International Journal of Advanced Research in Engineering Technology & Science
ISSN: 2349-2819
Impact Factor: 7.10
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Email: editor@ijarets.org Volume-11 Issue-4 April-2024 www.ijarets.org

Oxidative degradation of antibacterial drugs in effiuents of hospital wastes: A mechanistic Approach

Dr. Mahima sharma

Assoc. Professor, Chemistry Department

Govt. College, Bundi

Abstract:

This study provides an overview of chemical kinetics, discusses various oxidant such as Hexacyanoferrate (III), Manganese dioxide, Diperiodatocuprate(III), Chloramine-T, Potassium permanganate, and their oxidizing qualities, and briefly touches on antibacterial, which are potent antibiotics used in both human and veterinary medicine. Environmental impact problems are raised by the fate of antibiotic parent and metabolite chemicals that enter environmental ecosystems through several mechanisms. The goal of the current study was to calculate the reaction kinetics and elucidate the reaction pathways involved in oxidative degradation of the environmentally relevant antibacterial drugs in an acidic/alkaline aqueous media. this work will be useful in treating wastewater in areas where fluoroquinolone antibacterial drugs have caused pollution. This study also provides a comparative discussion about oxidizing nature of various oxidants.

Introduction:

Chemical kinetics, the study of chemical process rates, encompasses the development of mathematical models that can characterize the properties of a chemical reaction as well as the exploration of how various experimental conditions can affect a chemical reaction's rate and provide insight into the mechanism and transition states of the reaction. Chemical engineers and chemists can better comprehend and describe chemical processes and the intricate chemistry of living systems by using the mathematical models that describe chemical reaction kinetics. Chemical reactors can be designed or modified using these models to optimize product yield, segregate products more effectively, and get elimination of by-products that are hazardous for the environment. For each reaction, an appropriate mechanism is suggested based on observations made within the experimental conditions. Reaction mechanism is the process by which molecules breakdown and atoms reorganize in accordance with the order of a reaction with regard to different reactive species. However, all of the chemical events in a chemical reaction cannot be explained by the order of the reaction with respect to the reactants and thermodynamic parameters. This is mostly because the reactions rarely proceed in a single step. Numerous basic reactions take place in the ongoing conversion of the reactants to the products and such types of reactions are either complex or

composite in nature. tion of the reactants and catalyst, the stereochemistry of the reactants and products, and the quantities of each must all be explained in a comprehensive mechanism. Further details regarding the specific stages that could be a part of the reaction mechanism are provided by the rate law. Setting up a kinetics experiment for the chemical reaction is the first step towards determining the rate law. To find the change in a species' concentration over time, a kinetics experiment is methodically designed to allow measurements to be taken at specific intervals.

Antibacterial drugs:

Every reactive intermediate, activated complex, transition state, broken and created bonds, and so on are all described by the reaction mechanism. Antibiotics, including tetracycline, β-lactum, microcline, sulphonamide, lincosamide, and fluoroquinolone, are among the different kinds of antibiotics that fall under the category of synthetic broad-spectrum antibiotics. Among these antibiotics, fluoroquinolones (FQs) are widely used antibacterial agents in a variety of applications, including the treatment of bacterial infections, urinary tract infections, treatment of STDs, infections of the bones and joints, typhoid fever, and tuberculosis, among others [1].

Gram-positive and gram-negative aerobic and anaerobic organisms are among the expanded spectrum of bacteria that the more recent FQs can inhibit clinically [2]. Originating as a by-product of the manufacture of the antimalarial drug chloroquine [3], nalidixic acid was the first member of the quinolone class of antimicrobials to be reported in 1962 [4]. The first 4-quinolone to be marketed for clinical usage was nalidixic acid. It has pharmacokinetic qualities that made it useful for treating urinary tract infections and was effective against some Gram-negative bacteria. The discovery of adding a fluorine atom and a piperazine ring to the basic quinolone nucleus at positions 6 and 7 marked a significant advancement for this class of antibacterial drugs. The "pharmacore" or fundamental fluoroquinolone molecule is depicted in (**Fig. 1**). These replacements lowered toxicities, enhanced absorption, and enhanced antibacterial action. Many FQs were patented after that and are still in use today. As a result, ongoing efforts have been made to replace the simpler fluoroquinolone pharmacophore with a complex one.

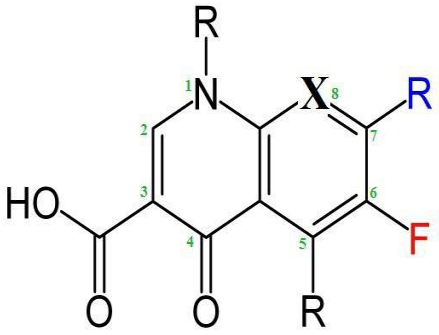


Fig. 1.1: General structure of 4-Quinolones. Quinolones: X = CH or C-R8; Naphthyridones: X = N.

Classification of Antibacterial Drugs

Bacteriostatic substances are those that prevent bacterial development, whereas bactericidal substances kill germs [5]. The term "antibiotic" is further classified as "antivirals," "antifungals," and "antibacterials" depending on the type of microorganisms they oppose [6].

There are several different kinds of antibiotics and they can be classified based on their chemical structure, mechanism of action, action spectrum and the route of administration [7]. Out of these classifications the most popular one is their mechanism of action and based on it the most common groups are β-lactam, sulfonamides monobactams, carbapenems, amino glycosides, glycopeptides, lincomycin, macrolides, polypeptides, polyenes, rifamycin, tetracyclines, chloramphenicol, quinolones, and fluoroquinolones, Nitro-derivatives Fusidanos, Pleuromulins, Diamino pyridines oxazolidinones, phosphonate's etc. [8].

1.3.1 Beta-lactams

This class of antibiotics' members have a 3-carbon and a single, highly reactive nitrogen ring (**Fig.2 and 3**). They obstruct the proteins necessary for the creation of bacterial cell wall, and thus either eliminates or prevents them from growing. ntibiotics have the ability to attach to this Penicillin-binding protein (PBP)- enzymes, and as a result, they obstruct the peptidoglycan production leading to cell death [9]. The most well-known beta-lactam class's representatives are Monobactams, Cephalosporins, Penicillins, and carbapenems.

