

METALS IN THE SERVICE OF MAN

An Inaugural lecture Delivered at the University of Ife on April 17, 1984

by

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I will begin this inaugural lecture with a testimony. In 1960, I was a foundation lower sixth former at Christ's School Ado-Ekiti. During that year, I read a penguin book entitled Metals in the Service of Man. There, I read about the discovery of metals, the stone age, bronze age and iron age.

There also, I read about the discovery of metals- gold and silver, and the coinage metals- Cu, Zn, Sn etc. At that time, I was not aware that I was preparing for an inaugural lecture that I would deliver twenty-four years later, because then I knew very little of chemistry and was not sure that I would even receive a degree in chemistry. Again, when I joined the Department of Chemistry, University of Ife, on October 1, 1970, I unconsciously stumbled on the study of the behavior of metal ions in solution. I had previously however undergone a successful doctoral degree training in gas-phase competitive alkali-metal flame reactions at the University of Ibadan. When recently I was requested to give this inaugural lecture, the topic that came to my mind immediately was the title of that penguin book I read in 1960. So, the title of my inaugural lecture, "Metals in the Service of Man" being delivered today, emerged from a chain of activities that started in 1960.

In the beginning, God created heaven and earth, then light, sun, moon and stars. The earth contained among many other things, three commodities that are essential to human survival - soil, water and air. After the creation of the earth, with these essential commodities, God created animals, made man specially in his own image and gave him dominion over the earth and all the other creatures. God was happy that everything he made was good. Then man and his wife sinned in the precious garden by eating the forbidden fruit. They were driven out of the garden and the man was made a tiller of the ground. Carved stones were used to till the ground and there is abundant evidence today that these stones contain metals. Cain, one of the two issues of the first man was a farmer and he used metal-containing implements to till the ground.

In the most popular Christian literature text-book - the Bible - stones, gold and silver are mentioned very frequently to serve several purposes. This implies that in the beginning God created metals for man's use. The love of man for gold and silver was first displayed by Achan's stealing of two hundred shekels of silver and fifty shekels of gold, on the fall of Jericho to Israel, Achan and his entire family were stoned to death.

When the queen of sheba heard of the fame and wisdom of Solomon, she visited him in Jerusalem and gave him abundant gifts of precious stones and gold. These amounted to bribes, because the queen presumably wanted to learn from the wise king and also extract information on matters of security of state from him. Solomon was very much richer than the queen because he gave her whatsoever she asked for, besides all she originally brought to him. Solomon had a throne of ivory overlaid with pure gold and there were six steps made of gold to the golden throne and also a footstool of gold. All the drinking vessels in the house of Solomon were made of gold. Solomon built a temple for the Lord

and overlaid every little thing in it - walls, beams, chairs, floors, etc - with gold and made an altar of brass.

When Jesus our Lord, was born, the wisemen from the east visited him and gave him gold, frankincense and myrrh as gifts. As Jesus grew up and started his ministry, the pharisees were not pleased. They sought, on several occasions, ways to catch him and put him to death, but Jesus always defeated them. On one occasion, they asked from him whether it was lawful to give tribute (tax) to ceasar (Roman Emperor then) or not. If Jesus answered that it was unlawful to give tribute to ceasar, it would have been treason, punishable possibly by death. Jesus asked them to show him a coin. that coin was made of a metal. When the coin was shown to Jesus, he asked from them the emblem the coin bore. They said "Ceasar's". He then cleverly asked them to give unto Ceasar what is Ceasar's and unto God, what is God's.

The point being made here is that from time immemorial metals have been used for making money. Judas Iscariot, who later betrayed Jesus, got a bribe of thirty pieces of silver. Of course, the bribe was useless to Judas later and he got condemned by it till today and probably for ever. The soldiers that followed Judas in the betrayal, to arrest Jesus, came with swords and staves made of metals. Up till today, most weapons of war are made of metals. The love of money is the root of all evil in any society and this is certainly true of our present-day society.

I have used the above paragraphs to outline some of the early uses of metals, mainly based on their physical properties of high tensile strength and shining appearance. The Christian text-book, the Bible, has been used. I owe no apology, in this connection, to all who do not have Jesus Christ as their Lord and Saviour; and who worship stones and idols made of metals and wood. The reasons why I do not owe these people any apology for using the Bible first are clear:

- (i) I know no other God, trust in no other God and take instructions from no other God other than the father of our Lord Jesus Christ mentioned in that Bible;
- (ii) As for me and my house we will serve the Lord. May that God bless you all.

