CHAPTER I

Organic Reactions with Supported Reagents

ORGANIC REACTIONS WITH SUPPORTED REAGENTS

Abstract —— A brief literature survey of "Reactions in Solid Matrix" has been reviewed. The present Chapter has been written with a view to summarize recent developments involving deliberate placement of different reagents on alumina and silica gel and illustrate the most important results for organic synthesis.

ORGANIC REACTIONS WITH SUPPORTED REAGENTS

1. INTRODUCTION

The concept of utilising reagents adsorbed on inert inorganic supports for organic synthesis is not new. Catalytic hydrogenation and numerous other processes which occur at metal and other solid surfaces can properly be classified as examples of supported reagents, albeit of a transitory nature.

During the past ten years, there have been a number of important advances in the practical aspects of organic synthesis using supported reagents but little mechanistic or kinetic work has been carried out so far with supported reagents. The effectiveness of the inorganic supports in the reactions discussed appears to be due to a combination of factors:

(a) An increase in the effective surface area for reaction.

(b) The presence of pores which constrain both substrate and reactant and thus lower the entropy of activation of the reaction.[1]

(c) A synergism (for displacement reactions) resulting from bringing electrophile and nucleophile into proximity, while at the same time enhancing the nucleophilicity (and basicity) of the latter[2].

These heterogeneous organic reactions effected by reagents immobilized on porous solids are becoming very useful for the following reasons:

(a) They are often more selective than the corresponding homogeneous counterparts, therefore some heretofore impossible transformations are made possible

(b) They are usually milder than the corresponding homogeneous reactions

(c) They are often simpler to perform than the corresponding homogeneous reaction.

The synthetic utility of the reagents, however is readily demonstrable. As illustrated below,many reactions can be carried out cleanly, rapidly and in high yield under mild conditions using supported reagents, whereas attempts to carry out the same reactions with unsuoported reagents frequently either fail or result in the formation of mixtures of products.

Posner has published a useful short review on Organic Reactions at Alumina Surfaces which deals largely with the use of alumina supported reagents[3]. Two informative reviews, titled Organic Synthesis Using Suoported Reagents have also appeared recently[4,5] and the present Chapter deals with the concept of utilising reagents or reactants adsorbed on, or intercalated in, an insoluble inorganic support for organic synthesis; coverage is restricted to those reagent particularly obtained by the deliberate introduction of a reagent into or onto an inert inorganic support especially on alumina and silica gel.

2. REAGENTS ON ALUMINA

Alumina is one of the most widely used catalyst and reagent in organic synthesis,but it is only recently that systematic investigation of the use of selected reagents adsorbed on alumina has been undertaken. Many forms and grades of alumina are available and all of them contain varying amounts of water, much- but not all- of which can be removed by high temperature ($\sim 400^{o}$) vacuum dehydration. Further details regarding structural properties of aluminas are available in the informative review by Lippens[6] and Joshi[7].

Secondary reactions caused by active alumina during chromatography has been summarized by E. Lederer and M. Lederer[8]. Various other reactions on alumina involving supported reagents, especially water in the form of surface hydroxy groups are as follows:

(a) Formation of olefins by dehydration[9]
(b) Formation of dihalocarbenes[10]
(c) Epimerisation[11]
(d) 1,5-Hydride shift[12]
(e) Cannizzaro's reaction[13]
(f) Aldol condensation[14]
(g) Beckmann rearrangement[15]
(h) Favoraski rearrangement[16]
(i) Acyloin rearrangement[17]
(j) Skeletal rearrangement[18]
(k) Elimination reactions[19]
(l) Hydrolysis[20]
(m) Hydrocarbon rearrangements[21]
(n) Formation of steroidal nitrates[22]

Detailed discussion of all these reactions is, however, outside the scope of the present article and only supported reagents on alumina such as alcohols, thiols, benzeneselenol, amines, acetic acid, chloral, isopropanol, sodiumborohydride, *t*-butylhydroperoxide etc. are being discussed here.

2.1. Role of the alumina

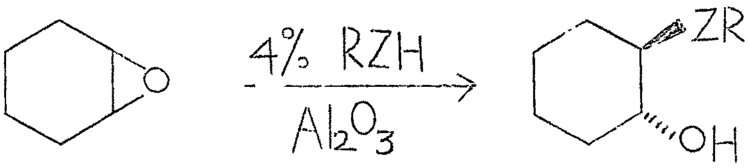
Although much more mechanistic (e.g. spectroscopic) work must be done before a detailed picture of the function of the solid support emerges, the alumina probably lowers the entropy of activation when a reactant and a reagent are adsorbed close to each other and in the proper orientation for chemical reaction[23]. Another important function of alumina probably is to activate the reactant and/or the reagent.[24]

2.2. Alcohols, thiols, benzene selenol, amines and acetic acid

Nucleophilic opening of epoxides leads to *trans*-1, 2-difunctionalized systems and partly because such cleavages usually occur specifically with *trans*-stereochemistry. However, standard methods for nucleophilic opening of epoxides are often far from ideal and in practice these reactions frequently give mixtures of products, largely as a result of secondary processes such as rearrangement, elimination, and redox reactions; moreover regioisomers are generally obtained from unsymmetrical epoxides. Acid catalyzed seission often leads to mixtures of regioisomers and is unsuitable for molecules with other acid sensitive functions.

The various types of reactions which can occur, and the factors which influence them have been studied in substantial detail for many years, especially by Sukh Dev and his co-workers. Sukh Dev et al. have also investigated the alumina catalyzed rearrangement of various eooxides,[25] including the effect on product distribution of using alumina containing various bases or inorganic salts.[26]

Alumina 'doped' with a few equivalents of nucleophiles (e.g. alcohols, thiols, benzene selenol, amines and acetic acid) opens the epoxides regioselectively at the less substituted epoxide carbon atom and stereospecifically (trans) to give the corresponding β-functionalized alcohols cleanly and in good yields.[27]



I

II

The symmetrical 5-,7-,8-,12-,membered cycloalkene oxides other than cyclohexene oxide also undergo mild and selective opening by RZH-doped alumina.

Medium ring (C_8-C_{12}) cycloalkene oxides are much less reactive than cyclohexene oxides and are difficult to open homogeneously to only 2-functionalized cycloalkanols; direct 1,2-epoxide opening is usually accompanied by substantial amounts of side products derived from trans-annular interactions.[28] In contrast to these homogeneous reactions, no products arising from trans-annular interactions were found in the RZH-doped alumina-catalyzed opening of these medium-ring cycloalkene oxides.