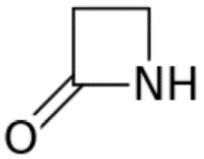
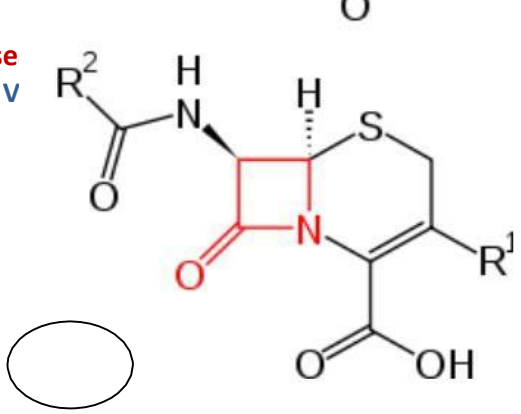


Fig. 1.2: Chemical structure of Beta-lactam ring

1



2

Fig. 1.3 Chemical structure of beta lactam structure. Core structure of Penicillins (1) and Cephalosporins (2)

1.3.2 Macrolides

As a metabolic byproduct of the fungus Saccharopolyspora erythraea, which inhabits soil, J. M. McGuire identified and isolated the first antibiotic in this class in 1951 [10].

The distinctive deoxy polysaccharides L-cladinose and D-desosamine are connected to 14-, 15-, or 16-membered macrocyclic lactose rings, which are the hallmark of macrolides (**Fig. 4**). Macrolides typically have a broad spectrum of action, While certain bacterial species, like Streptococcus pneumoniae, are resistant to

the antibiotics. Erythromycin, azithromycin, and clarithromycin are a few examples of members [11]

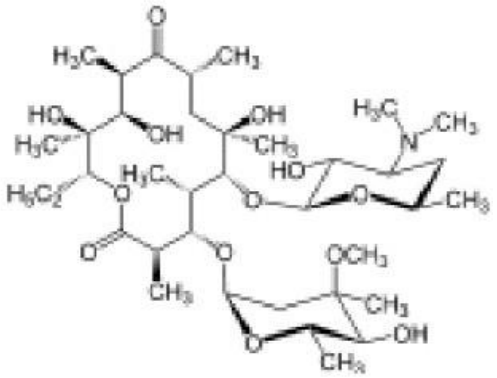


Fig. 1.4: Structure of Macrolide

1.3.3 Tetracyclines

Benjamin Diggar isolated tetracycline in 1945 from a soil bacterium belonging to the genus Streptomyces [12]. Aureomycin, also known as chlorotetracycline, was the original member of this class. Members of this class are identified by their names ending in "-cycline" and possess four (4) hydrocarbon rings (**Fig. 1.5**). This class of antibiotics has been divided into several generations according on how they were synthesized. Tetracycline, Chlortetracycline, Oxytetracycline, Demeclocycline, Doxycycline, Lymecycline, Meclocycline, Methacycline, Minocycline, Rolitetracycline tigecycline belongs to various class of tetracyclins [13].

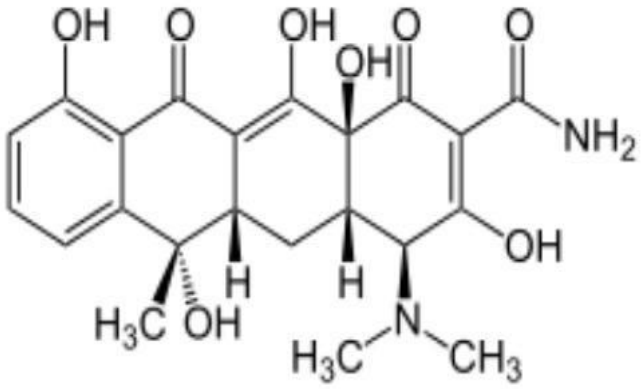


Fig. 1.5 Structure of Tetracycline

1.3.4 Quinolones

Scientists searching for antimalarial medications initially found this class of antibiotics as nalidixic acid. Two important families of drugs are quinolones and naphthyridones. These groups of compounds include nalidixic acid, enoxacin, ciproxacin, temafloxacin, sparfloxacin, cinoxacin, norfloxacin, and ofloxacin [14]. Numerous changes to its parent structure since its discovery gives many other anti bacterials which boosted their bioavailability, spectrum of activity, and potency, improving their effectiveness in treating a variety of diseases, including respiratory tract, systemic, and urinary tract infections [15].

1.3.5 Aminoglycosides

Streptomycin, which was initially identified in 1943, was the first medication to be found within this class of antibiotics [16]. The range of antibiotic action exhibited by aminoglycosides is extensive. By attaching to a ribosomal subunit, they can prevent bacteria from synthesizing proteins [17]. They work well against aerobic Gram-negative rods and some Gram-positive bacteria. According to Talaro and Chess [18], streptomycin is used to treat tuberculosis, tularemia, and the bubonic plague on several times.

1.3.6 Sulfonamides

Sulfonamides are widely used to treat a variety of infections, such as tonsillitis, septicemia, meningococcal meningitis, bacillary dysentery, and some urinary tract infections. They inhibit both Gram-positive and Gram-negative bacteria, including Nocardia, E. coli, Klebsiella, Salmonella, Shigella, and Enterobacter, as well as some protozoa [19]. Research has demonstrated that sulfonamides can also obstruct chemicals that cause cancer [20]. Synthetic antimicrobial drugs containing the sulphonamide group are known as the original antibacterial sulfonamide [21]. Due to their toxicity and adverse effects—some of which include hemolytic anemia, porphyria, urinary tract disorders, and hypersensitivity reactions—they should be used with caution [22].

1.3.7 Glycopeptides

Since the last 20 years, semi-synthetic derivatives of glycopeptide antibiotics, also known as GPAs, have emerged with better pharmacokinetic and activity characteristics [23]. GPAs are often shortened forms of natural drugs. Glycopeptides are naturally composed of a cyclic peptide consisting of seven amino acids and two sugars attached to it. Yim and Researchers [24] presents the structures of several types of glycopeptides in an effective manner. Additionally, a lipophilic side chain extends the half- life of glycopeptides and has antibacterial activity[25].

1.3.8 Oxazolidinones

A class of synthetic antibiotics called oxazolidinones have only recently been permitted for usage. The first component to be synthesized, linezolid (Figure 6), was only allowed for use in clinical settings in 2000. By attaching to the P site of the ribosomal 50S subunit, oxazolidinones prevent the synthesis of new proteins[26]. According to Moellering [27], linezolid is used to treat skin infections and respiratory tract infections. While following the recommended standard procedures for administering linezolid is generally safe, extended treatment might lead to adverse effects such myelosuppression, which can cause anemia and thrombocytopenia [28].