About 80% of the elements on earth are metals. History reveals that before man discovered metals in their pure states, stones were used as tools. Later developments that resulted in the extraction of the pure metals from rocks suggest that the original stones used as tools contained metals. The bronze age marked the use of the alloy of copper and tin as knives and axes. Iron age followed and it became clear that iron, particularly as steel, was more useful than copper as a tool, because it (steel) is harder, though more expensive to produce (because it requires a higher temperature to extract).

Application based on Physical Properties

Many of the Physical properties of metals find applications in everyday life and industry. As a result of their structure, they are good conductors of electricity and hence their use in the construction of various electrical equipments - stereo sets, television, scientific apparatus, and the transmission of electrical power from one place to another. Silver is about the best conductor of electricity, but it is very expensive and cheaper metals like copper and aluminium wires are preferred. Metals are ductile and can therefore be drawn into wire and used to carry current over long distances.

Aluminium which is stronger and lighter than copper is used for over-head power cables. Metals are good conductors of heat and therefore copper, iron and aluminum for instance are used in making cooking pots, pans and boilers in industry.

They are malleable and therefore easily hammered into sheets for coverings and roofs.

They have high melting points and high tensile strength and are therefore used for making numerous tools and are employed in various construction work - bridges, frames, chairs, solid equipments etc. They possess shining surfaces and can therefore be polished to reflect heat and light, and are used in jewelry work. On December 19, 1983, I read in the dailies of Nigeria that the Jules Rimet World Cup (won thrice by Brazil and therefore kept for good) was stolen in Rio de Janeiro. A search was conducted by Brazil and in the last week-end of January, 1984 it was reportedly found with three men (one of them, a former employee of the Brazillian Football Association). It was already smelted by these jewellers and it contained about 1.8 kg of gold.

Another gold world cup (a replica of the stolen one) was presented to the Brazillian national team as a replacement only last month....Silver mirrors are used for dressing and also in solar furnaces.

Metals can be mixed in various proportions to produce alloys. These alloys are often more useful than any of the original component metals. Bronze for instance (90% Cu + 10%Sn) is used in making statues. Brass (Cu and Zn) is used for decorative ornaments, coins are now made from alloys of silver, copper, Zinc etc., ships propellers are made from bronze containing magnesium.

Applications based on Chemical Properties

The ability of metals to lose electrons and become positively charged both in the gas-phase and in solution, finds very many useful applications in living things (plants and animals) and industry. The presence of iron, magnesium, cobalt and copper ions as integral components of haemoglobin, chlorophyll, Vitamin B12 and some plant proteins respectively, is well-known. Their roles in the various biological activities occurring in these plants and animals are very crucial to the existence of these living things. Iron in the haemoglobin of the blood for instance is responsible for oxygen transport in the body. This is to provide a reliable up-take of oxygen in the lungs, together with efficient unloading of oxygen in the parts of the body it is most needed for various metabolic processes. Inability of the haemoglobin to perform these functions efficiently, as a result of many factors (environment surrounding the iron in the haem, such as amino-acid sequence, being one) often leads to discomfort for the patient or even death in some cases. Arrays of chlorophyll molecules in photosynthetic bacteria or plant chloroplasts serve to trap radiant energy as a driving force for the chemical reduction of carbon dioxide in photosynthesis. Mg in the oxidation state +2 lies in the centre of the chlorin ring of the chlorophyll molecule. Also Co in some co-enzymes and enzymes (collectively called cobalamins) catalyse C-atom and H-atom transfer reactions. The blue copper proteins from plants, algae and bacteria contain Cu in an unusual co-ordination site. They transfer electrons at high potential (+180 to 400m V) using the Cu^I/Cu^{II} couple. In plastocyanin and azurin, Cu is tetrahedrally co-ordinated to the organic moiety. Similarly, there are several metalloenzymes such as the iron-containing xanthine oxidase in which the presence of the appropriate metal ion is essential for biological activity. In 1926, the American physicians Minot and Murphy discovered that patients suffering pernicious anaemia, a previously fatal disease, responded well, when fed with a diet containing raw

liver. The long search for the 'antipericious anaemia factor' led to the isolation in 1946 of the red crystalline compound, cyanocobalamin - a form of vitamin B₁₂. The structure of the compound as an hexa-co-ordinate complex of cobalt (III) was elucidated using classical chemical techniques and x-ray crystallography. Familiarity with the few metal ions mentioned above, in which the metal is not readily separable from the organic moiety, tends to divert attention from the free metal ions that are also present in biological systems and from the dynamic equilibria involving them.

