reaction will not occur because the first step in the oxidation reaction is removal of a hydrogen from the benzylic carbon.

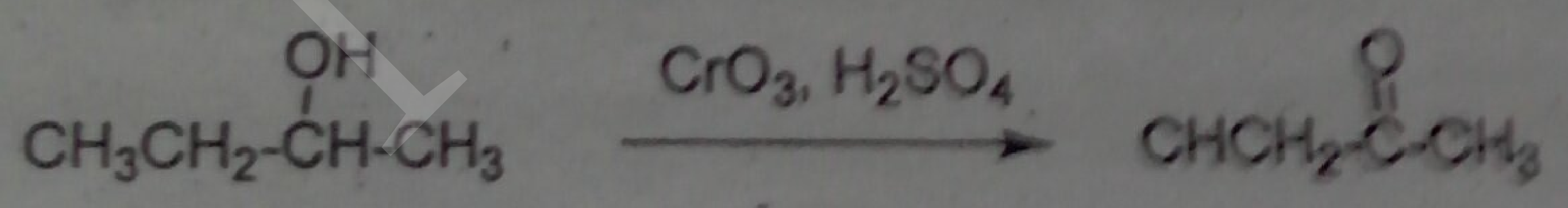


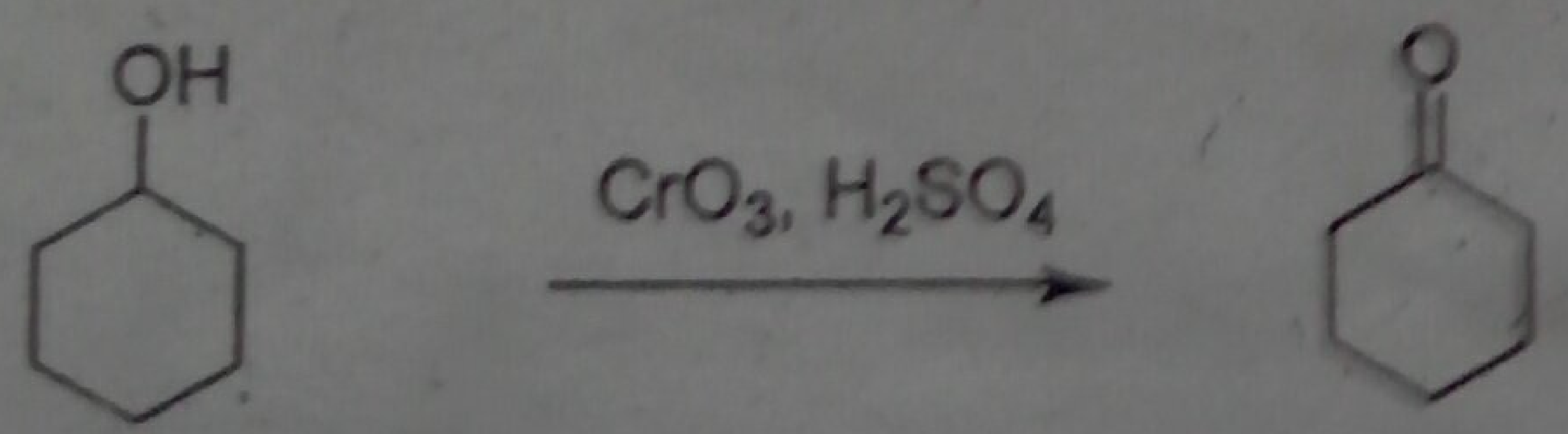
tert-ButylBenzene

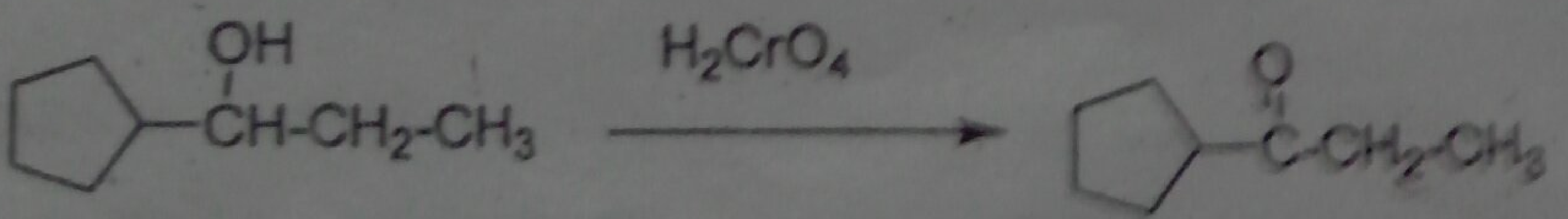
The same reagents that oxidize alkyl substituents will oxidize benzylic alcohols to benzoic acid.

Oxidation of Alcohols

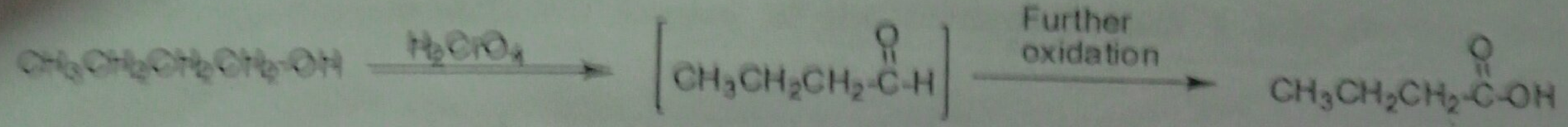
A reagent that is often used to oxidize alcohols is chromic acid (H_2CrO_4), which is formed when chromium trioxide (CrO_3) or sodium dichromate ($Na_2Cr_2O_7$) is dissolved in aqueous acid.







Primary alcohols are initially oxidized to aldehydes by these reagents. The reaction, however, does not stop at the aldehyde. Instead, the aldehyde is further oxidized to a carboxylic acid.

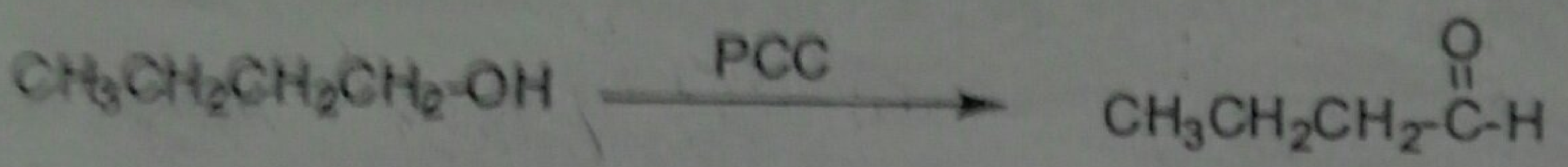


$$\mathrm{CH_3CH_2CH_2CH_2\text{-}OH} \xrightarrow{\mathrm{H_2CrO_4}} \left[\mathrm{CH_3CH_2CH_2\text{-}\overset{O}{\overset{\|}{C}}\text{-}H}\right] \xrightarrow{\text{Further oxidation}} \mathrm{CH_3CH_2CH_2\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH}$$

A primary alcohol — An aldehyde — A carboxylic acid

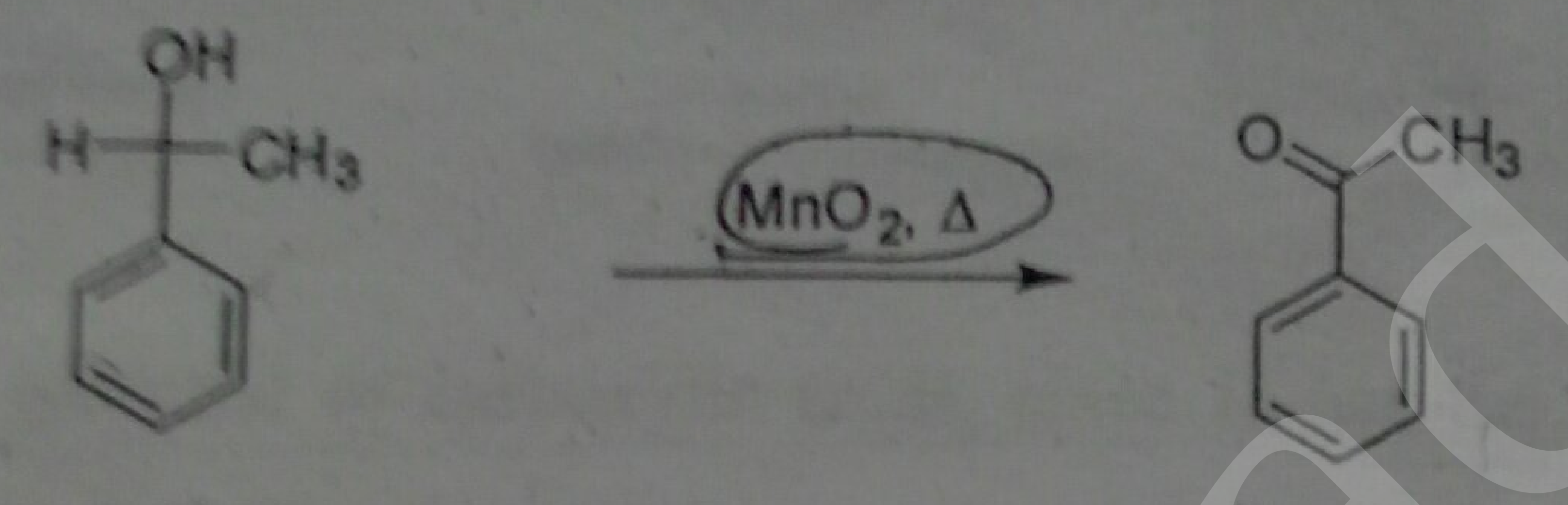
Oxidation with PCC

The oxidation of a primary alcohol can be easily stopped at the aldehyde stage if pyridinium chlorochromate (PCC) is used as the oxidizing agent

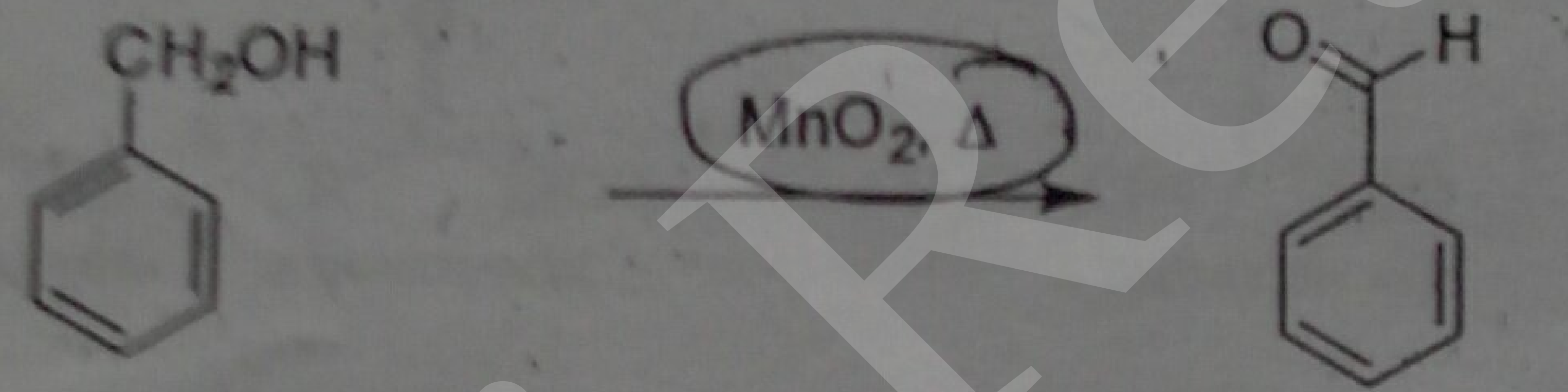


$$\mathrm{CH_3CH_2CH_2CH_2\text{-}OH} \xrightarrow{\mathrm{PCC}} \mathrm{CH_3CH_2CH_2\text{-}\overset{O}{\overset{\|}{C}}\text{-}H}$$

If, however, a mild oxidizing agent such as MnO_2 is used, benzylic alcohols are oxidized to aldehydes or ketones.