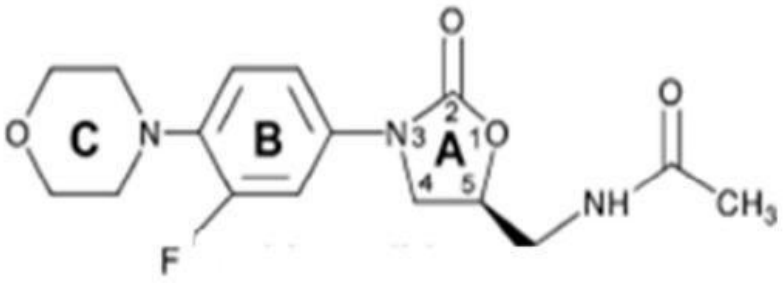


Fig. 1.6 Structure of Linezolid [17]

1.4. Oxidation of Antibacterial Drugs

It is quite concerning that antibiotics are present in the aquatic environment. Ongoing research aims to effectively eliminate or convert antibiotics into species with a reduced risk. An efficient method for the goal is the transformation of antibiotic by oxidation [29]. The oxidizing ingredient in water treatment combines with the impurities to produce less toxic molecules. Enhancing the efficacy of antibiotics removal in natural waterways requires several types of chemical techniques and advanced oxidation processes (AOPs). These consist of sonolysis [30], chlorination [31], chloramination [32], and oxidation of chlorine dioxide [33], ozonation [34], photocatalytic and photolytic degradation [35], persulfate (PS) [36], peroxomonosulfate (PMS) techniques [37], Fenton reaction processes [38], permanganate [39], and ferrate(VI) [40]. Reactive oxygen species (ROS), reactive sulfur species (RSS), reactive halogen species, and high-valent transition metal species were used in the majority of these technologies to eliminate antibiotics [41]. The order of oxidants' reactivity in basic solution is as follows: $SO_4^{\bullet-}$ >$^{\bullet}OH$ > O_3> ClO_2> H_2O_2> ClO^- > Fe (VI)> Mn (VII). The in-situ creation of highly reactive radicals, like $^{\bullet}OH$ or $SO_4^{\bullet-}$, is used as a substitute or addition to traditional wastewater treatment techniques for this reason [42]. Furthermore, two high-

valent metal oxidants, Mn (VII) and Fe (VI), have been developed [43,44] as promising technologies for the oxidative treatment of several pharmaceuticals.

1.4.1 Metal-based catalytic ozonation

Ozonation has been widely used in drinking water treatment as well as wastewater treatment over the past few decades to effectively remove a variety of micro- pollutants [45]. The aqueous breakdown of organic compounds by ozonation generally happens via two chemical pathways: indirect assault with $^{\bullet}OH$ generated by O_3 decomposition in water and direct oxidation, also known as ozonolysis [46]. In the process of aqueous ozonation, O_3 targets specific organic molecules' nucleophilic moieties, like unsaturated bonds, aromatic, and amino groups, using an electrophilic mechanism, while $^{\bullet}OH$ interacts much more broadly with the majority of organic compounds through hydrogen atom transfer, adduct formation and single electron transfer routes[47].The removal and mineralization of CIP by ozonation were effectively increased by the addition of Manganese oxides supported by carbon nanotubes (MnO_x/MWCNT), according to Sui et al. [48]. Application with MnO_x/MWCNT enhanced the elimination of CIP in actual water matrix when compared to ozonation. The faster $^{\bullet}OH$ generation in the MnOx/MWCNT catalytic ozonation system is thought to be caused by three factors: (i) O_3 decomposition initially began by OH^-, (ii) O_3 improvement by MWCNTs to produce $^{\bullet}OH$, and (iii) electron transfer between MnO_x and O_3. [49].

1.4.2 The Fenton Reaction System

Fenton oxidation, which uses Fe^{2+} and H_2O_2 in an acidic medium (pH 2-4), is a commonly used treatment for the removal of micro-pollutants from industrial wastewater and surface water [50]. This metal-catalyzed oxidation is a straightforward and adaptable process that can produce reactive $^{\bullet}OH$ in homogeneous or heterogeneous systems via free radical chain reactions, all without the need for specialized equipment or reactants [51]. $^{\bullet}OH$ has a high redox potential and is a non-selective oxidizing species that can remove numerous organic micropollutants at once. Fe^{2+} functions as a catalyst and quickly combines with the oxidant H_2O_2 to form Fe^{3+} and $^{\cdot}OH$, which have potent oxidizing abilities. Fe^{3+} combines with H_2O_2 in a solution to form Fe^{2+} when Fe^{3+} is present. The Fe^{2+} cycle can produce more $^{\bullet}OH$ if there is enough H_2O_2 present [52].

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^{\cdot}OH + OH^- \quad (1)$$

$$\cdot OH + H_2O_2 \rightarrow HO_2^{\cdot} + H_2O \quad (2)$$

$$Fe^{2+} + {}^{\cdot}OH \rightarrow Fe^{3+} + OH^{-} \quad (3)$$

$$Fe^{3+} + HO_2^{\bullet} \rightarrow Fe^{2+} + O_2 + H^{+} \quad (4)$$

$$\text{Organic compounds} + {}^{\bullet}OH \rightarrow H_2O + \text{mid-product} \rightarrow CO_2 + H_2O \quad (5)$$

By using UV radiation, H_2O_2, and ultrasound in combination with a unique marine sediment/titanate, Tavasol et al. were able to remove cefadroxil from aqueous media [53]. The rate of Cephalexin removal was as high as 94.71% with increased titanium loading on the sediment, which had a high specific surface area and photocatalytic activity **(Fig.7)**.