Many enzymic reactions for instance are directly metal - ion dependent. Examples include Mg, Ca, and Mn-activated phosphoryl transferases, Cu and Zn. In addition, there may be variable amounts of non-essential or even potentially toxic cations, notably Pb, Hg, and Cd. Complex forming species like amino acids, peptides, proteins, carboxylic acids, organic phosphates, nucleic acids together with inorganic ligands such as Cl⁻, HCO₃⁻ and PO₄⁻⁻⁻ also exist in biological materials and by complexing with the toxic metal ions, their activities are impaired.

In the mammalian body, the total ligand concentration greatly exceeds the metal ion content, so that the living tissues and fluids have been likened to areas in which the various complexing species compete for the different kinds of metal ions that are present. Even Na and K which are usually thought of as simply maintaining the ionic strength of solutions appear to be able to form complexes, so as to maintain a ratio of [Na⁺]/[K⁺] against a concentration gradient in the operation of the 'sodium pump' in the red blood cells.

It is impossible to list and outline all the industrial applications of metals and their derivatives in a single lecture such as this. The best I will be able to do in this lecture will be to outline as many as possible and assure this audience that there are many others since there are about eighty-four metals in the periodic table of elements. Many metal carbo-xylates and complexes are employed in the manufacture of paints, vanish, printing ink, linoneum, notably those of Ti, Co, Mn, Pb, Zn, Ca and Zr. Calcium in form of calcium carbonate is used extensively in the cement industry. Many of these are also used in the manufacture of greases. Ti complexes are particularly useful in the processing of paper, ceramics and plastics, Pb, Ca and Zn compounds are useful in the processing of rubber. Zr and Mg compounds are employed in cosmetics industry - powders and body creams. Sodium and potassium salts of fatty acids are employed in the manufacture of soaps by a process termed saponification and employing 'Raney' nickel as catalyst. Some optically active Pt(II) complexes are now being employed clinically on experimental bases in the treatment of cancer, and if this succeeds in the long run, it would be a major break-through in Science. Ru(II) complexes are potential mediators in photodecomposition of water by visible light and this process seems to have the capability of storing solar energy. Some metal soaps, notably those of Zn, Cu and Hg are fungicidal and are employed as such in the manufacture of fungicides. Monodispersed colloids of hydrous metal oxides have begun to find roles in solving industrial problems as well as extending fundamental knowledge of surfaces and colloidal state.

Monodispersed colloids which have uniform particle shape, size and composition - have long been known for a few elements, water-insoluble salts and polymer latexes. But only in the past few years have a number of general reproducible methods been developed to make monodispersed colloidal metal oxides. Following this, research workers at many companies and universities around the world have sought ways to apply these materials

to studies of corrosion, catalysis, pigments, magnetic tapes and memory devices. Iron, Nickel, cobalt and ruthenium derivatives are particularly useful in this area. Uranium is used as a fuel in nuclear power generation and technology.

Many industrial processes that lead to the production of highly indispensable materials employ metal catalysts. These catalysts, though required in small quantities, are quite specific and effective in their roles in the industrial processes.

They are either the finely divided metals or their complexes. Haber's process for the manufacture of ammonia (an important chemical for the manufacture of fertilisers, smelling salts, glass etc.) employ finely divide iron, with some traces of Mo, Ca.



The important commercial products HNO₃ and H₂SO₄ are made using Pt catalyst, the contact process specifically employs MgSO₄ crystals to aid the Pt catalyst. The 'hardening of oils in the manufacture of Margarine(butter) uses Ni catalyst. Crude oil is refined commercially by employing Ni catalyst. It is however discovered now that vanadium (another strange metal) is contained in considerable quantities in crude oil and this 'poisons the catalyst. Venezuela crude oil which Nigeria imports in large quantities for refining contains high levels of vanadium, and I believe that a stage will have to be reached where means of removing the vanadium prior to refining the crude oil would have to be devised. The catalytic decomposition of ethanol using Aluminium oxide and copper leads to the production of two very important commercial chemicals ethylene and acetaldehyde respectively. Palladium (II) catalysed oxidation of hydrocarbons to yield other valuable synthetic intermediates is now being very vigorously pursued in industry. Many polymerisation reactions leading to the production of plastics, terylenes etc. employ metal catalysts and I believe that the first ever petrochemical industry in Nigeria, now being established in Kaduna will not be an exemption.