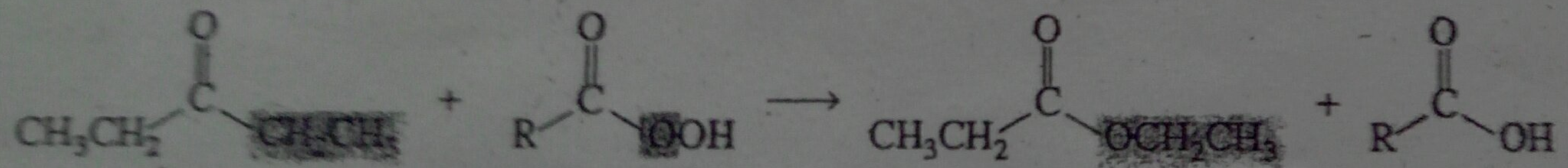
1-Phenylethanol — Acetophenone



PhenylMethanol or Benzyl alchol — Benzaldehyde

Baeyer-Villiger oxidations

A peroxyacid (also called a percarboxylic acid) contains one more oxygen than a carboxylic acid, and it is this oxygen that is inserted between the carbonyl carbon and the H of an aldehyde or the R of a ketone. The reaction is called a **Baeyer–Villiger oxidation.**



$$\mathrm{CH_3CH_2\overset{O}{\overset{\|}{C}}CH_2CH_3} + \mathrm{R\overset{O}{\overset{\|}{C}}OOH} \longrightarrow \mathrm{CH_3CH_2\overset{O}{\overset{\|}{C}}OCH_2CH_3} + \mathrm{R\overset{O}{\overset{\|}{C}}OH}$$

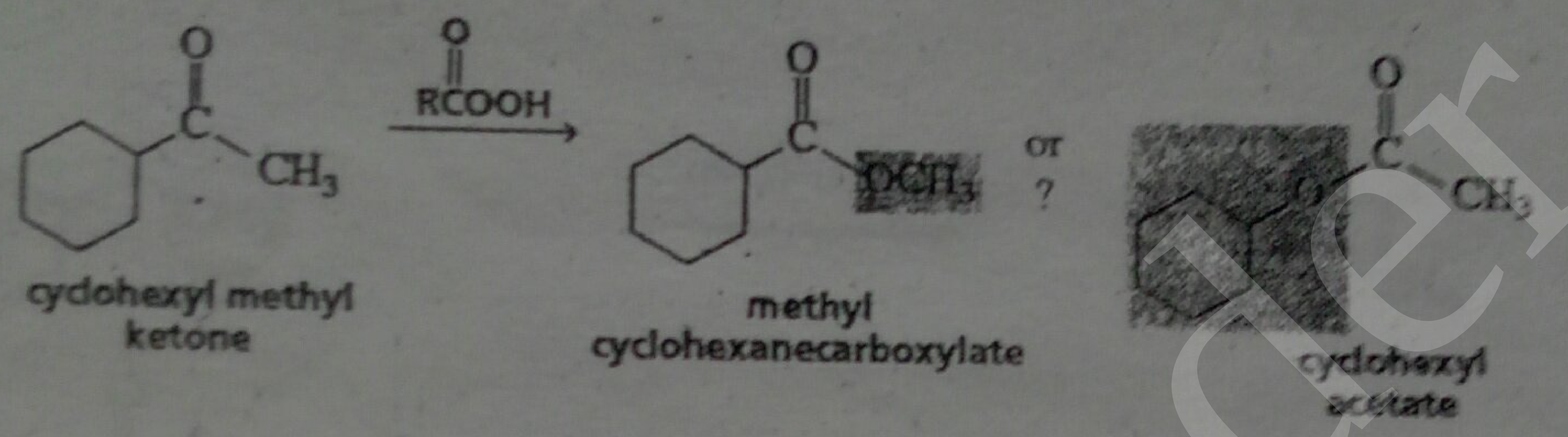
a ketone — a peroxyacid — an ester

If the two alkyl substituents attached to the carbonyl group of the ketone are not the same, on which side of the carbonyl carbon is the oxygen inserted? It depends upon the relative migratory aptitude of the substituent. A more electron rich substituent has more tendency to migrate to the electron deficient oxygen of the peroxyacid than a less electron rich substituent.

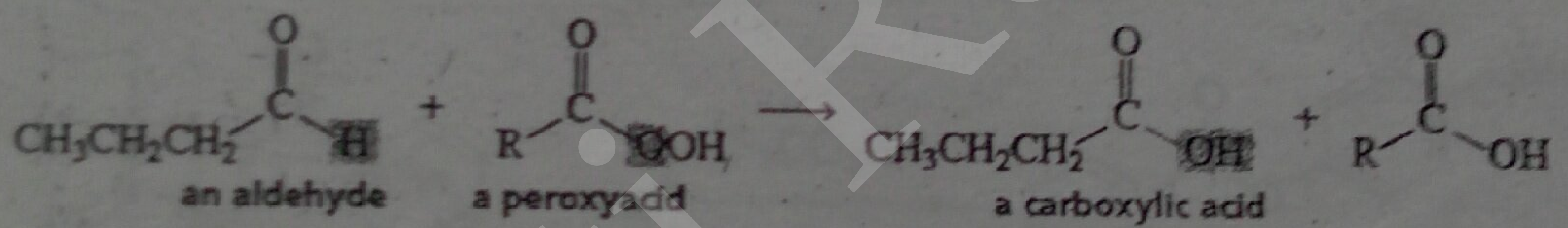
relative migration tendencies

most likely to migrate > H > *tert*-alkyl > *sec*-alkyl = phenyl > primary alkyl > methyl < least likely to migrate

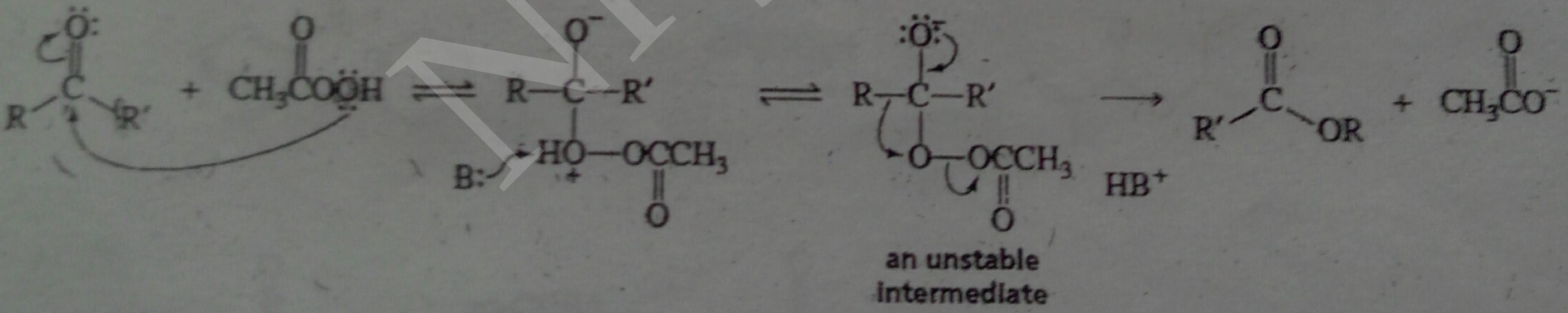
Therefore, the product of the Baeyer–Villiger oxidation of cyclohexyl methyl ketone will be cyclohexyl acetate because a secondary alkyl group (the cyclohexyl group) is more likely to migrate than a methyl group.

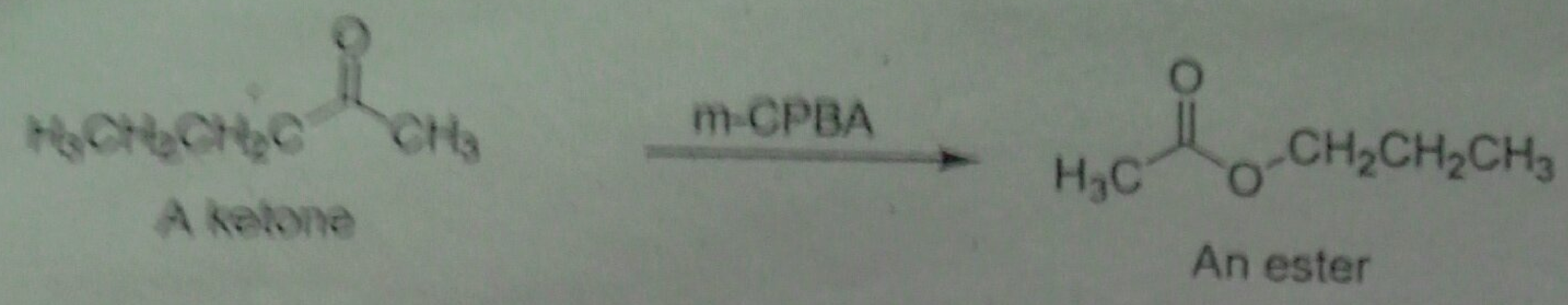


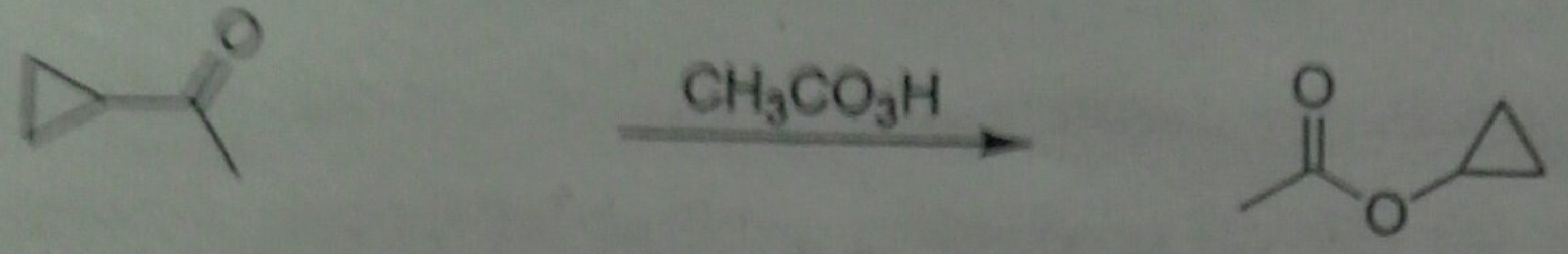
Aldehydes are always oxidized to carboxylic acids, since H has the greatest tendency to migrate.