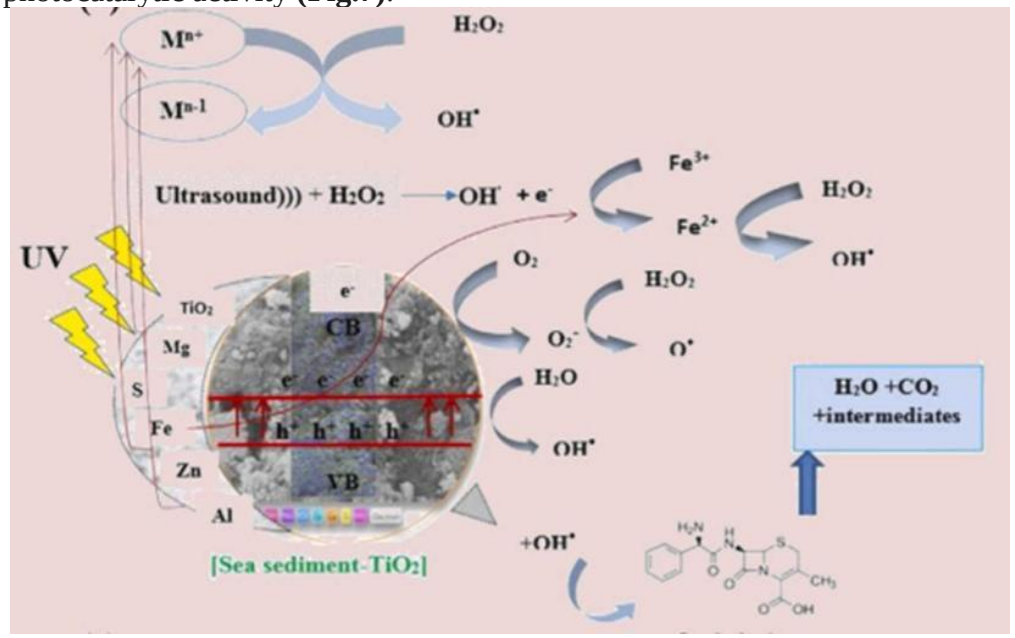


Fig.1.7: Process suggested for the "sea sediment/titanium-H_2O_2-UV-ultrasonic" system's eliminating cephalexin [53].

1.4.3 Oxidation systems based on $SO_4^{\bullet-}$ Radicals

Research in activated PS/PMS technology for wastewater and water treatment is growing [54,55]. PS/PMS can be efficiently activated by energy inputs like heat [56] or UV [57], but a more practical way for its practical application is single- electron transfer activation by transition metals like iron, copper, and cobalt.

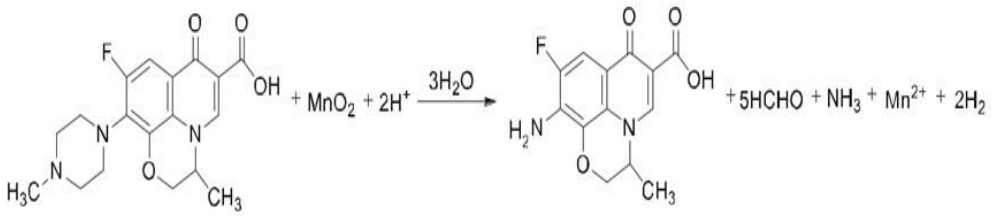
Fe^{2+} in the aqueous phase or on the surface of the catalyst may generally activate PS to produce reactive $SO_4^{\bullet-}$ species quickly, which speeds up the early- stage breakdown of these FQs [58]. According to Sturini et al. [59], the functional groups oxidized during the photodegradation of FQs followed

this order: piperazinyl ring > benzo ring > pyridine ring.

1.4.4 Manganese dioxide

The oxidation state of manganese varies from +7 to +2. The most stable oxidation states among them are +2, +4, and +7. In the aquatic environment, Mn(IV) oxide/hydroxide colloidal particles, plays a crucial role in initiating chemical transformations of organic molecules [60]. Due to its changeable valence, it has been widely studied and employed for electrochemical capacitor, oxidation, and catalysis applications [61].The preparation of water-soluble colloidal manganese dioxide from the reduction of aqueous $KMnO_4$ by $Na_2S_2O_3$ under neutral conditions is made possible for the first time quantitatively by Perez- Benito et al. [62]. In an aqueous acidic solution at 25^0C temperature, the kinetics of levofloxacin

oxidation by water-soluble manganese dioxide have been investigated [63]. According to the reaction's stoichiometry, 1 mol of manganese dioxide is required for the oxidation of 1 mol of levofloxacin [**Fig. 1.8**]. In various permanganate processes, colloidal MnO_2 has been employed as an auto catalyst [64]. Mn(III) and Mn(IV) oxides are two of the major manganese oxides that act as oxidizing agents for different organic molecules.



Levofloxacin

Fig. 1.8. Stoichiometry of reaction between Levofloxacin & Manganese dioxide

1.4.5. Hexacyanoferrate (III)

Environmentally friendly oxidants, iron in its various oxidation states from +3 to

+6, have drawn a lot of interest [65]. Iron (III) complexes are receiving significant attention as oxidants because of their affordable availability, low evaluation challenge, and ability to react in both acidic and alkaline media [66]. Hexacyanoferrate(III){HCF(III)} is an environmentally benign oxidant, and employed as a coagulant [67]. Their redox potential is the only factor that affects their oxidation capacity [68]. It is a single-electron oxidant with

a pair of $[Fe(CN)_6]^{3-}$ / $Fe(CN)_6^{2-}$] redox potential. In acidic media, 4− is +0.36 V,

while in basic media, it is +0.45 V. [69,70].

In alkaline conditions, HCF(III) has been frequently utilised to oxidise a wide range of organic and inorganic compounds [71]. Using HCF(III), the absorbance at 420 nm was measured to explore the kinetics of the oxidation of fluoroquinolones, such as ciprofloxacin (CIP), norfloxacin (NOR), enrofloxacin (ENR), and nalidixic acid (NAL). Based on the results of this experiment utilizing

electrochemical oxidation methods, it can be concluded that the piperazine ring is the active site for the oxidation of fluoroquinolones by HCF(III) [72]

.

Oxidative degradation of Cefuroxime (CFA) by Hexacyanoferrate (III) [HCF (III)]in aqueous alkaline medium at 40^0C temperature. The stoichiometry of the reaction indicates that the oxidation of one mole of cefuroxime requires two moles of Hexacyanoferrate (III) [73].