The specificity of the action of these catalysts implies chemical union between the catalyst and the reactants at a certain stage of the process- chemisorption. The rationale for specificity can also be found in the positions of the elements in the periodic table, molecular structure data (particularly inter-atomic distances) and the different energetics of different reactions.

Metal ions in Solution

The mechanism and precise roles of metals and their complexes in living and non-living things have been subjects of active study, for sometime now. These are still far from

being understood Some of the parameters that have slowed down progress in this area are:

- (i) The fluid surrounding the metal ion and its effect on the mechanism of the reaction of the metal ion.
- (ii) In many cases, denaturation, changing structure etc. occur in unfavourable conditions during handling--acidic and alkaline media, temperature etc. Under these circumstances, results can be misleading.

It is therefore customary practice in the first instance nowadays to mimic the complicated substitution and redox processes occurring in these living and non-living systems by studying substitution and redox processes in simple metal ion systems. In fact, Henry Taube Of Stanford University U.S.A. (until 1983), a 1983 Noble Prize winner worked extensively on the substitution and redox processes of simple metal ion systems. This I have in the last fourteen years of my service in this University attempted to do.

I have, during the period, investigated the substitution and redox behaviour of Mo (VI), Mo(V), Mo(IV), Fe(II), Fe(III), Co(II), Ru(III), Ti(III), U(III) and Ru(II). Some of my findings are as follows:

- (1) Mo in the +6 state is essentially, monomeric and unprotonated in alkaline solution. In acidic solution, it is extensively protonated and aggregation leading to the formation of polymeric species tends to occur.
- (2) Mo in the +5 state is dimeric in acidic and alkaline media. In a redox reaction with $\text{Fe}(\text{Phen})_3^{3+}$, one of the dimeric Mo(v) species is oxidised first by outersphere mechanism. There is no oxidation of Mo(v) by the strong two-electron oxidant hexachloroplatinate ion $[\text{PtCl}_6]^{2-}$.
- (3) Mo in the +4 state is hydrolysed in acidic solution and tends to complex easily with thiocyanate ion by an associative mechanism. The measured negative entropy of activation supports this view.
- (4) Fe in the +2 state reduces Cl_2 and Br_2 by a series of univalent changes and the reaction is unaffected by added anions. Fe (II) can not reduce I_2 and rather Fe in the +3 state oxidises I ions to I_2 . The reaction is anion-catalysed and a free-radical mechanism is suggested.
- (5) Ti in the +3 state is extensively hydrolysed in acidic solution and the hydroxo species so formed reacts faster than the aquo species. Ti^{3+} is very labile and engages in inner-sphere redox path-ways with Co(III) and Ru(III) complexes possessing efficient bridging ligands such as F; N_3 , Scn ; NCS ; carboxylato(oxalate, acetate, etc.) species. Some of our observations also seem pertinent to the mechanism of the technologically important phenomenon of stress corrosion of Ti involves formation of Ti (IV) oxide on the metal surface. When Ti is in contact with water, the tendency for stress corrosion cracking is increased by the presence of Cl^- ion. These facts have usually been interpreted by

mechanisms involving chloro complexes of Ti(III). Our experience has however shown that Ti^{3+} has a low affinity for Cl^- , but that Cl^- has a strong effect on the rate of polymerisation (and eventual precipitation) of Ti(IV). It therefore seems to suggest that the dramatic influence of halide ions (in sea water, aeroplanes fly over the sea) on the stress corrosion cracking of Ti is more due to their effect on Ti(IV) aggregation than on any complex formation involving Ti(III).

(6) Generally, Co(III) is more of an inner-sphere oxidant than Ru(III), as a result of the electronic configuration differences between them requiring different energetics and hence mechanism. Ru(III) complexes that react by outer-sphere mechanism react much faster than the corresponding Co(III) complexes for a given reductant.

(7) Uranium in the +3 state is a very labile and powerful reductant. It also reduces most oxidants possessing suitable efficient bridging ligands by inner-sphere mechanism.

