

# SAVITRIBAI PHULE PUNE UNIVERSITY, PUNE



## SYLLABUS FOR University Department

Master of Science

In

Analytical Chemistry

PART-I and II

(Semester I, II, III and IV-choice based Credit  
system)

w.e.f. July 2018

**Total Number of Credits: 80**

<b>Semester I</b>		
<b>Subject Code</b>	<b>Subject Title</b>	<b>Number of Credits</b>
IC 120	Symmetry, Group Theory and Spectroscopy	4
OC 130	Reaction Mechanisms in Organic Chemistry	4
PC 140	Kinetics and Thermodynamics in Chemistry	4
<b>Elective Courses (any one)</b>		
IC 125	Physical Methods in Inorganic Chemistry and Main Group Chemistry	4
OC 135	Stereochemistry of Organic Reactions	4
PC 145	Chemical Mathematics and Elements of Computer Programming	4
<b>Practicals for First Year</b>		
IC 128	Experiments in Inorganic Chemistry	4
OC 138	Experiments in Organic Chemistry	4
PC 148	Experiments in Physical Chemistry	4
<b>Semester II</b>		
IC 220	Coordination and Bioinorganic Chemistry	4
OC 230	Synthetic Organic Chemistry and Spectroscopy	4
PC 240	Chemical Bonding and Molecular Spectroscopy	4
<b>Total Number of Credits: 40</b>		

<b>Semester III</b>		
<b>Subject Code</b>	<b>Subject Title</b>	<b>Number of Credits</b>
AC 350	Principles of Analytical Chemistry	4
AC 351	Spectroscopic Methods of Analysis	4
<b>Elective Courses (any two)</b>		
AC 355	Introduction to Biomolecules, Biosensors and Analysis of Clinical and Consumer Products	4
AC 356	Modern Analytical Techniques	4
AC 357	Fluorescence Spectroscopy and Its Applications in Chemistry and Biology	4

<b>Practicals for Second Year</b>		
AC 358	Experiments in Analytical Chemistry I	4
AC 359	Experiments in Analytical Chemistry II	4
<b>Semester IV</b>		
AC 450	Polymers and Agrochemicals	4
AC 451	Electroanalytical and Pharmaceutical Analysis	4
<b>Elective Courses (any two)</b>		
AC 455	Industrial Products and Forensic Analysis	4
AC 456	Recent Advances in Analytical Chemistry	4
AC 457	Research Project	4
PC 446	Nanoscience and Nanotechnology	4
<b>Total Number of Credits: 40</b>		

<b>UGC recommended courses (Additional 10 credits)</b>		
<b>Subject Code</b>	<b>Subject Title</b>	<b>Number of Credits</b>
	Cyber Security/Information Security	4
	Skill Based Credits	4
	Human Rights Education	2

<b>Courses which can be opted by students from outside departments:</b>		
<b>Sub. Code</b>	<b>Subject Title</b>	<b>Number of Credits</b>
<b>Elective courses</b>		
AC 356	Semester- III Modern Analytical Techniques	4

### **SEMESTER-I**

## **IC 120: Symmetry, Group Theory and Spectroscopy (4Credits, 60L)**

1. Definitions and theorems of group theory, subgroups, classes. **(4L)**
2. Molecular symmetry and symmetry groups - symmetry elements and operations. Symmetry planes reflections, inversion centre, proper / improper axes and rotations, products of symmetry operations, symmetry point groups, classes of symmetry operations, classification of molecular point groups. **(10L)**
3. Representations of groups. Great orthogonality theorem, character tables, properties of characters of representations. **(8L)**
4. Group theory and quantum mechanics. Wave function as bases for irreducible presentation. **(2L)**
5. Symmetry Adapted Linear Combinations - (SALC) - projection operators and their use to construct SALC. **(6L)**
6. Molecular Orbital Theory. Transformation properties of atomic orbitals, MO's for Sigma bonding in AB<sub>n</sub> molecules, tetrahedral AB<sub>4</sub> case, Hybrid orbital's, MO's for pi bonding in AB<sub>n</sub> molecules. **(10L)**
7. Application of group theory to infrared spectroscopy (Ref.-2, Chapter-8) Introduction, selection rules, polyatomic molecules, possible vibration in a linear Molecule, bending modes, symmetry of vibrations and their IR activity, Group vibration concept and its limitations, IR spectra related to symmetry of some compounds, IR spectra of complex compounds. **(10L)**
8. Raman spectroscopy: Theory of Raman spectroscopy, Instrumentation, Sample handling and Illumination, structural analysis, polarization measurements, quantitative analysis, applications of Raman spectroscopy, other types of Raman spectroscopy, Comparison of Raman and Infrared spectroscopy, Problems (Ref. 7: p.533-549) (Ref.8: p.321-336) **(10L)**