(Cefuroxime) + $[Fe(CN)_6]^{3-}$ + $[Fe(CN)_6]^{4-}$ + CO_2 + H^+ ..(3.1)

Fig 1.9 : Stoichiometry of CEF / HCF III reaction

1.4.6. Diperiodatocuprate (III)

Due to its limited solubility and stability in aqueous medium, DPC [74], a flexible one-electron oxidant, is insufficient or scarce in oxidation reactions [75]. It is also employed as a reagent for analysis [76].Malatesta [77] achieved the first chemical synthesis of Diperiodatocuprate(III) almost fifty years ago. Since then, a significant amount of study on the synthesis, structural identification, and analytical uses of this complex have been described [78].

In kinetic studies of the oxidation of different inorganic and organic substrates, Diperiodatocuprate (III) (DPC) is employed [79-82]. DPC was found to oxidize MF in an aqueous alkaline media is a fractional order reaction.

The kinetics and mechanism of oxidation of nalidixic acid (NA) by diperiodatocuprate (III)(DPC) in aqueous alkaline medium has been studied spectrophotometrically at 303 K. The reaction exhibits first order with respect to oxidant but substrate dependence is complex. The stoichiometry of the reaction has been observed to two moles of the oxidant for a mole of the substrate. According to spectroscopic evidence, 1-ethyl-2-hydroxy-1, 4-dihydro-7-methyl-4-oxo-1, and 8-naphthyridine-3-carboxylic acid are the oxidation products of the substrate[83].

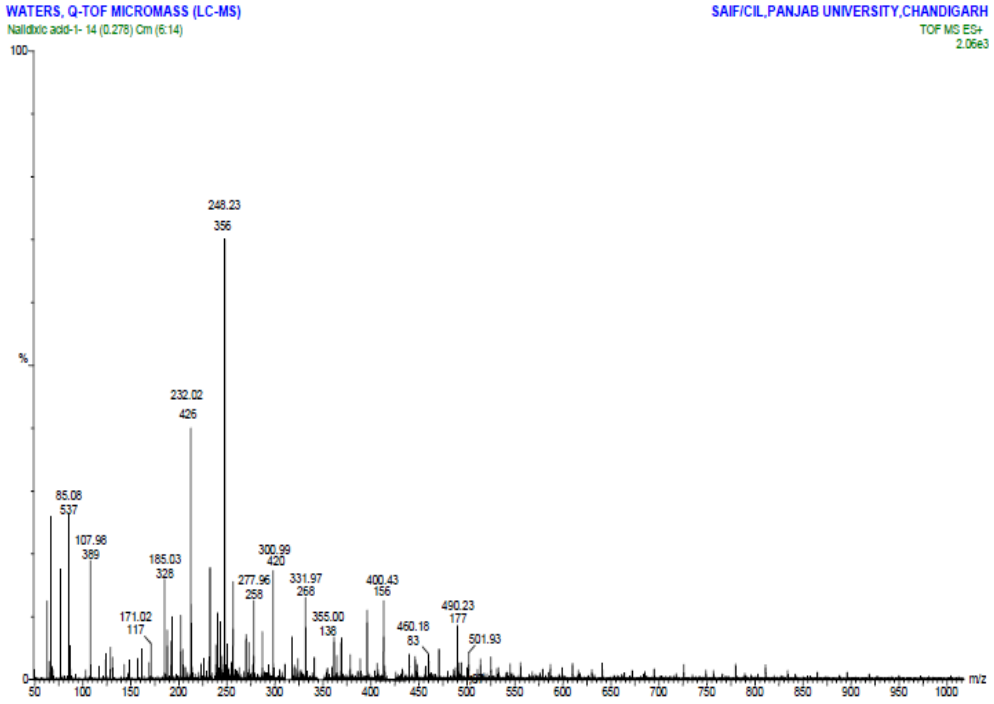
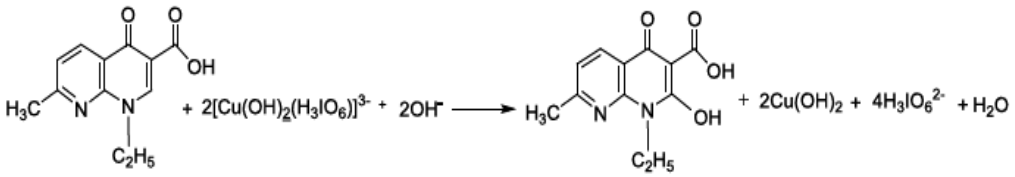


Fig1.4: LC-MS spectra of oxidation product of NA/DPC III reaction



Nalidixic acid

Fig. 1.10 : Stoichiometry of NA/ DPC III reaction

REFERENCES:

1. Millanao, A. R., Mora, A. Y., Villagra, N. A., Bucarey, S. A., & Hidalgo, A. A. (2021). Biological effects of quinolones: A family of broad-spectrum antimicrobial agents. *Molecules*, *26*(23), 7153.
2. Ezelarab, H. A., Abbas, S. H., Hassan, H. A., & Abuo-Rahma, G. E. D. A. (2018). Recent updates of fluoroquinolones as antibacterial agents. *Archiv der Pharmazie*, *351*(9), 1800141.
3. Bailly, C. (2021). Pyronaridine: An update of its pharmacological activities and mechanisms of action. *Biopolymers*, *112*(4), e23398.

4. Bisacchi, G. S. (2015). Origins of the quinolone class of antibacterials: an expanded "discovery story" miniperspective. *Journal of medicinal chemistry*, *58*(12), 4874-4882.
5. Walsh, C. (2003). *Antibiotics: actions, origins, resistance*. American Society for Microbiology (ASM).
6. Russell, A. D. (2004). Types of antibiotics and synthetic antimicrobial agents. *Hugo and Russell's Pharmaceutical Microbiology*, 152-186.
7. Soares, G. M. S., Figueiredo, L. C., Faveri, M., Cortelli, S. C., Duarte, P. M., & Feres, M. (2012). Mechanisms of action of systemic antibiotics used in periodontal treatment and mechanisms of bacterial resistance to these drugs. *Journal of applied oral science*, *20*, 295-309.
8. Zango, U. U., Ibrahim, M., Shawai, S. A. A., & Shamsuddin, I. M. (2019). A review on β-lactam antibiotic drug resistance. *MOJ Drug Des. Develop. Ther*, *3*(2), 52-58.isms of bacterial resistance to these drugs. *Journal of applied oral science*, *20*, 295-309.
9. Adeladlew, T., Taddie, W., & Dessie, D. (2016). Review on mechanisms of action and resistance of antibiotics.
10. Jelić, D., & Antolović, R. (2016). From erythromycin to azithromycin and new potential ribosome-binding antimicrobials. *Antibiotics*, *5*(3), 29.
11. Sanchez A. R., Rogers R. S. & Sheridan P. J. (2004). Tetracycline and other tetracycline-derivative staining of the teeth and oral cavity. Int. J. Dermatol. 43(10):709-715.
12. Liu, F., & Myers, A. G. (2016). Development of a platform for the discovery and practical synthesis of new tetracycline antibiotics. *Current Opinion in Chemical Biology*, *32*, 48-57.
13. Ezelarab, H. A., Abbas, S. H., Hassan, H. A., & Abuo-Rahma, G. E. D. A. (2018). Recent updates of fluoroquinolones as antibacterial agents. *Archiv der Pharmazie*, *351*(9), 1800141.
14. Etebu, E., & Arikekpar, I. (2016). Antibiotics: Classification and mechanisms of action with emphasis on molecular perspectives. *Int. J. Appl. Microbiol. Biotechnol. Res*, *4*(2016), 90-101.
15. Horta, P., Secrieru, A., Coninckx, A., & Cristiano, M. L. S. (2019). Quinolones for Applications in Medicinal Chemistry: Synthesis and Structure. *Targets in Heterocyclic Systems; Attanasi, O., Merino, P., Spinelli, D., Eds*, 260-297.