2.3. Trichloroacetaldehyde

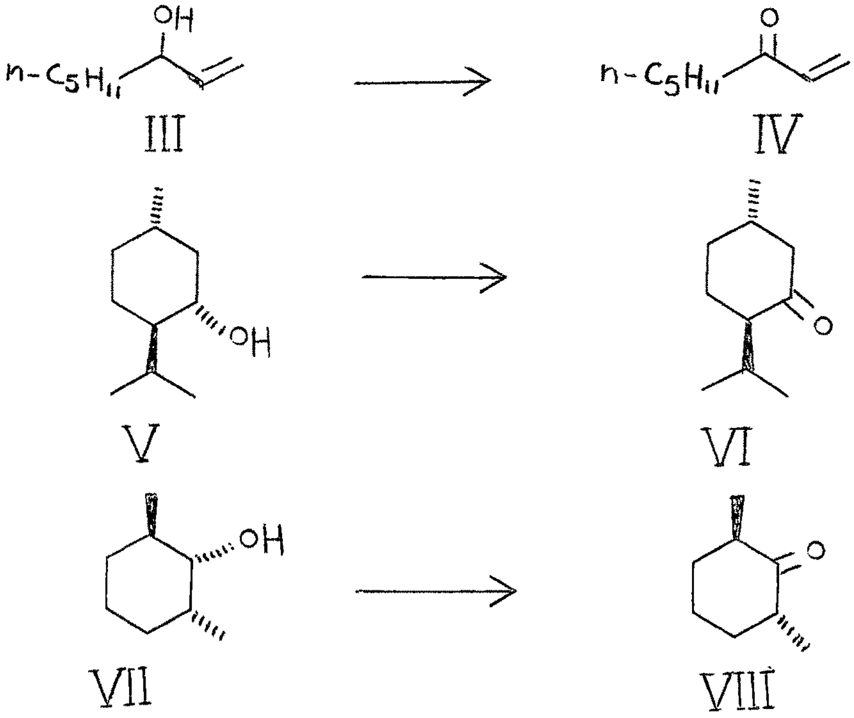
Posner et al. have examined trichloroacetaldehyde (and in one case benzaldehyde) supported on alumina as reagent for oxidation of alcohol.[29,30,31] The most useful aspects of this heterogeneous procedure are its mildness, its tolerance of acid and base sensitive functional groups, and its chemospecificity.

The mildness of chloral on activated alumina is illustrated by:

(a) Oxidation of allylic alcohol III into vinylic ketone IV which usually polymerizes at the slightest provocation.

(b) Oxidation of substituted cyclohexanols V, VII to ketones VI, VIII without epimerization to the thermodynamically more stable isomers; and

(c) High yield oxidation of cyclobutanol to cyclobutanone,[31] which process is often accompanied by fragmentation.[30]



Such functional groups as primary iodides, benzylic chlorides, methyl esters, nitrogroups, lactones and ethers survive this heterogeneous procedure.[29]

The chemospecificity of chloral on alumina is illustrated by:

(a) Oxidation of secondary but not primary alcohols

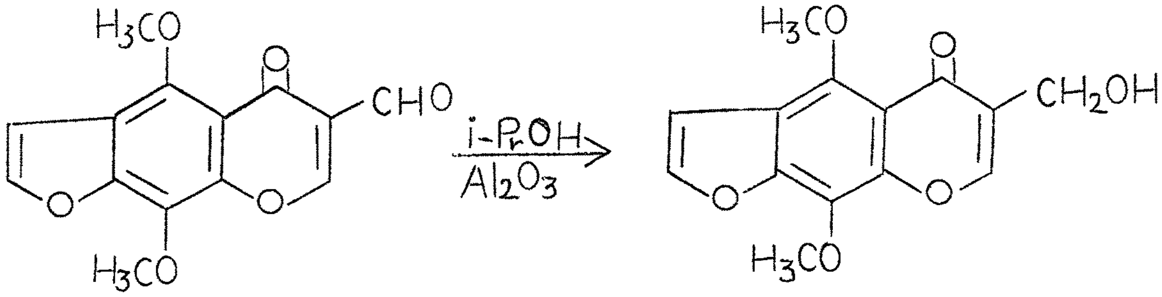
(b) Oxidation of olefinic alcohols to corresponding olefinic ketones

(c) Oxidation of β-hydroxy sulfides and selenides to the corresponding β-keto sulfides and selenides.

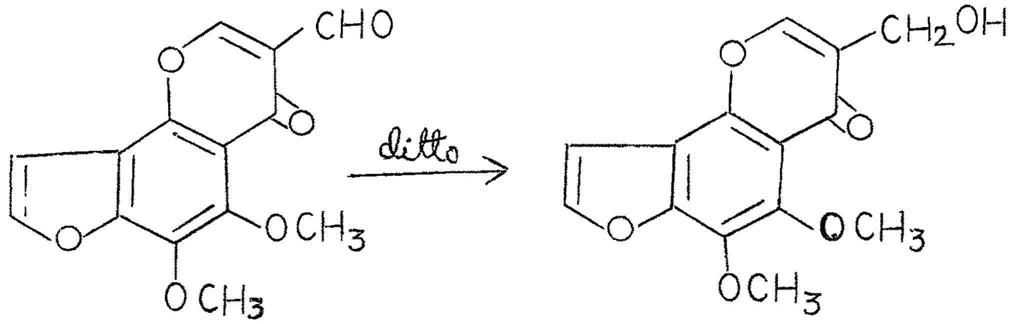
2.4. Isopropanol

2-Propanol adsorbed on alumina is an efficient reagent for the reduction of aldehydes and ketones and a detailed study of this has been made by Posner et al.[32,33] Although aldehydes are reduced by isopropyl alcohol on alumina, various other functional groups - ester, nitro, amide, nitrile, halogen - are stable under the reaction conditions.

The synthetic utility of this reagent can be further illustrated, e.g. chromones IX and X suffered reduction of both aldehyde carbonyl and α,β-ethylenic groups with the following reagents $NaBH_4$, $NaBH_4/AlCl_3$, diisobutylaluminium hydride in THF, and $NaB(CN)H_3$ in the presence of acid. Although chromones IX, X were inert to Meerwin-Ponndorf-Verley homogeneous conditions using aluminium isopropoxide, selective and effective aldehyde reduction occurs heterogeneously with 2-propanol on dried alumina.

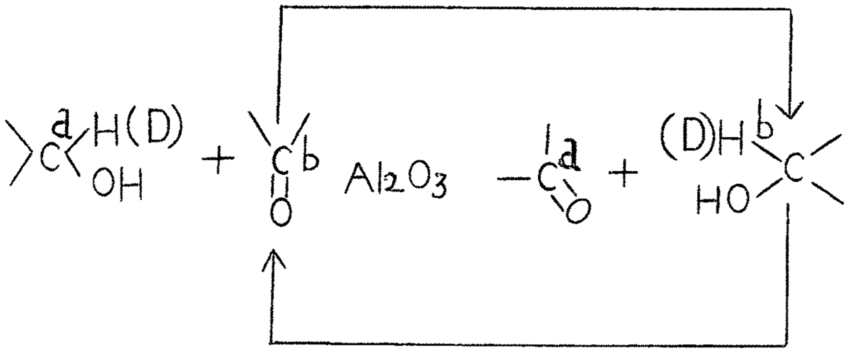


IX



X

That this carbonyl reduction involves hydride (rather than, for example, hydrogen atom) transfer has been established by use of deuterium labelled compounds[34] and by use of cyclobutanol as the hydride donar.[31]



2.5. Sodium borohydride

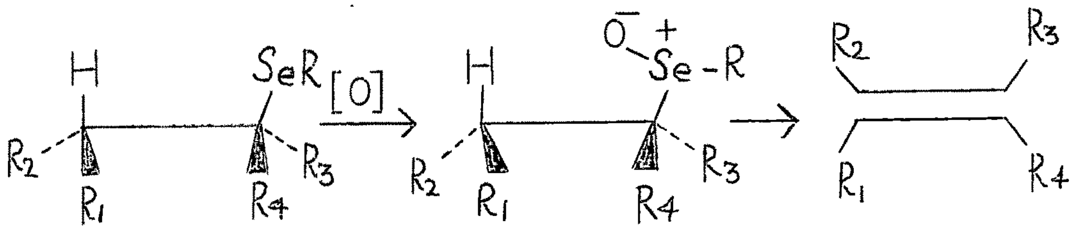
Hodosan *et al.*[35] have shown that sodium borohydride can be deposited on alumina simply by treating neutral alumina with an aqueous solution of $NaBH_4$ followed by removal of excess water. The main advantages of the reagent are that alkali-sensitive groups are not affected.