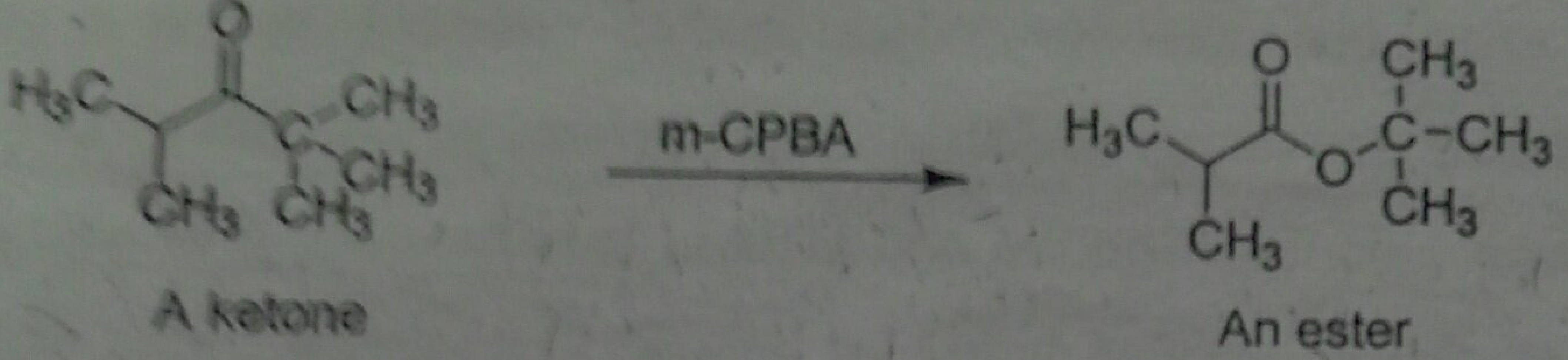


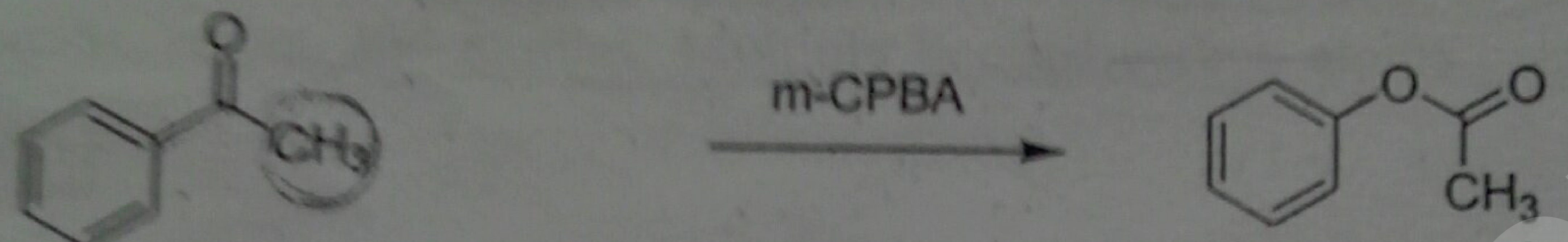
mechanism of the Baeyer–Villiger oxidation