(8) Hexaammineruthenium (II) ion is a typical outer-sphere reductant for all oxidants by the virtue of its substitution-inertness and lack of active co-ordination site. Aquapentammineruthenium (II), though substantially more substitution-labile than hexaammineruthenium (II) by virtue of the possession of a water molecule in the sixth co-ordination position (replacing an ammonia molecule in $Ru(NH_3)_6^{2+}$), reduces most oxidants by outer-sphere mechanism too. It could react by inner-sphere mechanism.

Recently, for the first time ever, we discovered in our laboratory here that it reacts inner-sphere with fluoro- and chloropentaammine cobalt(III) complexes, as a result

of the 'hard' nature of these ligands. I must mention that in arriving at these conclusions with respect to these metal ions in solution, the two existing mechanisms in each case,

of substitution (SN_1 and SN_2) and redox (outer-sphere and inner-sphere) processes

have been weighed - one against the other and the logical criteria used in distinguishing

one from the other employed. My research group in Ife is still actively pursuing the

Ru(II) studies for a number of reasons:

(i) Its substitution and redox properties are still insufficiently known.

(ii) Ru is in the Pt group of metals and as outlined earlier, some platinum complexes

are now being clinically used on experimental basis in the treatment of cancer.

(iii) As earlier mentioned also, Ru(II) as a result of its characteristic electronic configuration, is a potential solar energy agent. Everyone knows that today alternative sources of energy are being sought all over the world!

However, at this juncture in connection with what has been done so far in Ife, I like to inform the Vice-Chancellor that in Africa south of the Sahara, the Chemistry Departments of the Universities of Ife and Ahmadu Bello Zaria, are the only two places where the substitution and redox behaviour of metal ions in solution are being actively investigated. The bulk of the data and information from this continent in this field that have appeared in learned journals all over the world in the last fourteen years of my endeavour have come from Ife. With the crossing over from ABU to the University of Lagos by Professor Ade Adegite, it is hoped that very soon Lagos may join us.

Nigeria's Metal Resources

Nigeria is fairly rich in metal resources. Olade (1976) has tried to divide the country into five metallogenic provinces, namely:

- (1) South western part of central Nigeria (Itakpe hill near Okene) which has appreciable and industrial quantities of iron ore.
- (2) Jos plateau which has some tin ore as columbite and cassiterite.
- (3) Some restricted localities in parts of the Benue trough which have some lead and zinc.
- (4) The Sokoto-Kaduna greenstone belt which has mined quantities of gold. Ilesha schist belt in Oyo State has some deposits of gold too.
- (5) Some restricted parts of the Sokoto greenstone belt, and the upper Benue which have quantities of uranium. Of the five metallic minerals mentioned above, iron-ore, tin and gold occur in very large commercial quantities in their respective 'provinces'.

Unfortunately, these have not been tapped effectively to enable them play any significant role in the economy of the country. Iron-ore at Itakpe near Okene for instance is yet to be mined for smelting and for industrial consumption. It is to provide the main source of raw material for the Ajaokuta iron and steel plant. The plant, when completed should not (I hope) be restricted to the production of iron rods and steel pipes: the manufacture of machinery spare parts of both light and heavy industrial relevance should be a major venture.

As we all know, steel industry is the back-bone of technological take-off in any country. Nigeria is lucky to have an estimated 600×10^6 tons of iron ore that is particularly rich (35% - 60%) in Fe content. A similar deposit conservatively estimates as about 206×10^6 tons of iron-ore exists in lateritic Agbaja plateau.

The mining of tin was commenced in the Jos plateau area in 1904 and since then all of the very large quantities, in the order of over 10,000 tons had been exported annually to the UK and the USA system could be devised like the case of iron, in which the mined metal is refined locally and used in the country. One of the sources of drainage in our foreign exchange is importing most of our needed finished materials whereas most of the initial raw materials had been exported from the country at relatively low prices. The mining of gold started in North-western Nigeria in 1932, reached its peak in 1935 when about 38,216 ounces were mined annually. By 1940, gold mining had declined seriously and there is no production at all these days. The Ilesha gold deposit was first reported in 1940. Apart from the deposit found in Iperindo area, other deposits proved too small in quantity to interest large scale mining. However, small scale mining still goes on in Iperindo today, production standing at about 2,000 ounces per annum.

Large deposits of limestone (an ore of calcium) abound in some parts of Nigeria namely: Ogun, Lagos and Anambra States. Marble, (another ore of calcium) is found in commercial quantities in Oyo State (in Igbetti). It is a very precious material (we all know) in the making of statues, tiles, plates etc.