16. Mahajan, G. B., & Balachandran, L. (2012). Antibacterial agents from actinomycetes-a review. *Frontiers in Bioscience-Elite*, *4*(1), 240-253.
17. Allison, D. G., & Lambert, P. A. (2024). Modes of action of antibacterial agents. In *Molecular medical microbiology* (pp. 597-614). Academic Press.
18. Talaro, K. P., Talaro, A., Delisle, G., & Tomalty, L. (1996). *Foundations in microbiology* (Vol. 622, pp. 615-616). Wm. C. Brown.
19. Eyssen, H. J., Van den Bosch, J. F., Janssen, G. A., & Vanderhaeghe, H. (1971). Specific inhibition of cholesterol absorption by sulfaguanidine. *Atherosclerosis*, *14*(2), 181-192.
20. El-Gaby, M., A Ammar, Y., IH El-Qaliei, M., F Hussein, M., & A Faraghally, F. (2020). Sulfonamides: Synthesis and the recent applications in Medicinal Chemistry. *Egyptian Journal of Chemistry*, *63*(12), 5289-5327.
21. Verma, S. K., Verma, R., Xue, F., Thakur, P. K., Girish, Y. R., & Rakesh, K. P. (2020). Antibacterial activities of sulfonyl or sulfonamide containing heterocyclic derivatives and its structure-activity relationships (SAR) studies: A critical review. *Bioorganic Chemistry*, *105*, 104400.
22. Slatore, C. G., & Tilles, S. A. (2004). Sulfonamide hypersensitivity. *Immunology and Allergy Clinics*, *24*(3), 477-490.
23. Blaskovich, M. A., Hansford, K. A., Butler, M. S., Jia, Z., Mark, A. E., & Cooper, M. A. (2018). Developments in glycopeptide antibiotics. *ACS Infectious Diseases*, *4*(5), 715-735.
24. Yim, G., Thaker, M. N., Koteva, K., & Wright, G. (2014). Glycopeptide antibiotic biosynthesis. *The Journal of antibiotics*, *67*(1), 31-41.

25. Blaskovich, M. A., Hansford, K. A., Butler, M. S., Jia, Z., Mark, A. E., & Cooper, M. A. (2018). Developments in glycopeptide antibiotics. *ACS Infectious Diseases*, *4*(5), 715-735.
26. Bozdogan, B., & Appelbaum, P. C. (2004). Oxazolidinones: activity, mode of action, and mechanism of resistance. *International journal of antimicrobial agents*, *23*(2), 113-119.
27. Moellering Jr, R. C. (2003). Linezolid: the first oxazolidinone antimicrobial. *Annals of internal medicine*, *139*(10), 864.
28. Sharma, S., Syal, A., Gupta, M., Tahlan, A., & Kaur, B. (2020). Reversible myelosuppresion with prolonged usage of linezolid in treatment of methicillin-resistant staphylococcus aureus. *Cureus*, *12*(10).
29. Dong, F., Li, J., Lin, Q., Wang, D., Li, C., Shen, Y., ... & Song, S. (2022). Oxidation of chloroquine drug by ferrate: Kinetics, reaction mechanism and antibacterial activity. *Chemical Engineering Journal*, *428*, 131408.
30. Rayaroth, M. P., Aravind, U. K., &Aravindakumar, C. T. (2016). Degradation of pharmaceuticals by ultrasound-based advanced oxidation process. *Environmental Chemistry Letters*, *14*, 259-290.
31. Serna-Galvis, E. A., Jojoa-Sierra, S. D., Berrio-Perlaza, K. E., Ferraro, F., & Torres-Palma, R. A. (2017). Structure-reactivity relationship in the degradation of three representative fluoroquinolone antibiotics in water by electrogenerated active chlorine. *Chemical Engineering Journal*, *315*, 552-561.
32. Veena, M. S., Prashanth, M. K., Yogesh Kumar, K., Muralidhara, H. B., &Arthoba Nayaka, Y. (2015). Kinetics and mechanistic study of oxidation of amoxicillin by chloramine-T in acid medium. *Journal of the Chilean Chemical Society*, *60*(3), 3063-3068.
33. Feng, M., Wang, Z., Dionysiou, D. D., & Sharma, V. K. (2018). Metal- mediated oxidation of fluoroquinolone antibiotics in water: a review on kinetics, transformation products, and toxicity assessment. *Journal of hazardous materials*, *344*, 1136-1154.
34. Feng, M., Yan, L., Zhang, X., Sun, P., Yang, S., Wang, L., & Wang, Z. (2016). Fast removal of the antibiotic flumequine from aqueous solution by ozonation:

influencing factors, reaction pathways, and toxicity evaluation. *Science of The Total Environment*, *541*, 167-175.