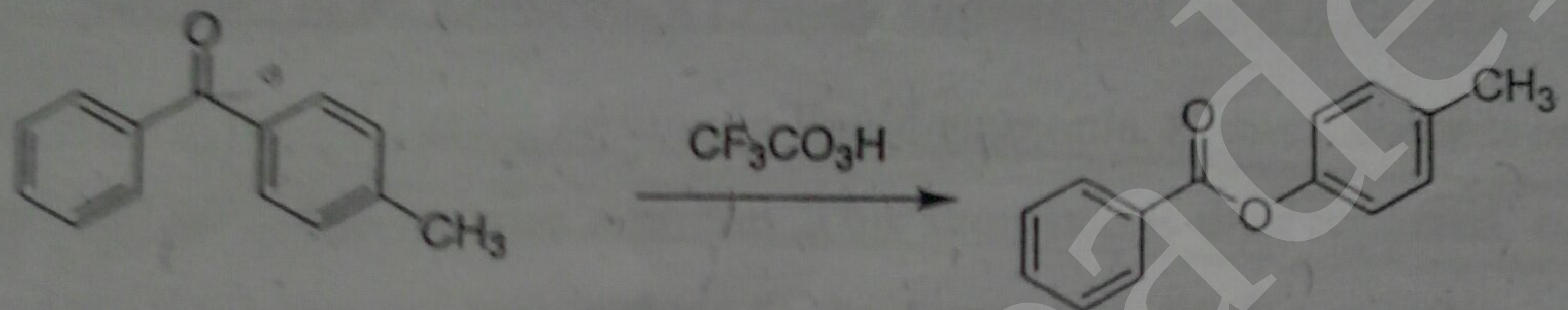


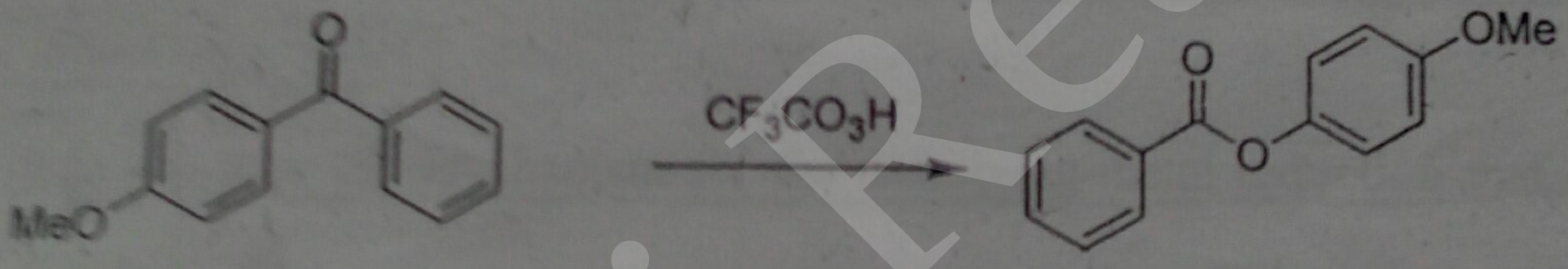


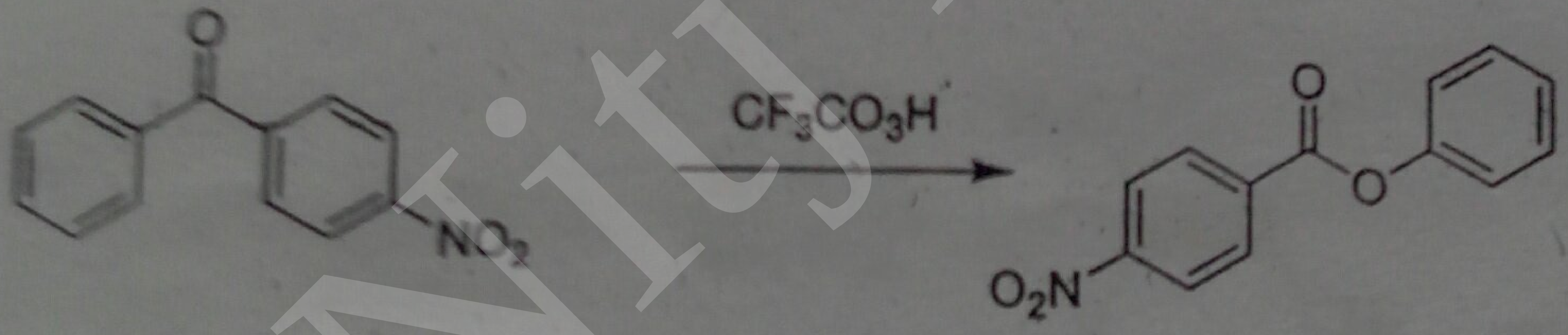


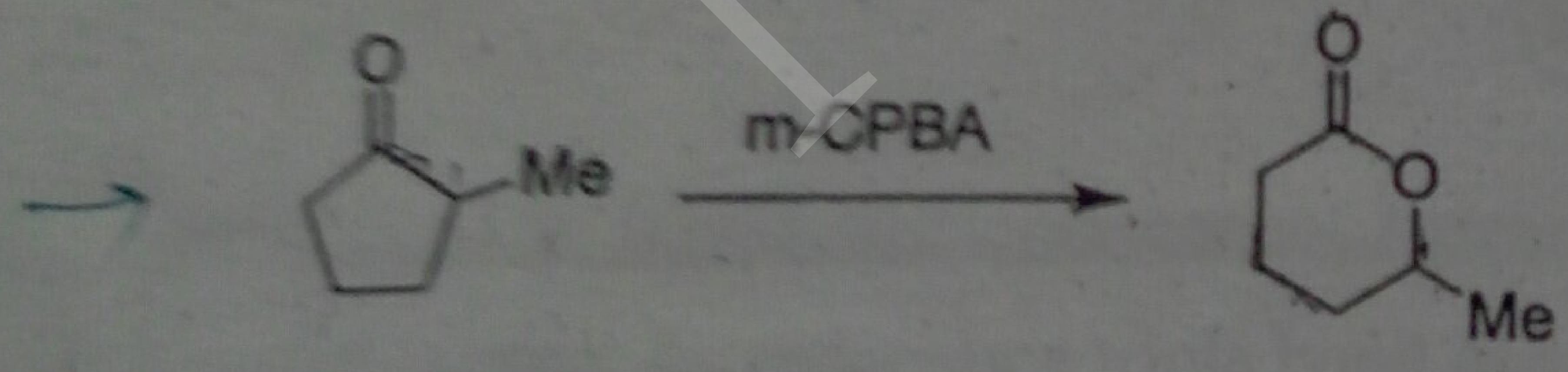


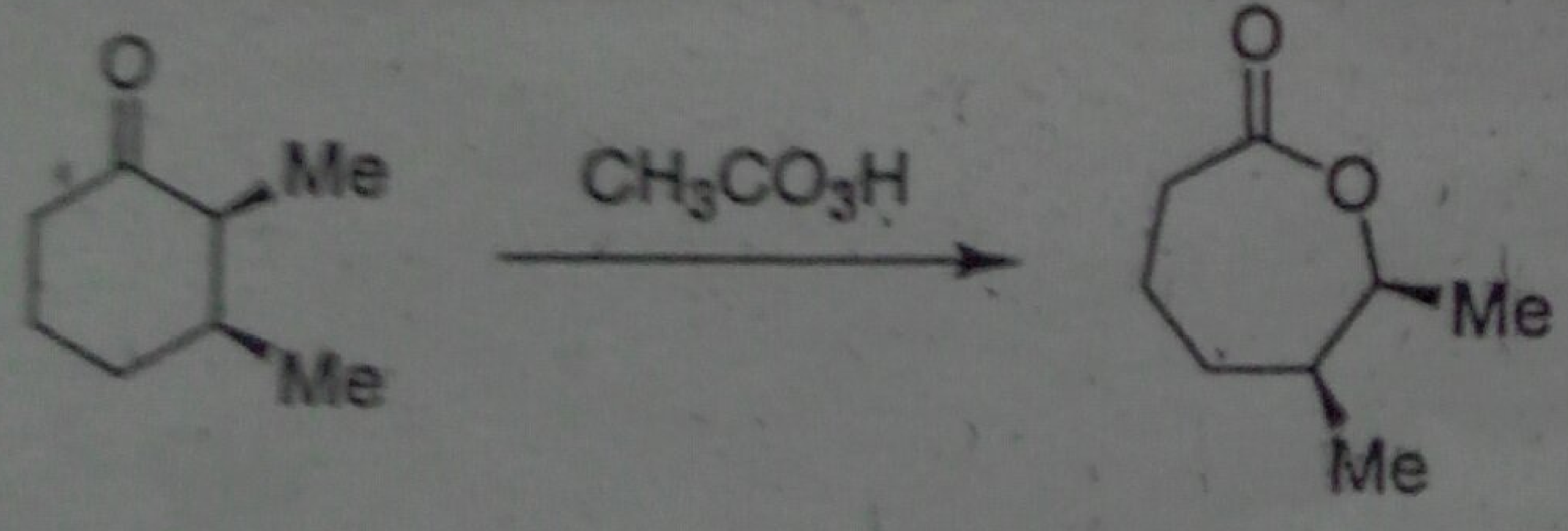




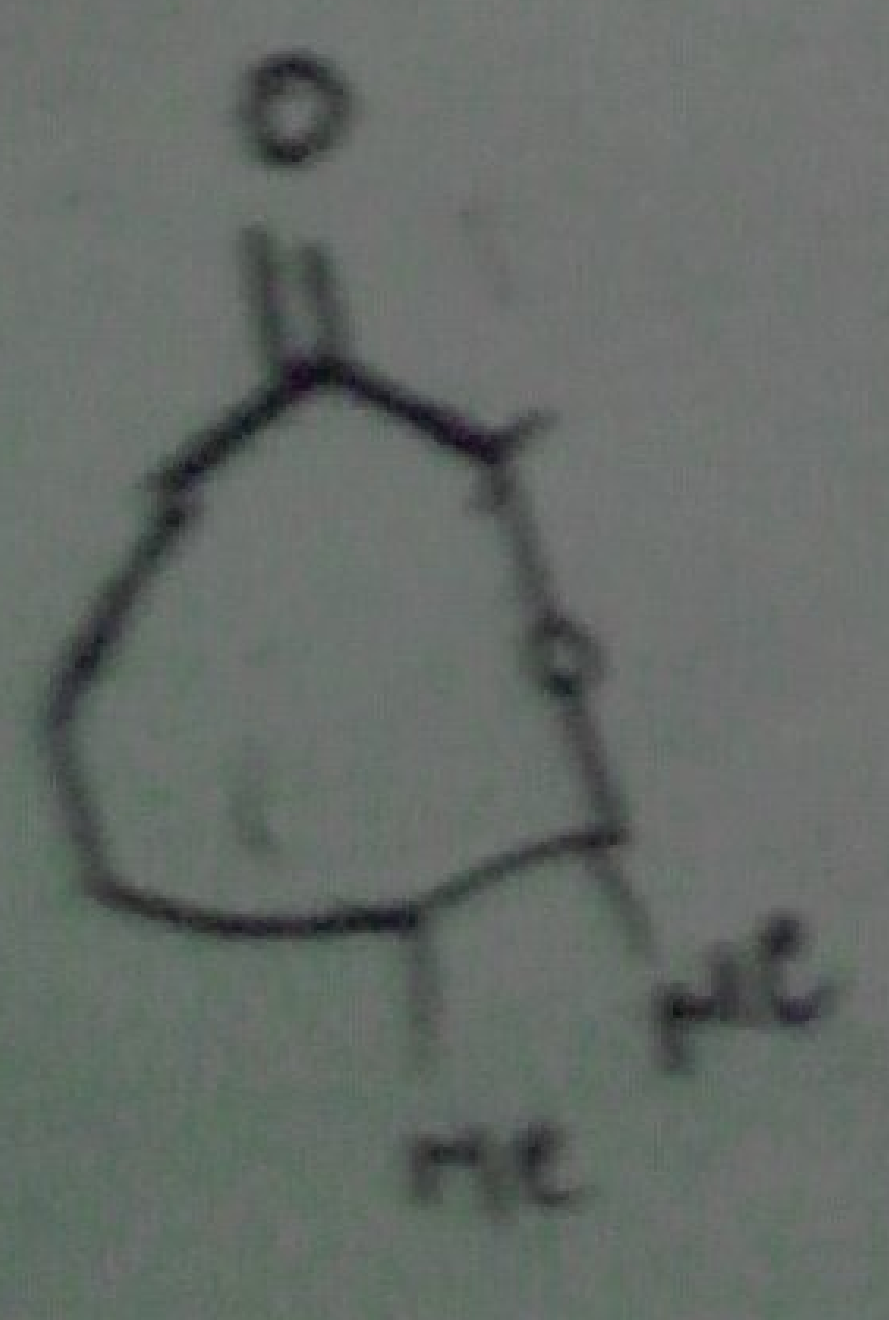








Ring expansion



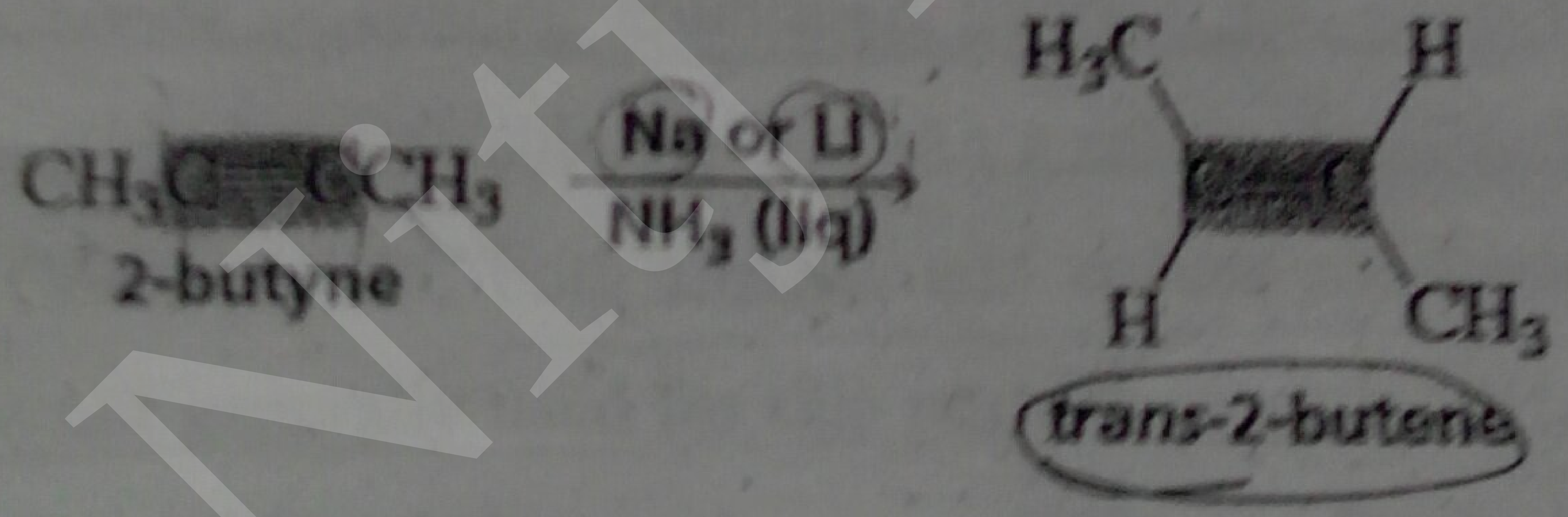
An organic compound is reduced by the addition of H_2 by one of three mechanisms: **Catalytic hydrogenations** add two hydrogen atoms, ***dissolving metal reductions*** add two electrons and two protons, and ***metal hydride reductions*** *involve* the addition of a hydride ion followed by a proton. Carbon–carbon, *carbon–nitrogen*, and some carbon–oxygen multiple bonds can be reduced by catalytic *hydrogenation*. *An alkyne is reduced by sodium* and liquid ammonia to a trans alkene. $LiAlH_4$ is a *stronger reducing* agent than $NaBH_4$. $NaBH_4$ is used to reduce aldehydes, ketones, and acyl halides. $LiAlH_4$ is used to reduce carboxylic acids, esters, and amides. Multiply bonded *carbon atoms* cannot be reduced by metal hydrides.

(Na) liq NH_3

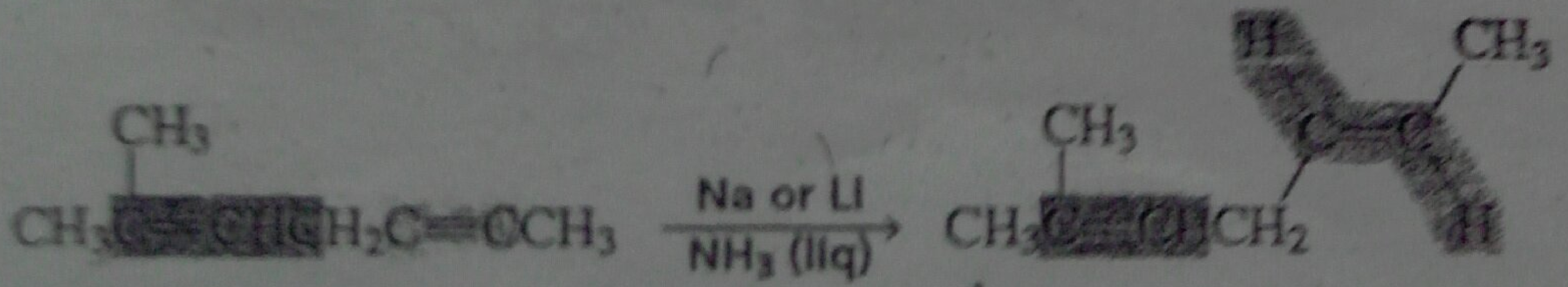
Reduction by Addition of an Electron, a Proton, an Electron, and a Proton

When a compound is reduced using sodium in liquid ammonia, sodium donates an electron to the compound and ammonia donates a proton. This sequence is then repeated, so the overall reaction adds two electrons and two protons to the compound. Such a reaction is known as a **dissolving-metal reduction.**

In Section 6.8, you saw the mechanism for the dissolving-metal reduction that converts an alkyne to a trans alkene



Sodium (or lithium) in liquid ammonia cannot reduce a carbon–carbon double bond. This makes it a useful reagent for reducing a triple bond in a compound that also contains a double bond.