Santaniello *et al.*[36] apparently unaware of the earlier work by Hodosan[35], have described recently the preparation of $NaBH_4$-supported alumina and its use for the high yield reduction of a number of simple aldehydes and ketones.

2.6. *t*-Butyl hydroperoxide

Elimination of selenoxide is a versatile and now well established method for the preparation of olefins.[37]

Literature survey reveals that various reagents (30% H_2O_2, peracids, ozone, singlet oxygen and periodate) have been used, olefins are rapidly formed from selenides (through the selenoxides). Though, the oxidations do not always proceed smoothly and various instances of side reactions and/or low yield have been reported,[37] these problems have recently been solved by Krief et al.,[38,39] by treatment of selenides with t-butyl hydroperoxide in the presence of basic alumina at 55° in THF. t-Butyl hydroperoxide/alumina was found to be superior to hydrogen peroxide/alumina, and the method appears to be general.

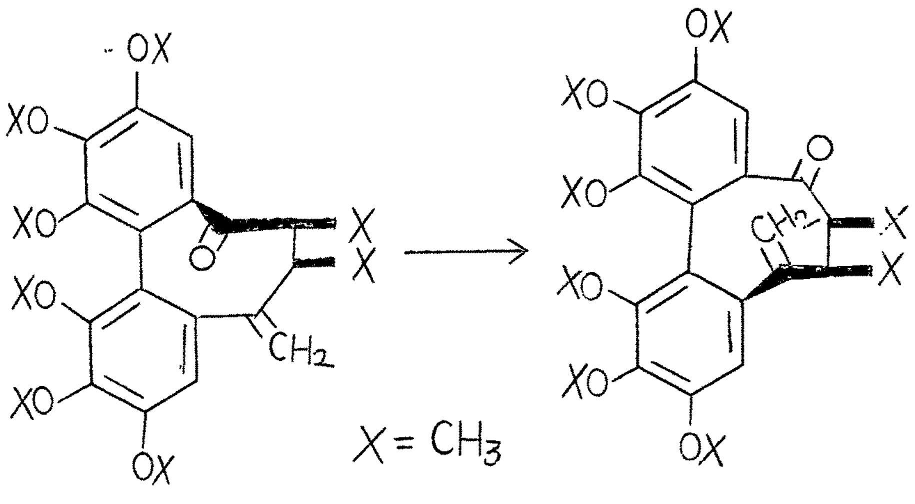


Krief and coworkers[40] have also described one further example of the use of the _t_-butyl hydroperoxide/alumina reagent in selenoxide fragmentation.

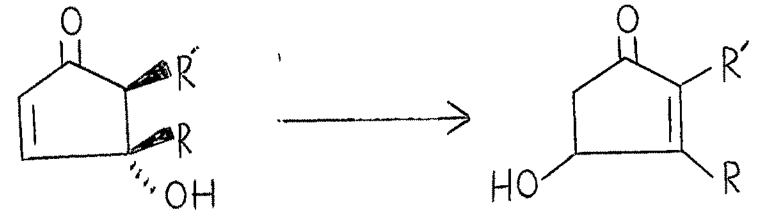
2.7. Miscellaneous reagents

Hudlicky[41] has reported that when a column of acidic aluminium oxide was soaked with a solution of benzyl chloride in chloroform containing hydrazoic acid, benzyl azide was obtained in 68.5% yield. Similar treatment of dialkyl α-bromo-α'-fluorosuccinate or ,$\alpha\alpha'$-dibromosuccinate with a solution of hydrazoic acid gave dialkyl α-azidofumarates in unspecified yield.

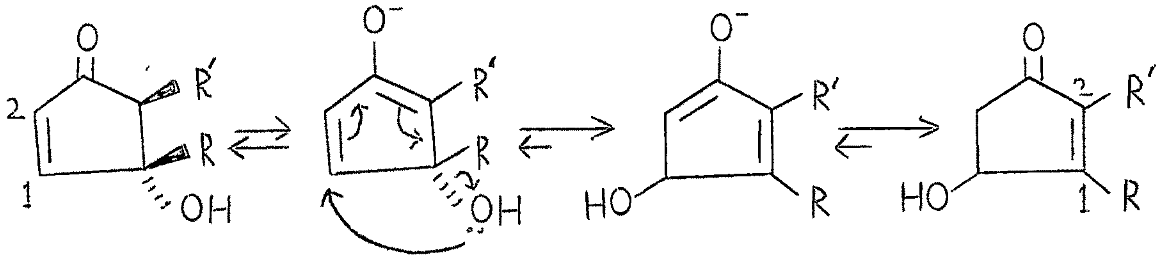
Sodium periodate supported on alumina has been used for the high yield oxidation of sulphides to sulphoxides.[42] The latter transformation can also be carried out in excellent yield using alumina-supported thallium (III) nitrate.[43] Other interesting application of alumina includes its use as a catalyst for the inversion of hindered bridged biphenyls[44] which, in the bridging ring contain a carbonyl group adjacent to one of the aromatic rings, and for the direct conversion of allylic alcohols XIII to the isomeric alcohols[45] XIV _via_ intramolecular migration of the alcohol function.



XI XII



XIII XIV



3. REAGENTS ON SILICA

Pure silica gel is inactive for demanding acid catalyzed reactions, evidently because surface SiOH groups have only a feeble acid strength. The pKa values of such groups fall somewhere in the range of 4 to 7. Morimoto et al.[46] recently carried out an IR study showing that silica gel has weak Bronsted acid sites which reacts with n-butyl amine but are inert towards pyridine under the same conditions.

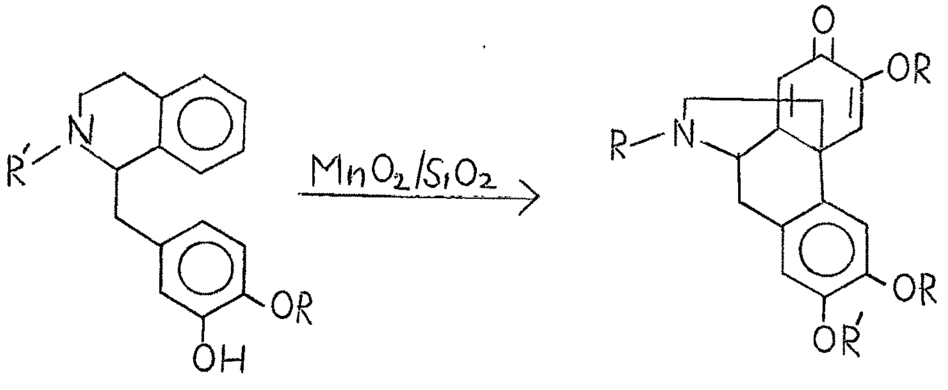
Mair[47] was first to observe the effect of silica gel upon the olefins. Rudakov and Shestaeva[48] used the isomerization of α-pinene as a system in studying characteristics of a variety of silica gels. The industrial silica gels which the Russian workers examined catalyzed the isomerization of α-pinene even at 20^o. These gels contained 1-10% alumina. Their study indicated that the activity of silica gels containing aluminium was due to the formation of aluminosilicate on the silica gel surface.