Conclusions and Recommendations

- (1) Metals will continue to be indispensable tools for making useful materials for household and industry.
 - (2) New uses are going to be discovered for them through research efforts in industry, medicine, agriculture and other areas of human endeavour.
 - (3) To achieve objective (2) above, in Nigeria in particular, government must support research efforts in the universities and research institutes, and also encourage researches that will seek to discover new use for metals.
 - (4) Government should seek information on the known metal resources in this country and apply this in tapping the resources. I spent the 1978/79 academic year in Texas A & M University employing activation analysis technique in the determination of carbon in steels. This was a sort of quality control study. Government should fund the centres for energy and research in universities adequately, so that when facilities are available, the training received by various personnel so far can be put to use. Government and industries should make use of these centres then in ensuring quality control of our products and food, rather than consulting and using foreign experts that are only interested in draining our foreign exchange assets.
 - (5) The unexplored metal resources should be explored and this may be a way of reviving the economy. When oil was discovered in Oloibiri wells in Nigeria some years ago, it was not immediately known that oil would be Nigeria's main source of income for sometime to come!
 - (6) The Ajaokuta steel project should be seriously and vigorously pursued and its objectives concertedly diversified.
This will enhance technological take-off in Nigeria. It will be recalled that the seven federal universities recently established were christened Federal Universities of Technology. They should indeed be Federal Universities of Technology for the sake of technological take-off.
- I do not believe that exploration of Nigeria's metal deposits is exhaustive enough yet. Exploration should continue and those already explored should be tapped profitably. The industrial applications of these metals had earlier been out-lined. These with respect to Nigeria cannot be over-emphasised. Oil as a non-lasting asset may not continue to

support our dwindling economy and for those forth-coming 'rainy' days, alternative resources of income should be sought now.

The exploration and tapping of our metal resources should be one of such alternatives. For our part in Ife, the properties, technology and importance of metals have been emphasised in our various chemistry courses and researches. These efforts will continue and improvements will be made, until the government will be sufficiently responsive as to apply the available information.

Mr. Vice-Chancellor, before I hand over a copy of this inaugural lecture to you officially, I will like to acknowledge my fruitful association with the following people and body:

(i) Professor Ade Adegite of the Department of Chemistry, University of Lagos. After training as a gas kineticist at the University of Ibadan on 'competitive Alkali-Metal Flame Reactions', I turned a solution kineticist in Ife and started with him on the behaviour of metal ions in solution in 1970 - 1975 spent on this research with him before he left for Ahmadu Bello University, was very fruitful.

(ii) Dr. Olusegun Olubuyide, Senior Lecturer, Department of Chemistry, University of Ife. I have worked on this project with him since 1975 and found him very co-operative and excellent.

(iii) Dr. Jide Ige, Senior Lecturer, Department of Chemistry, University of Ife. He was also very co-operative and has since 1979 started work in another related field - miscellar catalysis.

(iv) The University of Ife Research Grants Committee that has provided adequate funds for equipments used in this study.

Mr. Vice-Chancellor, distinguished colleagues, thank you all for listening.

REFERENCES

1. The Bible, Chapters in Genesis, Joshua, St. Luke's gospel etc
2. Metals and Alloys, Edited by Rod Sayers and Published by Addison-Wesley Publishers Ltd
3. 'Chemical and Engineering News', 12, (1977), 9, (1978).
4. Metals in Biochemistry by P.M. Harrison and R.J. Hoare (Chapman and Hall publishers, 1980).
5. J. Folorunso Ojo, R.S. Taylor and A.G. Sykes (1975). The Kinetics of the rapid monomer-dimer equilibration of Molybdenum (VI) in aqueous Perchlorate solution J. Chem. Soc. (Dalton), 500-505
6. R.K. Wharton, J.F. Ojo and A.G. Sykes (1975). 'The kinetics of the Oxidation of (MoV)₂ EDTA by Hexachloroiridate and Trisphenanthroline Iron (III) in Perchlorate solution, J. Chem. Soc. (Dalton), 1526-1530
7. J.F. Ojo, Yoichi Sasaki and A.G. Sykes, (1976). The kinetics and equilibrium of the reaction of Mo(V) with thiocyanate ion in perchlorate solution, Inorg. Chem., 15, 1006-1009.