### **Books**

1. Chemical applications and group theory F.A. Cotton, 3rd edition, John Wiley & Sons Asia Pvt. Ltd. (1999).
2. Group theory and its chemical applications: P.K Bhattacharya, 2nd edn, Himalaya pub. India,(1989).
3. Molecular symmetry and group theory -A. Vincent.
4. Symmetry in Chemistry: H.H. Jaffe' and M. Orchin, Dover Publications Inc, New York,(2002).
5. Symmetry in Inorganic Chemistry: J.P Fackler.
6. Principles of Materials Science and Engineering: William F. Smith (1980) (Chapter
7. Instrumental analysis – By Douglas A .Skoog, F. James Holler, Stanley R. Crouch

- (Publisher: Cengage Learning India Pvt. Ltd. New Delhi, 2007)
8. Instrumental method of analysis (7th edition) By- H.H. Willard, L.L. Merritt, Jr. J.A. Dean and F.A. Settle, Jr (Publisher: CBS Publishers and distributors Pvt. Ltd. (Copyright – Wordsworth publishing copy USA .2000).

**OC 130: Stereochemistry and Reaction Mechanism (4 Credits, 60L)**

**Aromatic Electrophilic substitution reactions (15)**

Arenium ion mechanism, orientation and reactivity, energy profile diagram, calculation of partial rate factor, the ortho/ para ratio, Ipso substitution, Orientation in other ring systems such as Naphthalene, Anthracene, six and five membered heterocycles, Diazonium coupling, Vilsmeier reaction, Gattermann–Koch reaction etc. The  $ArSN^1$ , benzyne and  $SNR1$ , mechanisms, reactivity effect of substrate structure, leaving group and attacking nucleophile.

**Kinetic and non-kinetic methods (7)**

Hammond Postulate, Curtin-Hammett Principle, Microscopic Reversibility, Kinetic/Thermodynamic Control, First, Second and Pseudo-First Order Kinetics, trapping of intermediate(s), competition experiments, testing proposed/common intermediate, isolation and identification, characterization using spectral methods of product and intermediate, Cross-over experiments, Structure variation methods, Stereochemical analysis, Isotope labeling, Techniques to study radicals, Transient spectroscopy.

**Hammett equation: (8)**

Substituent constant, reaction constant, +ve, -ve rho values, reaction with small -ve rho values, interpretation of mechanism using rho values, non-linear Hammett plots, kinetic isotopic effect, entropy of activation.

**Molecular rearrangement and reaction intermediate (15)**

Structure, generation and stability of carbenes, nitrenes, carbocations and carbanions intermediates. Rearrangement reactions viz. [Beckmann](#), [Curtius](#), [Hofmann](#), [Lossen](#), [Favorskii](#), [Baeyer-Villiger](#), [Wolff](#), [Claisen](#), [Pummerer](#), [Wagner-Meerwin](#), [Stevens](#), [Dienone-Phenol](#), [Sommelet-Hauser](#), [Benzilic acid](#), [Benzidine](#), [Cope](#), [Fries](#) and [Schmidt reaction](#).

**Basic Concept of Stereochemistry of Organic Compounds (15)**

Origin of Stereochemistry, Optical activity, Chirality and molecular symmetry, axial and central chirality. Projection formulae, Configuration (D/L, d/l, R/S, E/Z configuration in C, N, S, P containing compounds), Allenes, biphenyls and spiranes nomenclature and enantiomerism. Optical activity in biphenyls, spiranes, allenes and helical structures. Enantiomeric and distereomeric relationship, Isomerism in molecules with more than one chiral center, Pseudo-asymmetry, Prochirality. Enantiomeric excess.