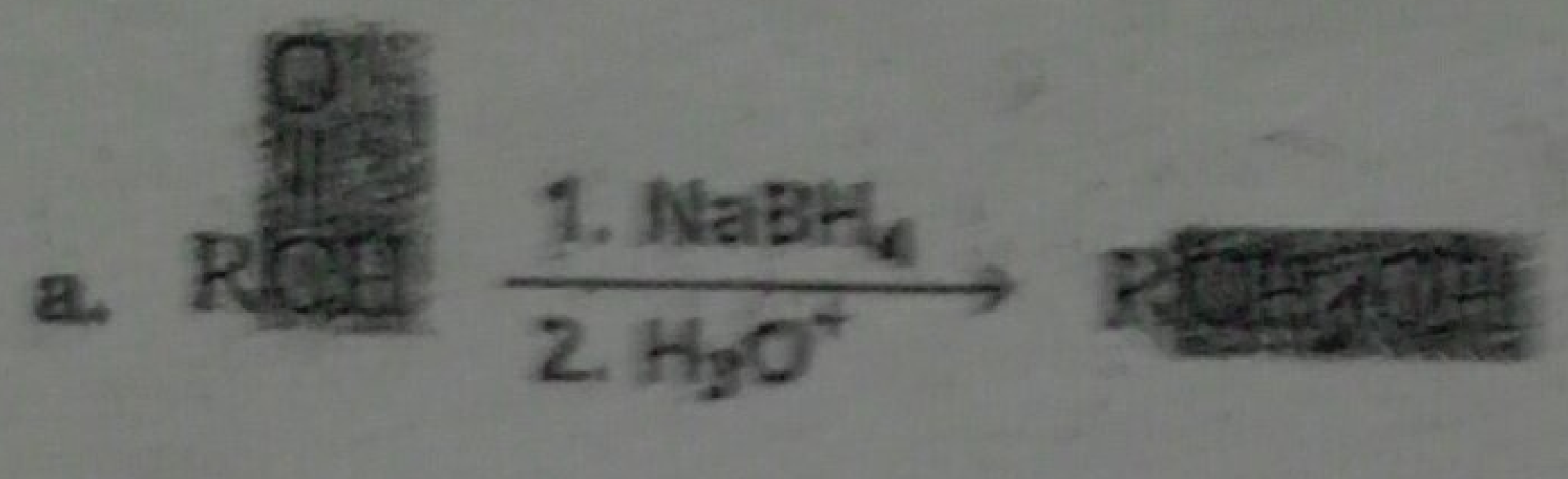


Reduction by Addition of a Hydride Ion and a Proton

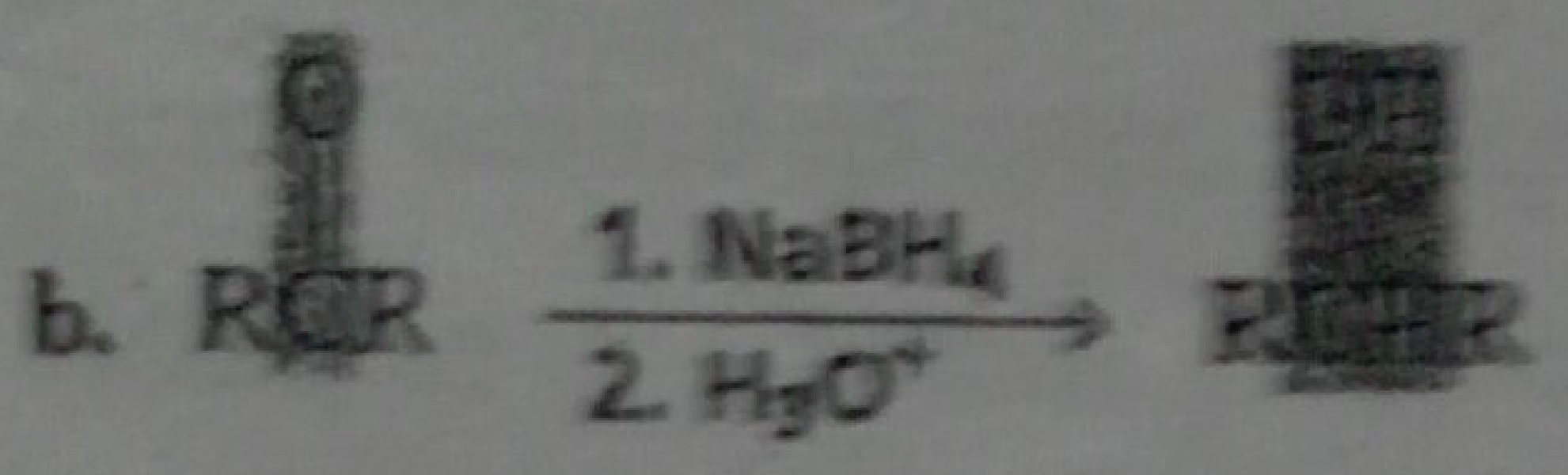
Carbonyl groups are easily reduced by metal hydrides such as sodium borohydride ($NaBH_4$) or lithium aluminum hydride. The actual reducing agent in metal-hydride reductions is hydride ion (H^-). Hydride ion adds to the carbonyl carbon, and the alkoxide ion that is formed is subsequently protonated. In other words, the carbonyl group is reduced by adding an H^- followed by an H^+. The mechanisms for reduction by these reagents are discussed in Section 18.5.

$H^{\ominus}$, $H^{\oplus}$

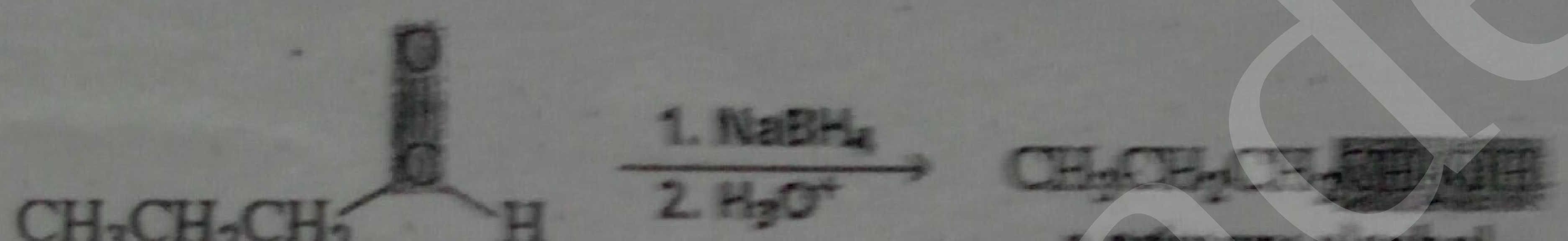
Aldehydes, ketones, and acyl halides can be reduced by sodium borohydride.

a. 

$$RCH(=O) \xrightarrow[2.\ H_3O^+]{1.\ NaBH_4} RCH_2OH$$

b. 

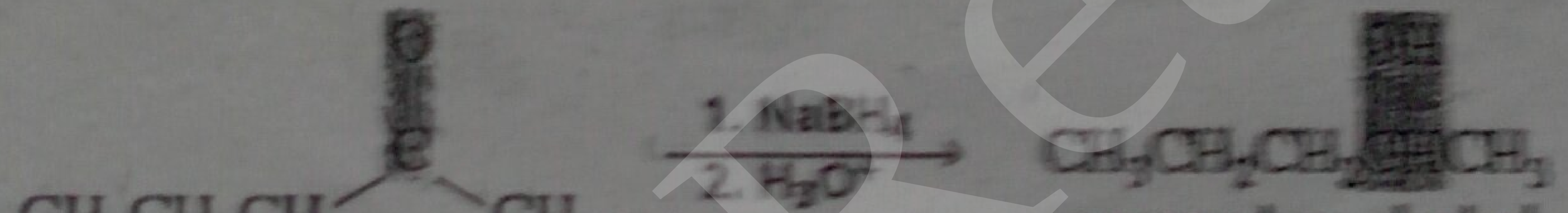
$$RCR(=O) \xrightarrow[2.\ H_3O^+]{1.\ NaBH_4} RCHR(OH)$$



$$CH_3CH_2CH_2CHO \xrightarrow[2.\ H_3O^+]{1.\ NaBH_4} CH_3CH_2CH_2CH_2OH$$

an aldehyde

a primary alcohol

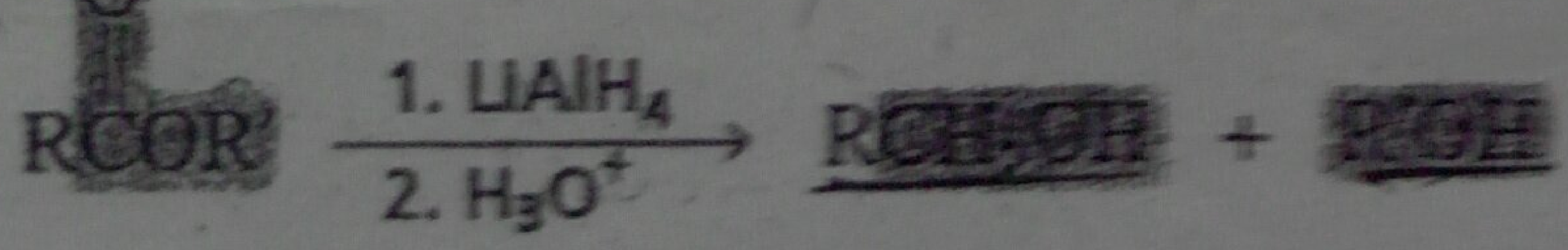


$$CH_3CH_2CH_2C(=O)CH_3 \xrightarrow[2.\ H_3O^+]{1.\ NaBH_4} CH_3CH_2CH_2CH(OH)CH_3$$