8. A. Adegite and J.F.Ojo (1977). Kinetics and Mechanism of the reduction of thiocyanato-pentaamminecobalt (III) by Titanium (III). *Inorg.Chem.* 16, 477-479.
9. A. Adegite, J.F. Iyun, and J.F.Ojo (1977). Kinetics and Mechanism of the electron-transfer reactions between U(III) and some Ruthenium (III) complexes, *J. Chem., Soc. (Dalton)*, 115-120
10. A. Adegite, H. Egboh, J.F. Ojo (1977). Kinetics and Mechanism of the oxidation of U(III) by aqueous acidic solutions of Iodine and Bromine. *J. Chem.Soc. (Dalton)*. 833-837.
11. A Adegite, M. Dosumu and J.Folorunsho Ojo(1977). Kinetics and Mechanism of the reduction of Azido, thiocyanato-and-thiocyanatopententammine cobalt (III) complexes by Hazaammine Ru(II), tris-(ethylenediammine) Ru(III) and tris-(Bipyridyl) Cr(II) in aqueous solutions *J. Chem. Soc. (Dalton)*, 630-634.
12. Jide Ige, R.Nnadi, J.F.Ojo and O. Olubuyide (1978). Kinetics and Mechanism of the reduction of thiocyanato-isothiocyanato and azidopentaammine cobalt (III) complexes by aquopentaamine-ruthernium(II) in Aqueous solutions *J.Chem.Soc.(Dalton)*,148-151
13. Niyi Akinyugha, jide Ige, J.F. Ojo, O. Olubuyide and R.Simoyi (1978). Kinetics and Mechanisms of the Titanium(III) reduction of $\text{Co}(\text{phen})_3^+$ $\text{Co}(\text{C}_2\text{O}_4)_3^-$ and $\text{Fe}(\text{phen})_3^+$ in aqueous solutions. *Inorg.Chem.*, 17, 218-221.
14. A.Adegite, Joseph E. Earley and J.Folorunsho Ojo (1979). Inner-sphere redox reactions between Titanium (III) and Ruthernium (III). *Inorg.Chem.* 18, 1535-1537.
15. Jide Ige, J. Folorunsho Ojo and Olusehun Olubuyide (1979). Kinetics and Mechanism of the oxidation of tris-(1,10-phenanthroline)- Iron(II) by chlorine and bromine and of the reduction of tris- (1,10-phenanthroline)- Iron(III) by Iodide ions. *Can.J.Chem.*57,2065-2070
16. Nike Adewumi, Jide Ige, J.Folorunsho Ojo and Olusegun Olubuyide (1979). Kinetics and Mechanism of the reduction of iodo and bromopentaammine - ruthernium (III) by Ti (III). *Inorg. Chem.*18, 1399-1401.
17. B.D Lass, J.F.Ojo and E.A. Schweikert (1980). Studies in Heavy Ion Activation Analysis IV: Li induced reactions for chemical analysis . *J. Radioanl Chem.* 60, 255-260
18. J.F Ojo, B.D Lass and E.A Schweikert (1980); Studies in Heavy Ion Activation Analysis V Determination of carbon in steels, *J. Radioanal. Chem.* 60, 261-265.

19. Jide Ige, J.Folorunsho Ojo and Olusegun Olubuyide (1981). Kinetics of Outer-sphere electron-transfer in some Ru(II)-Ru(III) reactions. *Inorg.Chem.* 20, 1757-1760.
20. J. Folorunsho Ojo, A.O. Ojudun, and O. Olubuyide, (1982) Kinetics and Mechanisms of the oxidation ruthenium (II) amines by oxalatotetraammine - and binoxalatopentaammine-cobalt (III) complexes. *J.Chem.Soc.(Dalton)*. 659-661.
21. B.D. Lass, N.G. Roche, A.O.Sanni, E.A.Schweikert and J.F.Ojo (1982). Heavy Ion Activation Analysis *J.Radioanal Chem.* 70, 251-272.
22. Gboyega Daramola, J.Folorunsho Ojo, Olusegun Olubuyide and Fidelis Oriaifo (1982). Kinetics and Mechanism of the reduction of the halompentaammine-cobalt (III) complexes by ruthenium (II) species in aqueous solution. *J. Chem. Soc (Dalton)* 2137 - 2140.
23. M.A Olade (1976). *Proc. 12th Annual Conference Nigeria, Min. Geol. and Met. Soc., University of Ibadan*, 45-46.