35. Zambrano, J., García-Encina, P. A., Jiménez, J. J., López-Serna, R., & Irusta- Mata, R. (2022). Photolytic and photocatalytic removal of a mixture of four veterinary antibiotics. *Journal of Water Process Engineering*, *48*, 102841.
36. Ding, D., Liu, C., Ji, Y., Yang, Q., Chen, L., Jiang, C., & Cai, T. (2017). Mechanism insight of degradation of norfloxacin by magnetite nanoparticles activated persulfate: identification of radicals and degradation pathway. *Chemical Engineering Journal*, *308*, 330-339.
37. Mahdi-Ahmed, M., & Chiron, S. (2014). Ciprofloxacin oxidation by UV-C activated peroxymonosulfate in wastewater. *Journal of hazardous materials*, *265*, 41-46.
38. Annabi, C., Fourcade, F., Soutrel, I., Geneste, F., Floner, D., Bellakhal, N., & Amrane, A. (2016). Degradation of enoxacin antibiotic by the electro-Fenton process: optimization, biodegradability improvement and degradation mechanism. *Journal of environmental management*, *165*, 96-105.
39. Tazwar, G., & Devra, V. (2020). Soluble colloidal manganese dioxide: Formation, characterization and application in oxidative kinetic study of ciprofloxacin. *Bulletin of Chemical Reaction Engineering & Catalysis*, *15*(1), 74-83.
40. Tazwar, G., Jain, A., Mittal, N., & Devra, V. (2017). Oxidation of ciprofloxacin by hexacyanoferrate (III) in the presence of Cu (II) as a catalyst: A kinetic study. *International Journal of Chemical Kinetics*, *49*(7), 534-542.
41. Yan, Y., Wei, Z., Duan, X., Long, M., Spinney, R., Dionysiou, D. D., ... & Alvarez, P. J. (2023). Merits and limitations of radical vs. nonradical pathways in persulfate-based advanced oxidation processes. *Environmental Science & Technology*, *57*(33), 12153-12179.
42. Ushani, U., Lu, X., Wang, J., Zhang, Z., Dai, J., Tan, Y., ... & Zhen, G. (2020). Sulfate radicals-based advanced oxidation technology in various environmental remediation: A state-of-the–art review. *Chemical Engineering Journal*, *402*, 126232.

43. Tazwar, G., Jain, A., & Devra, V. (2017). Oxidative degradation of levofloxacin by water-soluble manganese dioxide in aqueous acidic medium: a kinetic study. *Chemical Papers*, *71*(9), 1749-1758.
44. Tazwar, G., & Devra, V. (2019). Kinetic study of uncatalyzed and Cu (II) catalyzed oxidation of ofloxacin in aqueous alkaline medium and their mechanistic aspects. *SN Applied Sciences*, *1*, 1-12.
45. Derco, J., Gotvajn, A. Z., CizmarovaO., Dudas, J., Sumegova, L., &Simovicova, K. (2021). Removal of micropollutants by ozone-based processes. *Processes*, *9*(6), 1013.
46. Wei, C., Zhang, F., Hu, Y., Feng, C., & Wu, H. (2017). Ozonation in water treatment: the generation, basic properties of ozone and its practical application. *Reviews in Chemical Engineering*, *33*(1), 49-89.
47. Oller, I., Polo-López, I., Miralles-Cuevas, S., Fernández-Ibáñez, P., &Malato, S. (2016). Advanced technologies for emerging contaminants removal in urban wastewater. *Advanced Treatment Technologies for Urban Wastewater Reuse*, 145-169.
48. Sui, M., Xing, S., Sheng, L., Huang, S., & Guo, H. (2012). Heterogeneous catalytic ozonation of ciprofloxacin in water with carbon nanotube supported manganese oxides as catalyst. *Journal of hazardous materials*, *227*, 227-236.
49. Tian, Z. R., Tong, W., Wang, J. Y., Duan, N. G., Krishnan, V. V., & Suib, S. L. (1997). Manganese oxide mesoporous structures: mixed-valent semiconducting catalysts. *Science*, *276*(5314), 926-930.
50. Sönmez, G., Bahadır, T., & Işık, M. (2022). Removal of selected pharmaceuticals from tap water by the Fenton process. *International Journal of Environmental Analytical Chemistry*, *102*(16), 3855-3867.
51. Wang, J., & Wang, S. (2016). Removal of pharmaceuticals and personal care products (PPCPs) from wastewater: a review. *Journal of environmental management*, *182*, 620-640.
52. Liou, M. J., Lu, M. C., & Chen, J. N. (2004). Oxidation of TNT by photo- Fenton process. *Chemosphere*, *57*(9), 1107-1114.
53. Tavasol, F., Tabatabaie, T., Ramavandi, B., & Amiri, F. (2020). Design a new photocatalyst of sea sediment/titanate to remove cephalexin antibiotic from aqueous media in the presence of sonication/ultraviolet/hydrogen peroxide: Pathway and mechanism for degradation. *Ultrasonics sonochemistry*, *65*, 105062.

54. Ji, Y., Ferronato, C., Salvador, A., Yang, X., &Chovelon, J. M. (2014). Degradation of ciprofloxacin and sulfamethoxazole by ferrous-activated persulfate: implications for remediation of groundwater contaminated by antibiotics. *Science of the total environment*, *472*, 800-808.

55. Matzek, L. W., & Carter, K. E. (2016). Activated persulfate for organic chemical degradation: a review. *Chemosphere*, *151*, 178-188.

56. Guo, H., Gao, N., Yang, Y., & Zhang, Y. (2016). Kinetics and transformation pathways on oxidation of fluoroquinolones with thermally activated persulfate. *Chemical Engineering Journal*, *292*, 82-91.

57. Pirsaheb, M., Hossaini, H., &Janjani, H. (2020). Reclamation of hospital secondary treatment effluent by sulfate radicals based–advanced oxidation processes (SR-AOPs) for removal of antibiotics. *Microchemical Journal*, *153*, 104430.

58. Feng, M., Qu, R., Zhang, X., Sun, P., Sui, Y., Wang, L., & Wang, Z. (2015). Degradation of flumequine in aqueous solution by persulfate activated with common methods and polyhydroquinone-coated magnetite/multi-walled carbon nanotubes catalysts. *Water Research*, *85*, 1-10.

59. Sturini, M., Speltini, A., Maraschi, F., Profumo, A., Pretali, L., Fasani, E., & Albini, A. (2010). Photochemical degradation of marbofloxacin and enrofloxacin in natural waters. *Environmental science & technology*, *44*(12), 4564-4569.