Despite the presence of sites that strongly chemisorb, a variety of molecules, pure silica gel is catalytically inactive for skeletal transformations of hydrocarbons. However, as has recently been emphasized by West et al.[49] only trace amounts of acid producing impurities such as aluminium need present in pure silica gel to provide catalytic activity - especially when a facile reaction such as olefin isomerization is used as a test reaction. They found that addition of 0.012% aluminium to silica gel resulted in a 10,000-fold increase in the rate of hexane-1 isomerization at 100° over that of pure silica gel. An earlier study by Tamele et al.[50] showed that introduction of 0.01% wt. aluminum in silica gel produces a 40-fold increase in cumene conversion when this hydrocarbon is cracked at 500°.

From the above examples, it is quite obvious that admixing has profound effect on the catalytic properties of silica gel. However, systematic investigation of the use of the reagents supported on silica gel is of very recent origin.

3.1. Manganese dioxide

The tertiary reticulene XV was oxidized by manganese dioxide/silica gel to give morphinan derivative, isosalutaridine XVI in 4% yield.[51]



$R = R' = CH_3$ $\qquad$ $R = CH_3,\ R' = H$

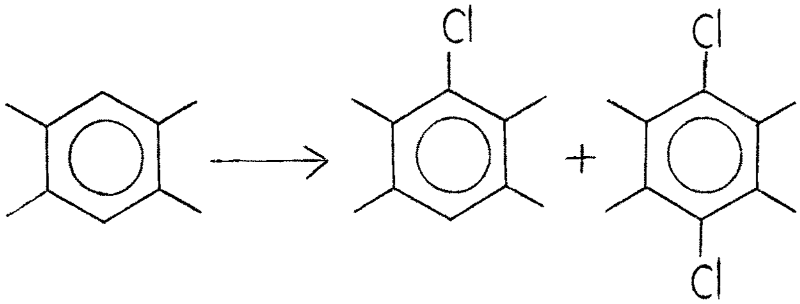
XV $\qquad$ XVI

3.2. Silver nitrate

Sukh Dev et al.[52] have described an interesting and potentially useful application of silver nitrate supported on silica gel. Oxidation of the sesquiterpene humulene with either pervanadic acid or perbenzoic acid in benzene/ petroleum ether or chloroform results in almost exclusive formation of the Δ^6-epoxide. Humulene is known, however, to form a crystalline adduct with silver nitrate in which Δ^6- and Δ^9-double bonds are π-complexed with Ag^+ [53]; the authors reasoned that a similar complex might be obtained if humulene were added to silver nitrate supported on silica gel, in which case selective oxidation of the Δ^2-double bond might be possible. In fact, oxidation of the humulene/$AgNO_3$/SiO_2 system with perbenzoic acid did give a significant amount of the $\Delta^{2,3}$-epoxide, together with the $\Delta^{6,7}$- and $\Delta^{9,10}$-epoxides and the $\Delta^{2,3}$- and $\Delta^{6,7}$-diepoxide.

3.3. Sulphuryl chloride

Silica gel has been found to have a profound effect on the reactivity of sulphuryl chloride in electrophilic aromatic chlorination reactions[54] and is supported by the view that, there is no reaction, for example, when sulphuryl chloride is added to a solution of durene XVII in n-hexane at room temperature; addition of small amounts of silica gel to the reaction mixture, however, results in the formation of mono XVIII and dichlorodurene XIX in 73 and 10% respectively. Similar results have been obtained for a variety of aromatic substrate.

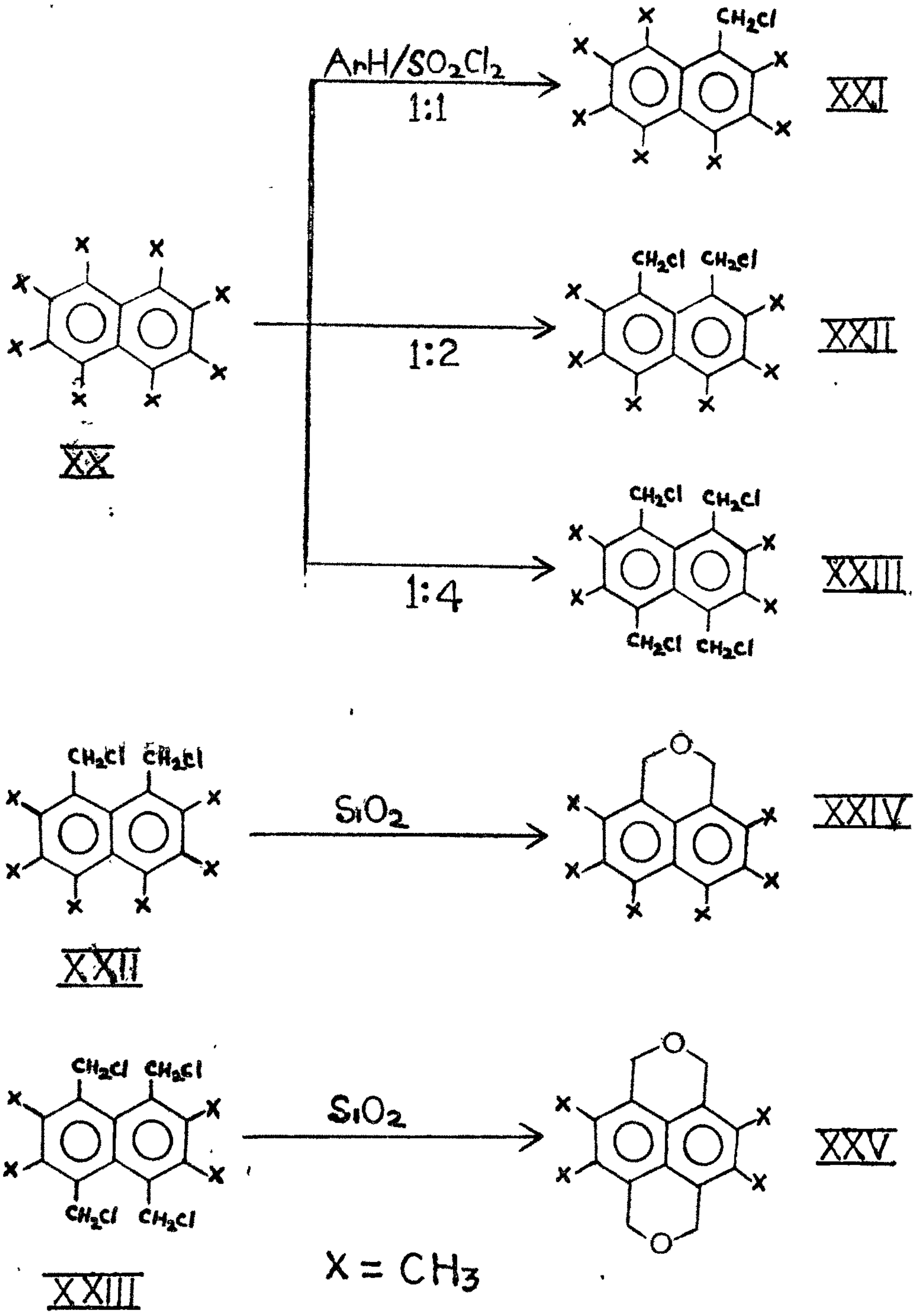


XVII XVIII XIX

Harold Hart et al.[55] have found an interesting result with octamethylnaphthalene XX, as the degree of chlorination can easily be controlled simply by variation of the ArH: SO_2Cl_2 ratio and products XXI, XXII, XXIII can be obtained in excellent yield. Moreover, chromatography of XXII and XXIII on silica gel converted it into the cyclic XXIV and symmetric bisether XXV (Chart 1).