**Books/References:**

1. Organic Chemistry by J. Clayden, N. Greeves, S. Warren and P. Wothers (Oxford)
2. Advanced Organic Chemistry by J. March 6<sup>th</sup> Edition
3. Advance Organic Chemistry (part A and B) by A. Carey and R. J. Sundberg
4. Stereochemistry of carbon compound by E. L. Eliel
5. Stereochemistry of organic compound by Nasipuri
6. The Hammett equation, C. D. Johnson, Cambridge University Press (1973)

**PC 140: Kinetics and Thermodynamics in Chemistry (4 credits, 60L)**

**Chemical Kinetics: (2 credits, 30L)**

1. Recapitulation:  
Rate of Reaction, empirical rate law, rate constants, order, molecularity, half-life and life time of reaction. Zeroth first and second, third and half-integral order reactions, methods to determine order of the reactions and temperature dependence of reaction rates (5L)
2. Complex reactions:  
Rate laws for complex reactions, parallel reaction with example of nuclear reactions and fluorescence decay, opposing reactions, rate constants by temperature jump method, consecutive reactions, rate determining step and steady state approximation (7L)
3. Approximate methods to solve complex reactions:  
Steady state and pre-equilibrium approximations, Lindemann mechanism for the unimolecular reaction. Enzyme catalysis – Michaelis Menton Mechanism, Lineweaver and Eadie plots, Chain reactions: free radical polymerization, oscillating reactions (8L)
4. Method of studying fast reactions:  
Flash photolysis, stop flow technique, pump and probe methods (3L)
5. Molecular reaction dynamics:  
Collision theory for bi-molecular reactions (derivation expected), steric factor, Transition state theory, Eyring equation (derivation expected)-thermodynamic aspects –entropy. – enthalpy and free energy of activation, effect of dielectric constant on the ionic reactions, primary and secondary salt effect, effect of pressure on the reaction rates. Linear free energy relationships (7L)

#### **Text Books:**

1. Atkins' Physical Chemistry, Peter Atkins and Julio e Paula ninth edition Oxford University Press 2011.
2. Physical Chemistry, D.A. McQuarrie, Viva Book private limited, 1998.
3. Chemical Kinetics, K. J Laidler, Third edition, Pearson Education Inc., 1987.

#### **Thermodynamics**

**(2 Credits, 30L)**

1. Zeroth, first and second law of thermodynamics, dependence of enthalpy, free energy and entropy on pressure and temperature, free energy change and equilibrium constant, partial molar quantities–Maxwells equations and their applications, Third law of thermodynamics and its applications, residual entropy (13L)
2. Thermodynamics of Real Gases  
Concept of activity, choice of standard states, Methods of determining activity coefficient and activity coefficient, variation of activity and activity coefficient of a gas with pressure and temperature, concept of fugacity, fugacity of a gas in mixture of real gases (7L)
3. Statistical Thermodynamics  
Boltzmann distribution law, partition functions and ensembles, calculation of translational, rotational and vibrational partition functions, statistical thermodynamics and Third Law of Thermodynamics, internal energy, heat capacity, entropy, free energy, equilibrium constants (10L)

#### **Text/Reference Books**

1. Physical Chemistry, P. W. Atkins, Sixth Edition, Oxford University Press, Oxford (1998).
2. Physical Chemistry, T. Engel and P. J. Reid, Benjamin-Cummings (2005).
3. Physical Chemistry, G. M. Barrow, Fifth Edition, Tata McGraw Hill, New Delhi.

### **Elective Courses**

**(any one)**

### **IC 125: Physical Methods in Inorganic Chemistry and Main Group Chemistry**

**(4Credits, 60L)**

#### **(a) Main Group elements: (30 Lectures)**

##### **1. Hydrogen & its compounds (2L)**

Hydrides, classification, e- deficient, e- precise & e- rich hydrides PH<sub>3</sub>, SbH<sub>3</sub>, AsH<sub>3</sub>, Selenides, Tellurides.

##### **2. Alkali & alkaline earth metals (4L)**

Solutions in non-aqueous Media. Application of crown ethers in extraction of alkali & alkaline earth metals.

##### **3. Organometallic compounds of Li, Mg, Be, Ca, Na (2L)**

Synthesis, properties, uses & structures.

##### **4. Boron group (4L)**

Boron Hydrides, preparation, structure & bonding with reference to LUMO, HOMO, interconversion of lower & higher boranes, Metalloboranes, Carboranes.