60. Lourenço, A. A., Silva, V. D., da Silva, R. B., Silva, U. C., Chesman, C., Salvador, C., ... & da Silva, F. F. (2021). Metal-organic frameworks as template for synthesis of Mn3+/Mn4+ mixed valence manganese cobaltites electrocatalysts for oxygen evolution reaction. *Journal of Colloid and Interface Science*, *582*, 124-136.

61. Imran, M., Afzal, A. M., Iqbal, M. W., Hegazy, H. H., Iqbal, M. Z., Mumtaz, S., & Qureshi, R. (2023). Manganese (Sulfide/Oxide) based electrode materials advancement in supercapattery devices. *Materials Science in Semiconductor Processing*, *158*, 107366.

62. Baral, A., Satish, L., Zhang, G., Ju, S., & Ghosh, M. K. (2021). A review of recent progress on nano MnO 2: synthesis, surface modification and applications. *Journal of Inorganic and Organometallic Polymers and Materials*, *31*, 899-922.

63. Perez-Benito, J. F., Arias, C., & Amat, E. (1996). A kinetic study of the reduction of colloidal manganese dioxide by oxalic acid. *Journal of Colloid and Interface Science*, *177*(2), 288-297.

63. Tazwar, G., Jain, A., & Devra, V. (2017). Oxidative degradation of levofloxacin by water-soluble manganese dioxide in aqueous acidic medium: a kinetic study. *Chemical Papers*, *71*(9), 1749-1758.

64. Šumichrast, R., & Holba, V. (1993). Kinetic study of the oxidation of alcohols with quaternary ammonium permanganates. *Collection of Czechoslovak chemical communications*, *58*(8), 1777-1781.

65. Luo, H., Zeng, Y., He, D., & Pan, X. (2021). Application of iron-based materials in heterogeneous advanced oxidation processes for wastewater treatment: A review. *Chemical Engineering Journal*, *407*, 127191.

66. Sharma, V. K., Chen, L., & Zboril, R. (2016). Review on high valent FeVI (ferrate): a sustainable green oxidant in organic chemistry and transformation of pharmaceuticals. *ACS Sustainable Chemistry & Engineering*, *4*(1), 18-34.

67. Precious Sibiya, N., Rathilal, S., &Kweinor Tetteh, E. (2021). Coagulation treatment of wastewater: kinetics and natural coagulant evaluation. *Molecules*, *26*(3), 698.

68. Day, M. C., &Selbin, J. (1962). *Theoretical inorganic chemistry*. Chapman and Hall.

69. Shimpi, R., & Mahavidyalaya, B. B. (2019). A review of kinetics of oxidation of organic compounds by hexacyanoferrate (III). *Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences, Original Review Article*.

70. Farokhi, S. A., &Nandibewoor, S. T. (2003). Kinetic, mechanistic and spectral studies for the oxidation of sulfanilic acid by alkaline hexacyanoferrate (III). *Tetrahedron*, *59*(38), 7595-7602.

71. Jose, T. P., Angadi, M. A., Salunke, M. S., &Tuwar, S. M. (2008). Oxidative study of gabapentin by alkaline hexacyanoferrate (III) in room temperature in presence of catalytic amount of Ru (III)–a mechanistic approach. *Journal of Molecular Structure*, *892*(1-3), 121-124.

72. Yu, D., He, J., Wang, Z., Pang, H., Li, L., Zheng, Y., ... & Zhang, J. (2021). Mineralization of norfloxacin in a CoFe–LDH/CF cathode-based heterogeneous electro-fenton system: preparation parameter optimization of the cathode and conversion mechanisms of H2O2 to· OH. *Chemical Engineering Journal*, *417*, 129240.

73. Devra, V., Sharma, M., Al-Subu, M., & Salim, R. (2019). Kinetics and Mechanistic study of Cefuroxime by Hexacyanoferrate (III) in Alkaline Medium. *Accent Journal of Economics ,Ecology and Engineering ,4*(4), 2019.

74. Hu, Y., Li, G., & Zhang, Z. (2011). A flow injection chemiluminescence method for the determination of lincomycin in serum using a diperiodato-cuprate (III)–luminol system. *Luminescence*, *26*(5), 313-318.

75. Bagoji, A. M., Magdum, P. A., &Nandibewoor, S. T. (2016). Oxidation of acebutolol by copper (III) periodate complex in aqueous alkaline medium: a kinetic and mechanistic approach. *Journal of Solution Chemistry*, *45*, 1715-1728.

76. Bagwan, U. R., Harihar, A. L., Lamani, S. D., Shaikh, I. N., &Teradale, A. B. (2017).Research Journal of Pharmaceutical, Biological and Chemical Sciences.8,1015-1025.

77. Angadi, M. A., &Tuwar, S. M. (2010). Oxidation of fursemide by diperiodatocuprate (III) in aqueous alkaline medium—a kinetic study. *Journal of solution chemistry*, *39*, 165-177.

78. Hu, Y., Li, G., & Zhang, Z. (2011). A flow injection chemiluminescence method for the determination of lincomycin in serum using a diperiodato-cuprate (III)–luminol system. *Luminescence*, *26*(5), 313-318.

79. Kulkarni, S. D., &Nandibewoor, S. T. (2006). A kinetic and mechanistic study on oxidation of Isoniazid drug by alkaline diperiodatocuprate (III)–A free radical intervention. *Transition metal chemistry*, *31*(8), 1034-1039.

80. Reddy, K. B., Sethuram, B., & Rao, T. N. (1984). KINETICS OF OXIDATION OF BENZALDEHYDES BY COPPER (III) IN TERT-BUTANOL- WATER MEDIUM. *INDIAN JOURNAL OF CHEMISTRY SECTION A- INORGANIC BIO-INORGANIC PHYSICAL THEORETICAL & ANALYTICAL CHEMISTRY*, *23*(7), 593-595.

81. Levason, W., & Spicer, M. D. (1987). The chemistry of copper and silver in their higher oxidation states. *Coordination chemistry reviews*, *76*, 45-120.

82. Chowdhury, B., Mondal, M. H., Barman, M. K., & Saha, B. (2019). A study on the synthesis of alkaline copper (III)-periodate (DPC) complex with an overview of its redox behavior in aqueous micellar media. *Research on Chemical Intermediates*, *45*, 789-800. 83. Tazwar,G.,Sharma, M.,(2018) . Kinetics and Mechanism of Electron Transfer Reaction.....*World Journal of Molecular Biology and Biochemistry 3(2) 37-45.*