3.4. Ozone

Ozone reacts slowly with saturated hydrocarbons inserting


ArH/SO2Cl2
1:1
1:2
1:4
SiO2
SiO2
CH2Cl
X
O
XX
XXI
XXII
XXIII
XXIV
XXV
X = CH3

CHART—1

oxygen atoms into their C-H bonds, resulting in alcohols and ketones.[56] The insertion occurs preferentially at the tertiary carbon atoms, with retention of configuration. This type of reaction has been little used until recently, however, mainly because ozone is only slightly soluble in organic solvents. It is on the other hand, silica gel adsorbs ozone efficiently at low temperatures[57] (~4.5% by weight at -78°) and the resulting reagent system is ideal for the direct hydroxylation of hydrocarbons[58] and results are listed in Chart 2.

The efficiency of the dry ozonation as a general method for stepwise hydroxylation of tertiary carbon atoms may be exemplified by hydroxylation of adamanton-1-ol, its acetate and the two isomeric <u>cis</u> and <u>trans</u>-1,4-dimethylcyclohexanols.

Under the same conditions secondary alcohols are oxidised to ketones as shown by a quantitative conversion of adamantane-2-ol to adamantanone.[58]

Moreover, the reagent could be of special utility in certain cases for the direct oxidation of a methylene group to a ketone <u>via</u> initial hydroxylation and subsequent oxidation of the secondary alcohols. Proksch and Meijere[59] showed that oxidation of the hydrocarbon XXVI with excess

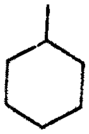
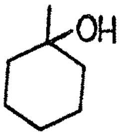
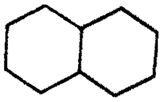
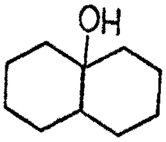
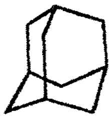
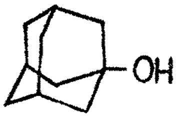
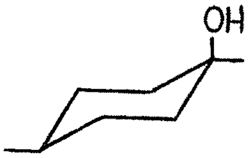
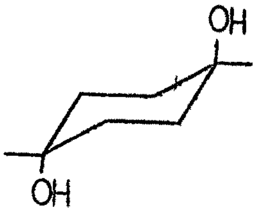
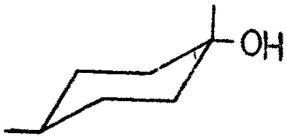
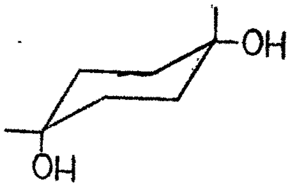
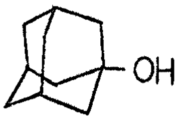
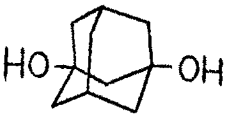
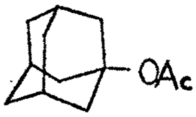
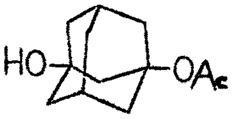
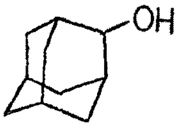
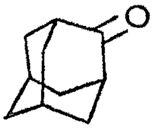
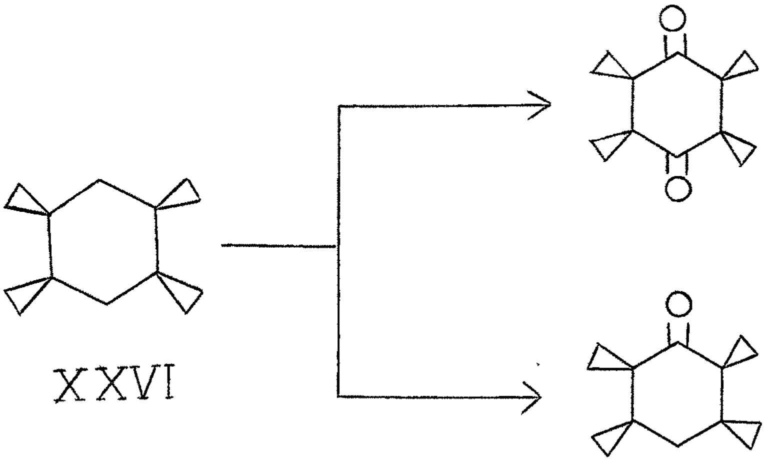
		65
		99
		99
		99·5
		76
		99
		86
		99

CHART — 2

ozone/silica gel gave the diketone XXVII in 61% yield; the monoketone XXVIII was the major product when less ozone was used.



XXVI

XXVII

XXVIII

As expected, the ozone/silica gel reagent will oxidatively destroy aromatic compounds in which the ring does not contain powerful electron with-drawing groups.[60] Phenyl and mesityl cyclohexane, for example, are converted to cyclohexane carboxylic acid in 80% and 70% yield respectively, while tetralin gives adipic acid in 50% yield (Chart 3).

Saturated primary amines undergo oxidation reactions. by ozone in solution.[61,63] These reactions thoroughly investigated by Bailey and his coworkers,[61,62] result in the corresponding nitroalkanes accompanied by several other compounds depending on the reaction conditions. Keinan

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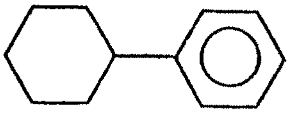
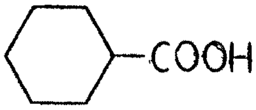
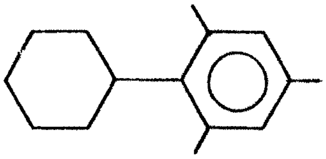
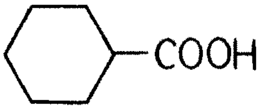
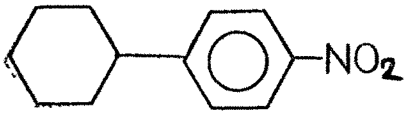
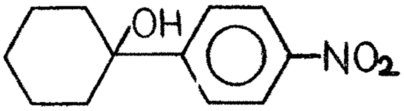
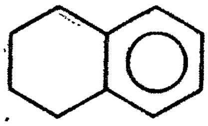
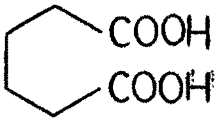
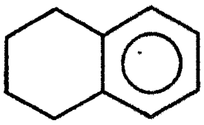
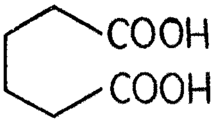
1			80
2			70
3			20
4			50
5			75

CHART—3

and Mazur[64] have used this dry ozonation method to convert primary amines (alkyl, alkylaryl and aryl) into the corresponding nitro-alkanes in good yield (40-70%). The only by-product isolated (except for tert-butyl amine, whose sole product is tert-nitrobutane) was the respective α-carbonyl derivative formed in yield between 2 and 6%. No other products were eluted from the silica gel neither with solvent mentioned above nor with ethyl acetate (Chart 4).