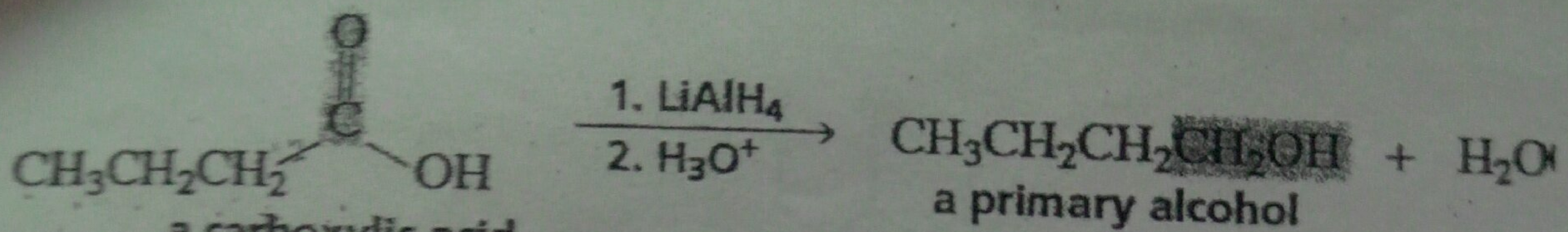
a ketone

a secondary alcohol

The metal–hydrogen bonds in lithium aluminum hydride are more polar than the metal–hydrogen bonds in sodium borohydride $NaBH_4$. As a result, $LiAlH_4$ is a stronger reducing agent than $NaBH_4$. Consequently, both $LiAlH_4$ and reduce aldehydes, ketones, and acyl halides, but $LiAlH_4$ is not generally used for this purpose since $NaBH_4$ is safer and easier to use. $LiAlH_4$ is generally used to reduce only compounds—such as carboxylic acids, esters, and amides—that cannot be reduced by the milder reagent.



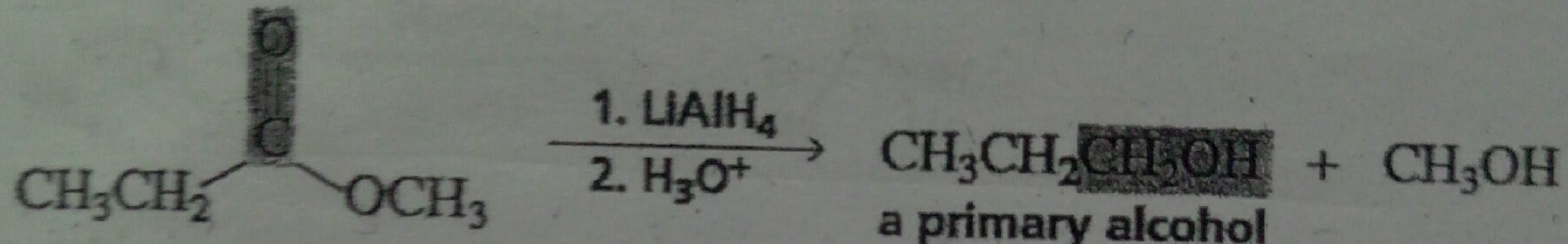
$$RCOR'(=O) \xrightarrow[2.\ H_3O^+]{1.\ LiAlH_4} RCH_2OH + R'OH$$



$$CH_3CH_2CH_2COOH \xrightarrow[2.\ H_3O^+]{1.\ LiAlH_4} CH_3CH_2CH_2CH_2OH + H_2O$$

a carboxylic acid

a primary alcohol

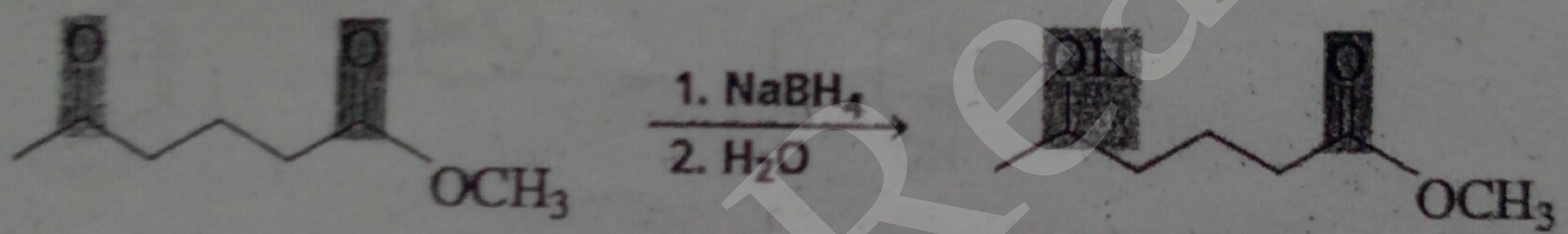


$$CH_3CH_2COOCH_3 \xrightarrow[2.\ H_3O^+]{1.\ LiAlH_4} CH_3CH_2CH_2OH + CH_3OH$$

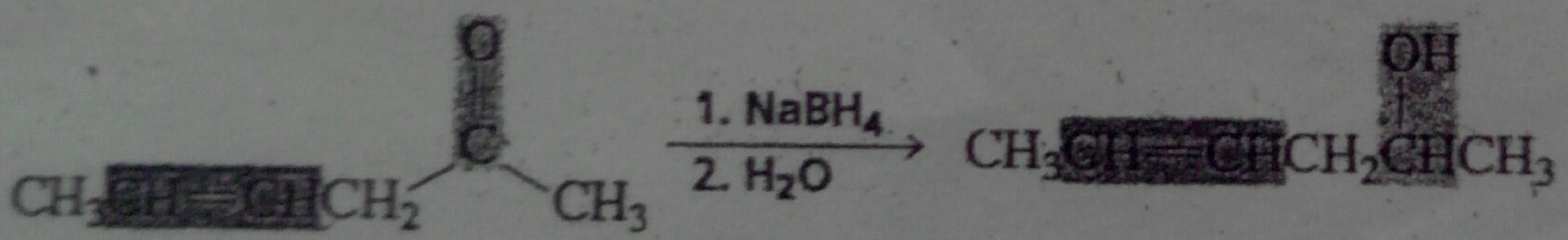
an ester

a primary alcohol

Because sodium borohydride cannot reduce an ester, an amide, or a carboxylic acid, it can be used to selectively reduce an aldehyde or a ketone group in a compound that also contains a less reactive group. Acid is not used in the second step of the following reaction, in order to avoid hydrolyzing the ester:



Because sodium borohydride cannot reduce carbon–carbon double bonds, a carbonyl group in a compound that also has an alkene functional group can be selectively reduced, as long as the double bonds are not conjugated (Section 18.13). Acid is not used in the second step of the reaction, in order to avoid addition to the double bond.



$$CH_3CH{=}CHCH_2COCH_3 \xrightarrow[2.\ H_2O]{1.\ NaBH_4} CH_3CH{=}CHCH_2CH(OH)CH_3$$

Assignment Organic Chemistry Oxidation and Reduction

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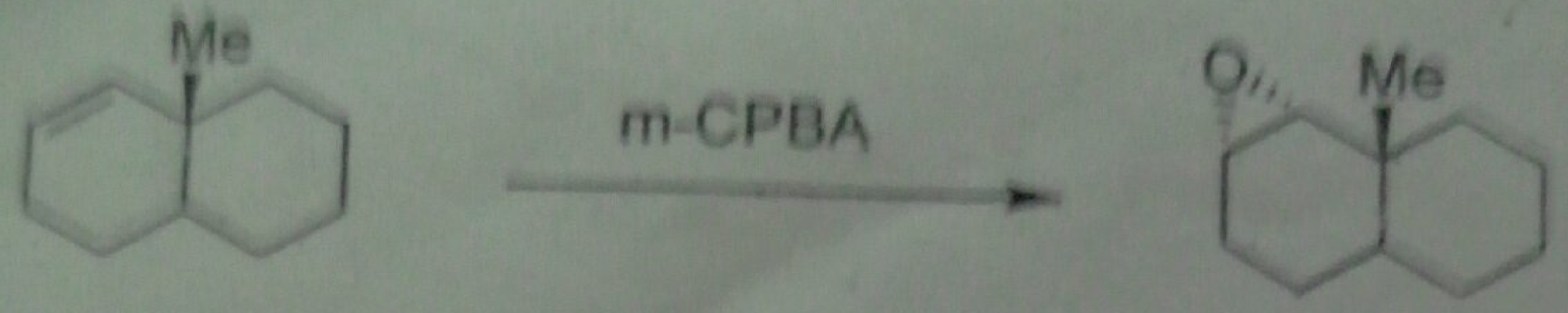

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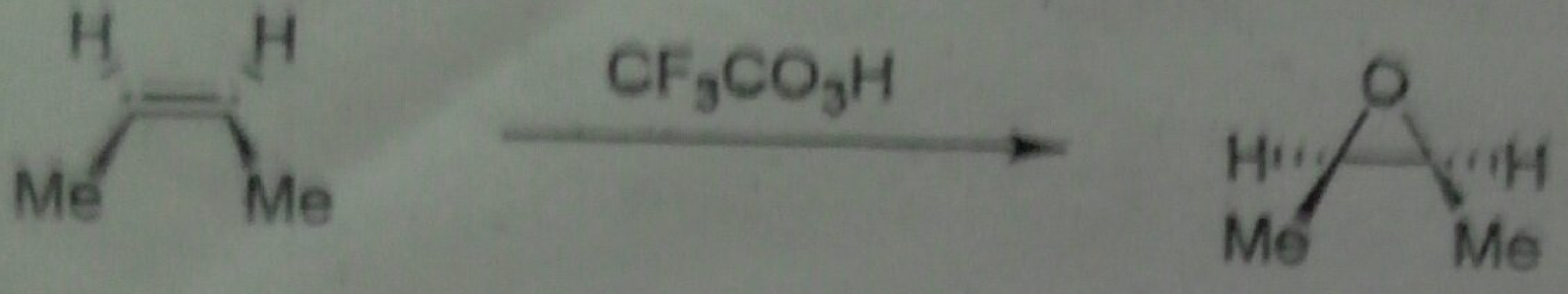