Ozonation mechanism of amines is probably similar to that proposed by Bailey et al.[61,62] for ozonation in solution. The pathway I leading to the formation of nitroderivatives involves an electrophilic attack of ozone on the amine nitrogen leading to an adduct, which is in equilibrium with the anion radical. Decomposition of adduct leads to the amine oxide; the precursor of nitroderivative.

The fact that the yield of carbonyl compounds is less dependent on the reaction conditions than the yield of nitroderivatives point to different pathways for their formation. They assured that the direct attack of ozone on the activated α-carbon hydron bond occurs concurrently with that on amine nitrogen leading to the α-hydroxy amines, whose decomposition generates the carbonyl function.

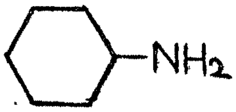
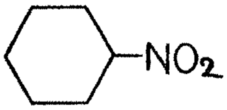
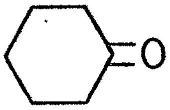
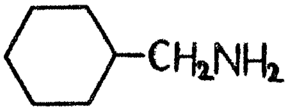
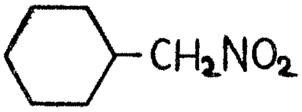
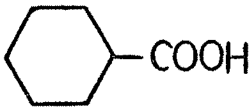
1.	$C_2H_5CH(CH_3)NH_2$	$C_2H_5CH(CH_3)NO_2$	70	$C_2H_5COCH_3$	2
2.	$(CH_3)_3CNH_2$	$(CH_3)_3CNO_2$	70	—	—
3.	$CH_3(CH_2)_3NH_2$	$CH_3(CH_2)_3NO_2$	65	$CH_3(CH_2)_2COOH$	5
4.			69		4
5.			69		6

CHART — 4

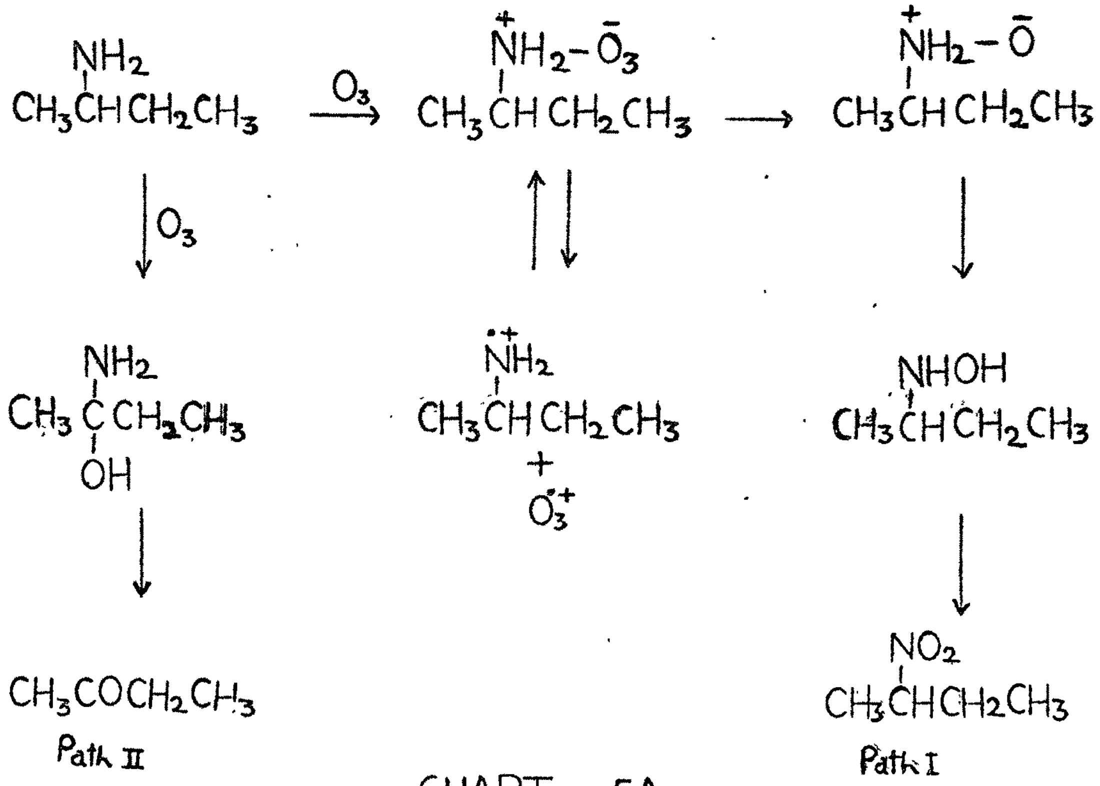
This second pathway was also suggested originally by Bailey[56g, 61b, 65] as an alternative mechanism for the formation of carbonyl derivatives on ozonation in solution. Similar insertion of oxygen in C-H bonds was previously observed in other saturated compounds[58, 66, 67] (Chart 5-A).

The procedure was much less successful when applied to a series of substituted anilines; nitroarenes were obtained in only low yield (2.8-20.5%). The low yield of nitroarenes may be explained by the reduced nucleophilicity of the amine group and by the competitive oxidation of the aromatic ring. The mechanism for aniline ozonation is depicted in Chart 5-B. It appears that the ozone-aniline adduct is less stable than the corresponding adduct of alkylamine,[67] decomposing readily in two independent pathways.

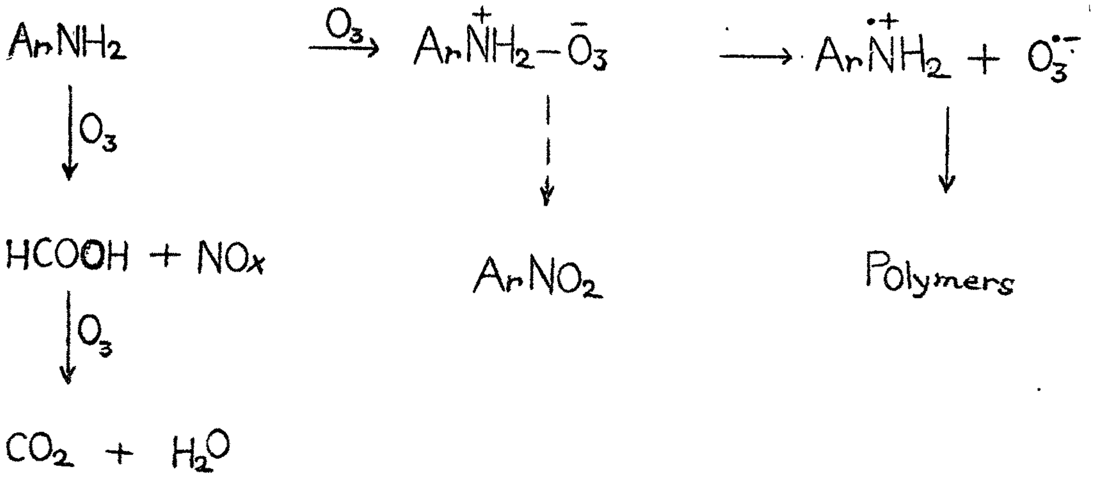
Oxidation of highly strained bicyclo[n.1.o] alkanes with the ozone/silica gel reagent have also been studied[68] and further examples of the use of this reagent for the direct hydroxylation of unactivated positions in sesquiterpenes[69] and a triterpene[70] have been reported.

3.5. Phase-transfer catalysis

Heterogeneous phase-transfer catalysts such as phosphonium



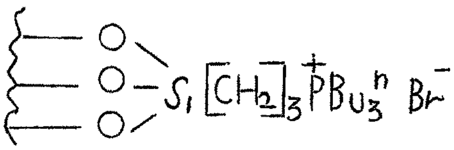
CHART— 5A



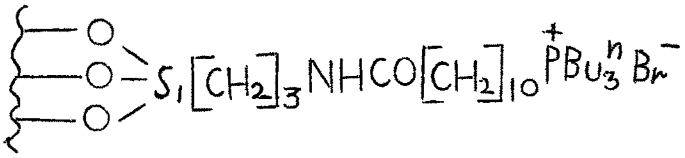
CHART— 5B

salts immobilized on silica gel show catalytic activity for anion promoted reactions both in liquid-liquid and solid-solid systems and the reaction rate is directly proportional to the concentration of the functionalized silica gel.

P. Tundo[71a] has prepared the phase-transfer catalyst XXIX & XXX and studied their catalytic activity in the Finkelstein reaction of 1-bromooctane, the reduction of 2-octanone by sodium borohydride, and the reaction of benzyl chloride with potassium phthalimide. Yields of products obtained using XXIX and XXX were very similar to those realised with standard quarternary ammonium and phosphonium salts.



XXIX



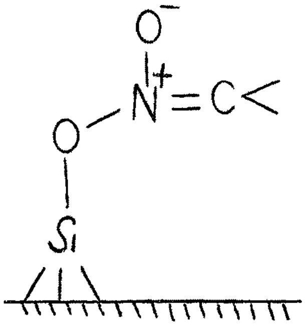
XXX

Though XXX is easier to prepare than XXIX, it is however, less reactive. Catalyst XXIX and XXX may be used several times after filtration, with almost unchanged catalytic activity. The above reagent can also be used for ordinary nucleophilic substitution reaction.[71b]

3.6. Sodium methoxide

The basic silica gel[72] is readily prepared by mixing chromatographic grade silica gel with a methanolic solution of sodium methoxide, followed by evaporation to dryness and heating at 400° for several hrs. With the resulting dry powder both primary and secondary nitro compounds are converted to the corresponding aldehydes and ketones.[73] Generally, additional carbonyl group does not interfere with these conversions, the exception being the 1-nitro-4-keto-alkanes, which are inert to basic silica gel. Thus, in order to obtain 4-ketopentanal, it was necessary to mask the keto-function of the 1-nitropentane-4-one by a ketal group (Chart 6, item 6).

Mazur <u>et al.</u>[73] assumed that the first step in the conversions is the formation of nitronate ion,[74] which reacts with the siloxane function of silica gel[75] resulting in the mixed anhydride[76] of nitronic acid and poly(silicic acid). This intermediate is then attacked by the silanoxide



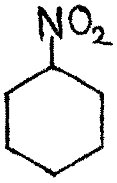
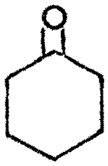
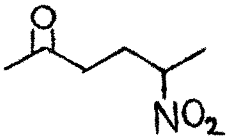
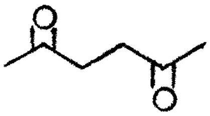
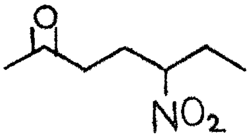
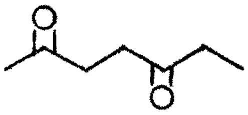
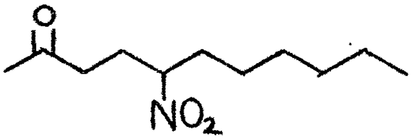
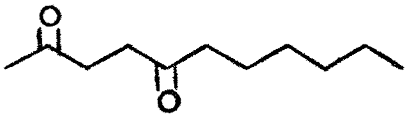
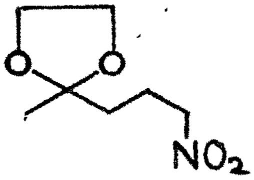
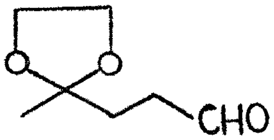
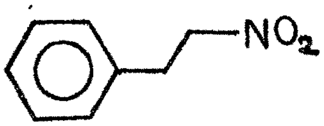
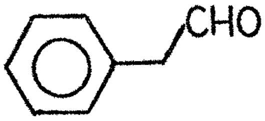
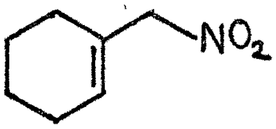
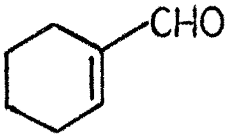
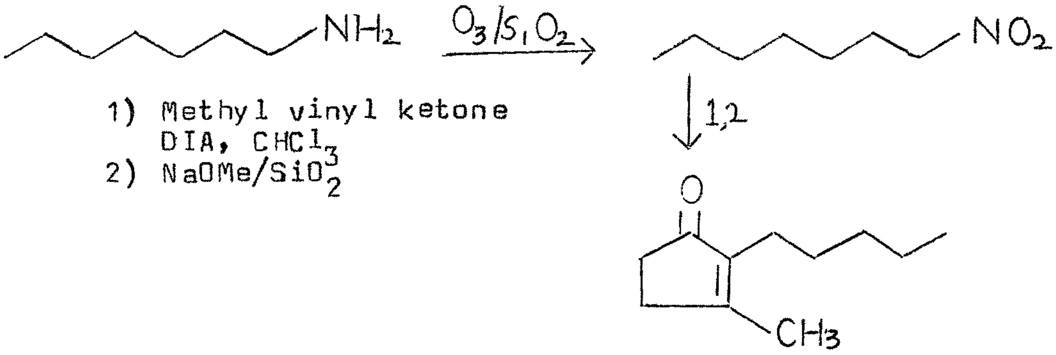
	Starting material	Product	Yield %
1.			99
2.			97
3.			81
4.			84
5.			80
6.			81
7.			60
8.[78]			—

CHART — 6

or by adsorbed hydroxide anion,[77] resulting in the carbonyl derivative and nitrogen oxides.

The usefulness of dry silica gel both as a reaction medium and a reagent may be eligantly demonstrated by technically simple synthesis of dihydrojasmone.