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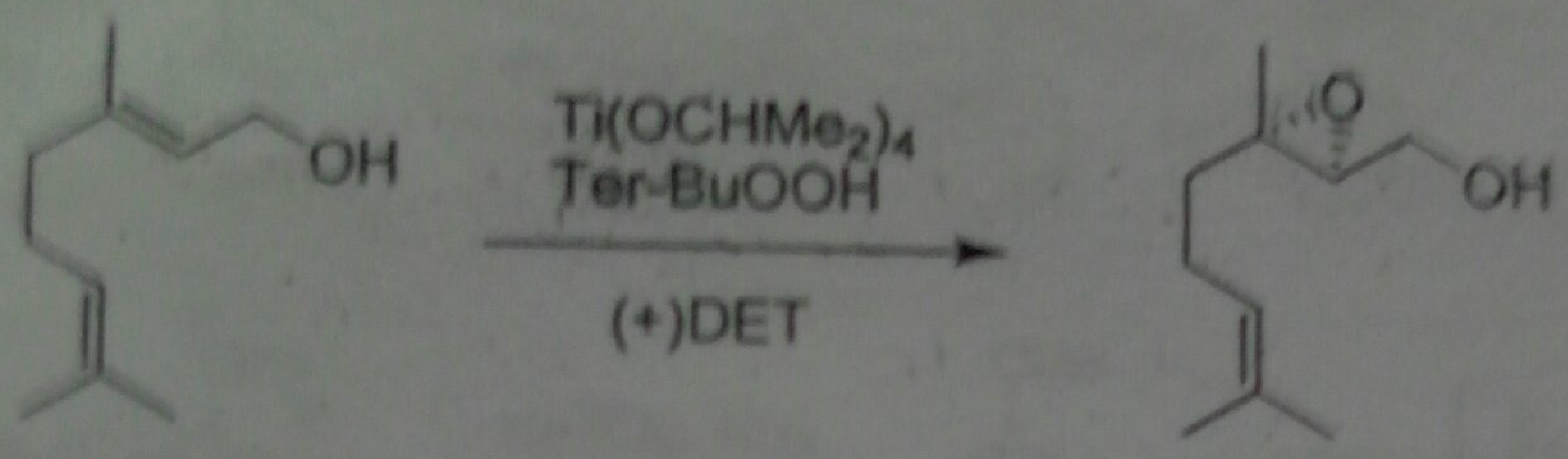

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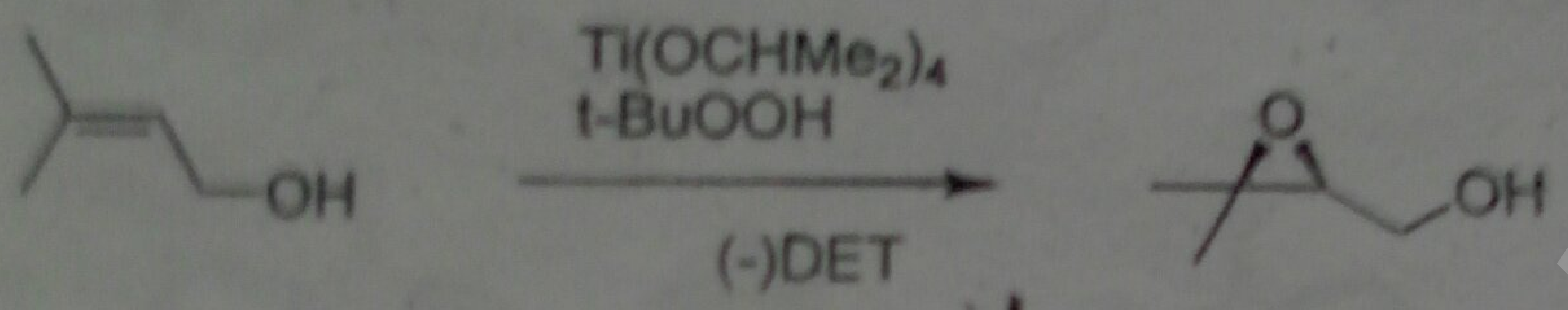

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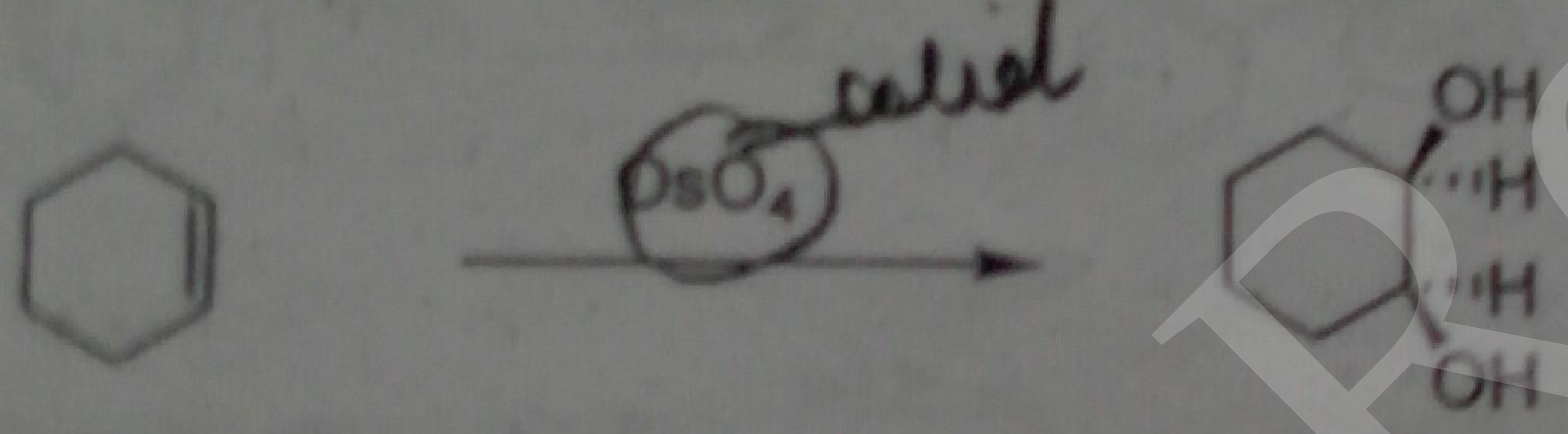

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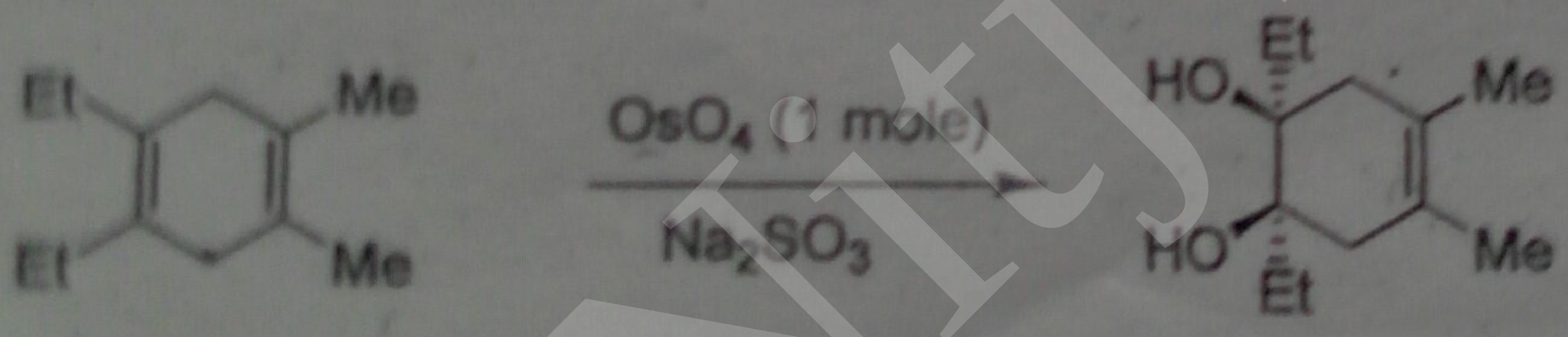

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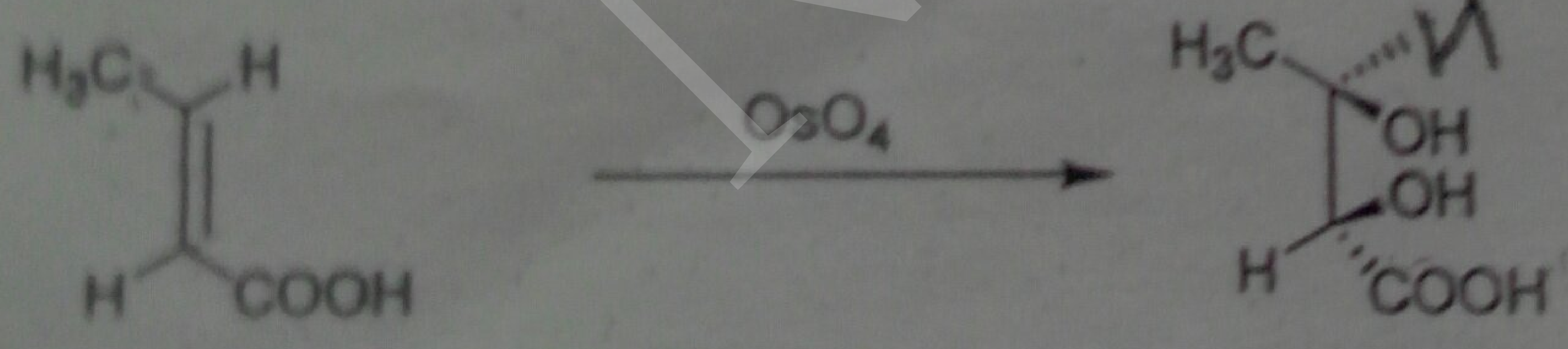

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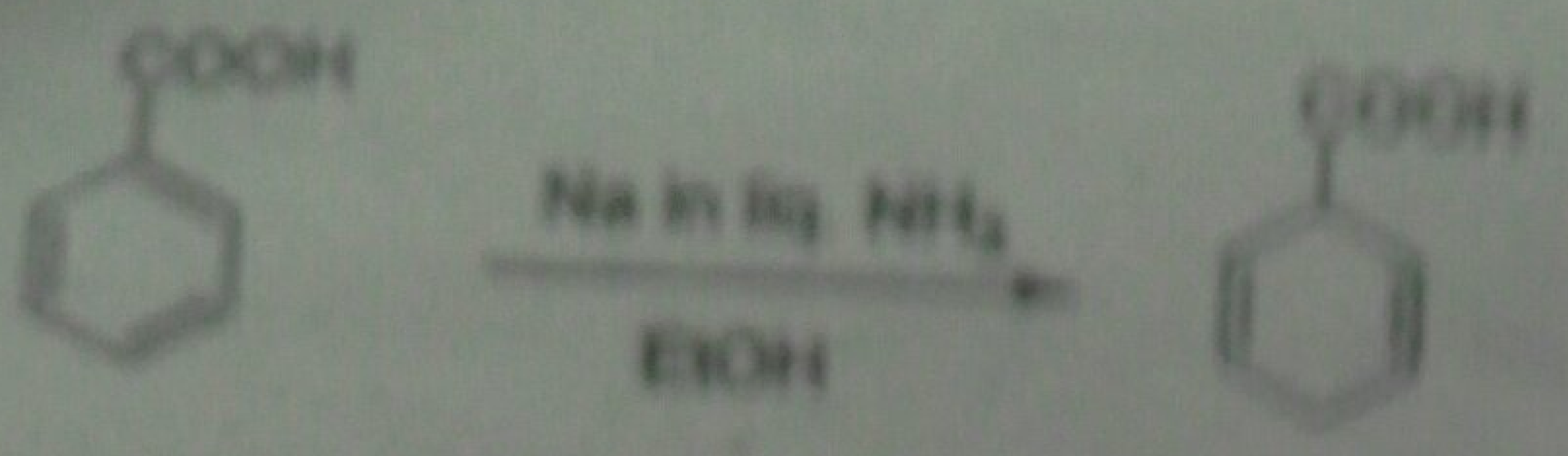

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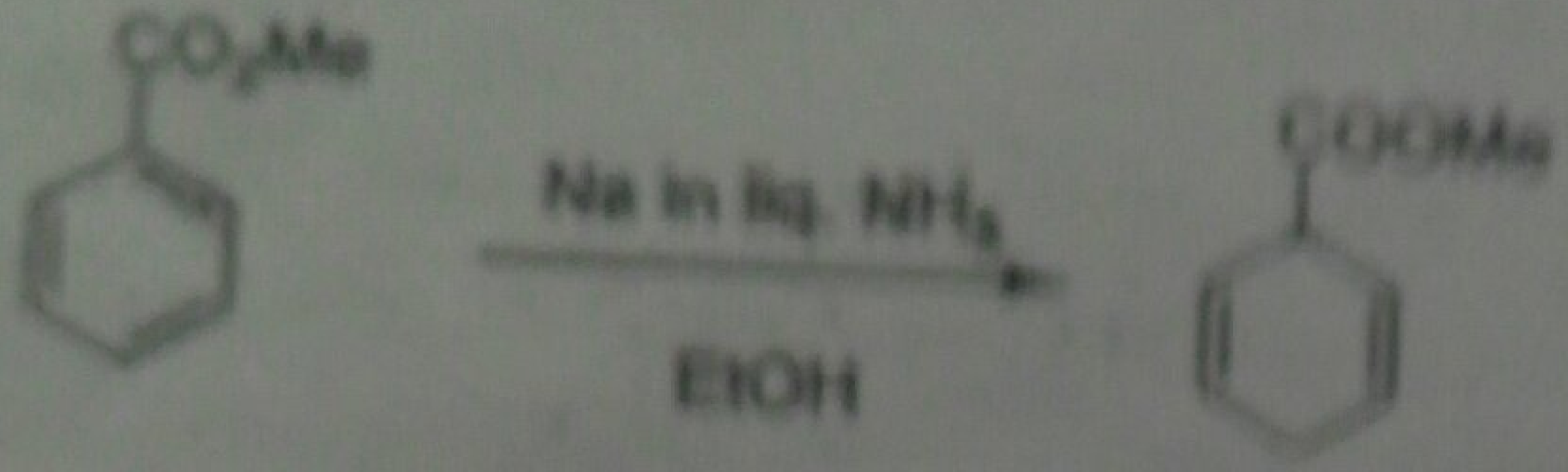

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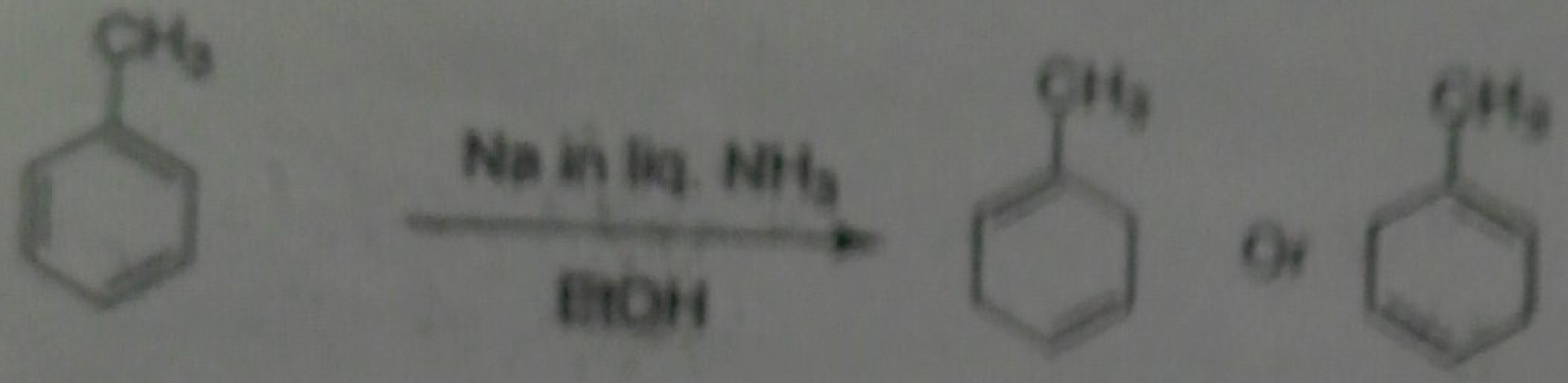

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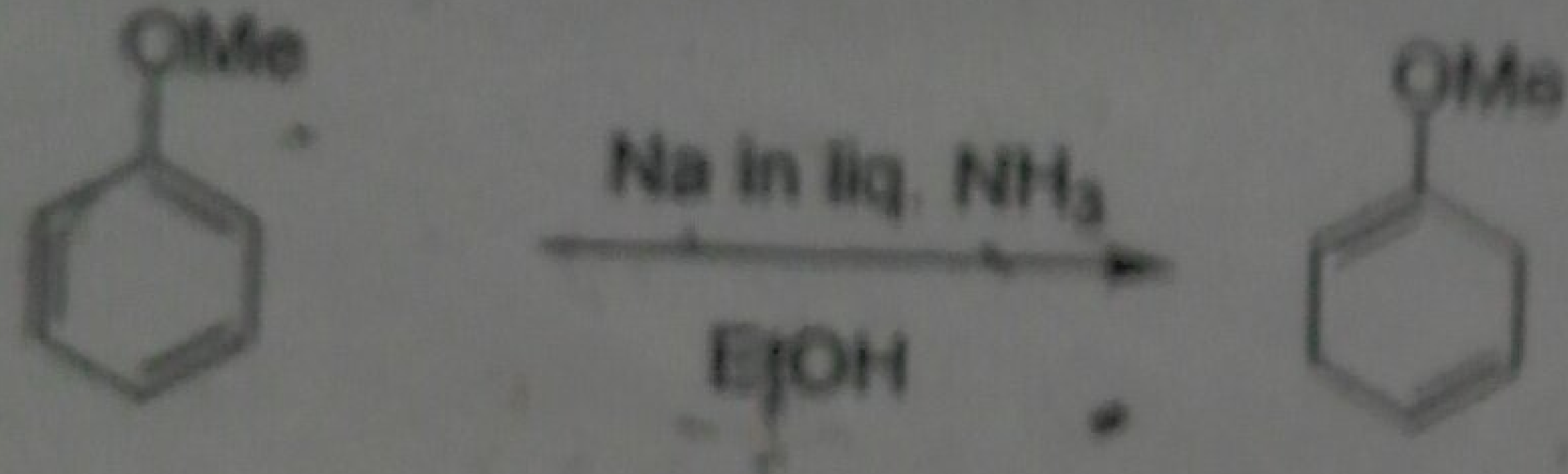
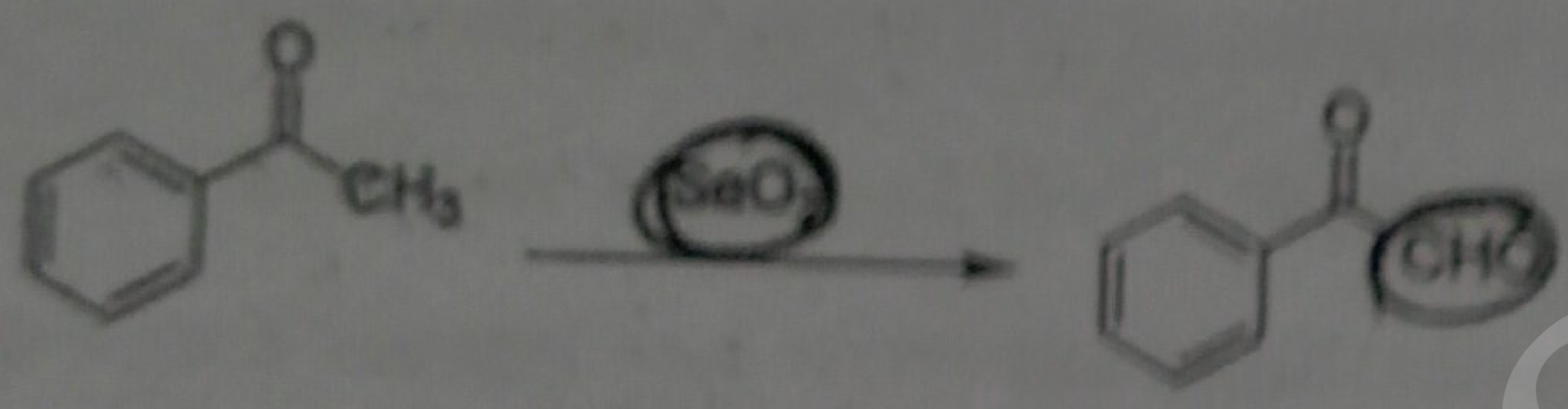


→ Birch Reduction

5)



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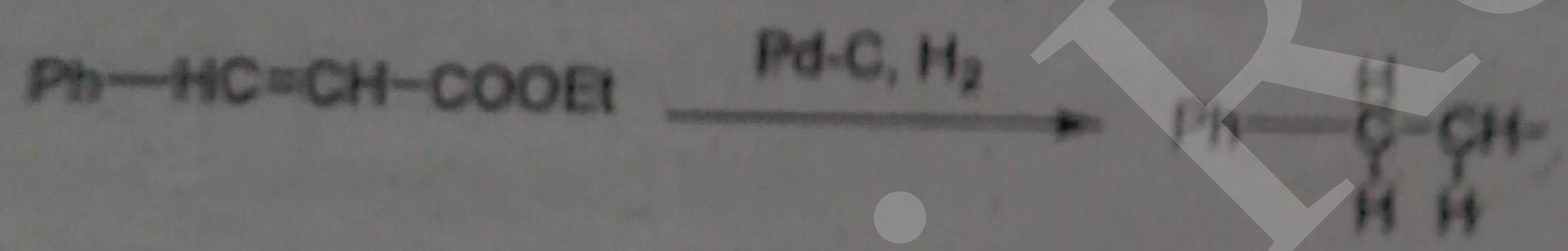

$$\mathrm{Ph{-}HC{=}CH{-}COOEt} \xrightarrow{\mathrm{Pd\text{-}C,\ H_2}} \mathrm{Ph{-}\overset{H}{\underset{H}{C}}{-}\underset{H}{CH}{-}}$$