(Dihydrojasmone)

3.7. Chromyl chloride

Filippo and Chern[79] have shown the utility of chromyl chloride chemisorbed in silica-alumina as an efficient, economical reagent for the oxidation of primary and secondary alcohols to the respective aldehydes and ketones under neutral, nonaqueous conditions and this reagent is a great deal more selective than the homogeneous reagent. It is not apparent, however, whether this enhanced selectivity is a result of the inherently reduced reactivity of the chemisorbed species relative to that of chromyl chloride, or to the stability of the rigid support to immobilize a highly reactive species e.g. Cr(IV) so as to prevent its further possible secondary reactions[80] or reactions which would ultimately lead to a complex mixture of reaction products such, as observed under homogeneous conditions.

$$RCH_2OH \xrightarrow{CrO_2Cl_2/SiO_2-Al_2O_3} RCHO$$

$$RR'CHOH \xrightarrow{CrO_2Cl_2/SiO_2-Al_2O_3} RR'CO$$

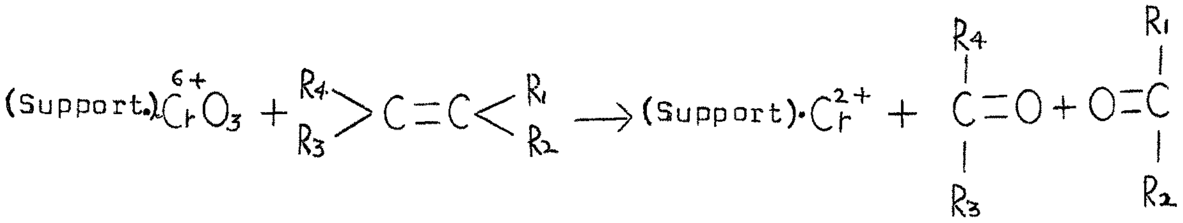
A preliminary examination of the functional group compatibility of this reagent indicates that halocarbons, esters, lactones, nitriles, and ethers appear inert. Olefins on the other hand, undergo oxidative cleavage. Thus the same reagent will for example, convert stilbene to benzaldehyde in 71% yield.

3.8. Ferric chloride

Ferric chloride absorbed on silica gel is a very useful reagent for dehydration of allylic, tertiary and sterically strained secondary alcohols.[81] Reactions are very rapid at room temperature and yields of olefins are excellent; moreover, regioselective monodehydration of various polyhydroxy steroids can readily be effected. The same reagent can be used for pinacol and acyloin rearrangements while a modified reagent, prepared by addition of ~ 2% water, can be used for the epimerization of tertiary alcohols and the conversion of epoxides into diols.

3.9. Chromium oxide and Chromic acid

3.9.1. Chromium oxide: Olefins react with chromium trioxide supported on silica gel or silica-alumina to give oxidative cleavage of the double bond, with formation of the corresponding aldehydes and ketones as primary oxidation products.[82]



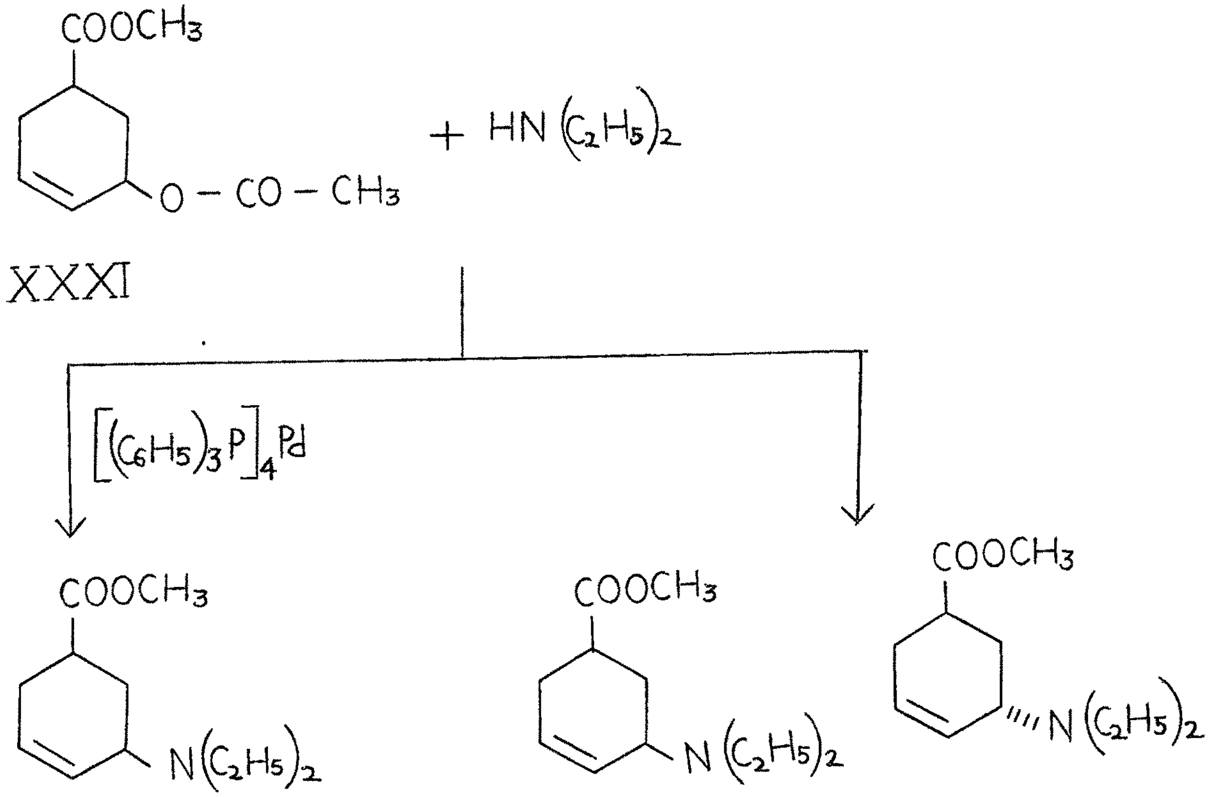
$$(\text{Support})\cdot\overset{6+}{Cr}O_3 + \begin{matrix} R_4 \\ R_3 \end{matrix}\!\!>C=C<\!\!\begin{matrix} R_1 \\ R_2 \end{matrix} \longrightarrow (\text{Support})\cdot Cr^{2+} + \begin{matrix} R_4 \\ | \\ C \\ | \\ R_3 \end{matrix}\!=O + O=\!\begin{matrix} R_1 \\ | \\ C \\ | \\ R_2 \end{matrix}$$

3.9.2. Chromic acid: E. Santaniello *et al.*[83] have reported that chromic acid (H_2CrO_4) adsorbed on silica gel is a useful reagent for the oxidation of alcohols to aldehydes and ketones in 68-90% yield, but the reagent is apparently not particularly stable and should be used within a week of preparation, on the contrary, silica gel supported chromic acid reagents described by R.P. Singh *et al.*[84] are equally active even after one year's storage under ordinary conditions and are very convenient and effective reagents for the oxidation of alcohols. This work is discussed in Chapter III of this Thesis.

3.10. Miscellaneous reagents

The extremely hygroscopic nature of tetraalkylammonium fluorides has probably restricted the wide scale use of these valuable reagents for organic synthesis, however, deposition of the salts on silica gel[85] circumvents this problem and the resulting "driflour" reagents are stable and useful for a number of organic reactions.

Reaction of phosphinylated silica gel with tetrakis triphenylphosphine palladium gives a deep red coloured palladium (0) supported catalyst. Reaction of diethylamine with the allylic acetate XXXI in the presence of tetrakis triphenylphosphine palladium gives a mixture of XXXII (67%) and XXXIII (33%) in 85% yield; when the silica gel supported reagent is employed, however, the sole product is XXXII in 72% yield.[86]



XXXII (72%)　XXXII (67%)　XXXIII (33%)

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