##### **5. Carbon group (4L)**

Allotropes of Carbon, C<sub>60</sub> and compounds (fullerenes), Intercalation compounds of Graphite, Carbon nanotubes, synthesis, properties, structure-single walled, multiwalled, applications, classification of organometallic compounds. Organometallic compounds of B, Si, Sn, Pb, Ga, As, Sb, Bi. Structures, Synthesis, Reactions

##### **6. Nitrogen group (4L)**

Nitrogen activation, Boron nitride, Oxidation states of nitrogen & their interconversion PN & SN compounds NO<sub>x</sub> & their redox chemistry

##### **7. Oxygen group (4L)**

Metal selenides & tellurides, oxyacids & oxoanions of S & N, Ring, Cage and Cluster compounds of p-block elements. Silicates, including Zeolites

##### **8. Halogen group (4L)**

Interhalogens, Pseudohalogen, synthesis, properties & applications, structure, oxyacids & oxoanions of Halogens Bonding.

##### **9. Noble gases (2L)**

Synthesis, properties, uses, structure & bonding with respect to VSEPR.

#### **(b) Physical Methods in Inorganic Chemistry (30 Lectures)**

## 1. Crystal Structure and Crystal geometry (08)

Space Lattice and basic unit cells, Crystal systems and Bravais Lattices, Classification of space lattice by crystal systems and their structures, the relation between interatomic distance (d) and atomic radius(R) of cubic unit cells. The Atomic Packing factor of BCC, FCC and HCP unit cell and their examples, Atomic positions in cubic unit cells with origin at eight corners of the cube, directions in Cubic Unit Cells, Direction Indices in cubic unit cells, Miller indices for crystallographic planes in Cubic unit cells, Crystallographic planes in Hexagonal unit cell, Miller-Bravais indices. Volume, planar and linear density calculations of cubic unit cells, application of Miller indices in solving crystal structures, problems of all the topics.

## 2. NMR of Inorganic Compounds (10)

Concept of nuclear spin and resonance, fundamentals of coupling (homonuclear heteronuclear) and decoupling, coupling constants. Predicting Intensity of NMR lines by binomial, trinomial, tetranomial etc Pascal triangles Examples of  $^{11}\text{B}$  and  $^{10}\text{B}$  NMR,  $^1\text{H}$  and  $^{11}\text{B}$  NMR spectra of  $\text{BH}_4^-$ ,  $\text{Me}_4^{11}\text{B}_2\text{H}_2$ ,  $\text{Me}_2\text{B}(\mu\text{-H})_2\text{BH}_2$ , second order coupling in diborane, Effect of natural abundance. Structure elucidation by  $^{19}\text{F}$  and  $^{31}\text{P}$  NMR spectroscopy. Examples:  $^{19}\text{F}$  NMR spectra of interhalogen compounds,  $^{19}\text{F}$  and  $^{31}\text{P}$  NMR to deduce structures of  $\text{PF}_3\text{R}_2$  type compounds,  $^{31}\text{P}$  NMR of Wilkinson catalyst, geometrical isomers of platinum compounds, *trans effect* and *meridional*, *facial* isomers of rhodium compounds. General trends in chemical shifts, factors influencing chemical shift-geometry, electronegativity, charge and oxidation state, coordination number, effect of ligands, coordination effect on transition metal. General trends in coupling constant, factors influencing coupling constant-gyromagnetic ratio, periodicity, 's' character in the bond, hybridization, coordination number, electronegativity, trans effect, inter bond angles lone pairs and oxidation state.

## 3. Mössbauer spectroscopy(12)

Basic principles of  $^{57}\text{Fe}$  Mössbauer spectroscopy, instrumentation, spectral parameters

- a) Mössbauer Parameters- Isomer Shifts, quadrupole splitting, Magnetic hyperfine interaction.
- b) Application of Mössbauer spectroscopy with respect to
  - i) Oxidation states of metal ion in compounds

- ii) Structural elucidation
- iii) Covalent and ionic compounds
- iv) High spin low spin behavior
- v) Magnetically ordered compounds

**Books:**

1. Advanced Inorganic Chemistry: F. A. Cotton, G. Wilkinson, C. A. Murillo, M. Bochmann, 6th edn. (2003).
2. Inorganic Chemistry: D. F. Shriver and P.W. Atkins, 4th edn. Oxford (2003).
3. Concise inorganic Chemistry, J.D.Lee 4th edition ( Chapman and Hall )
4. Physical Methods in Chemistry, R. S. Drago, Saunders, Harcourt Brace Jovanovich College Publishers, (1992).
5. NMR spectroscopy in Inorganic Chemistry, J. A. Iqbal, Oxford University press (2001).
6. Mössbauer Spectroscopy and Transition Metal Chemistry, P. Gülich, R. Link, A. Trautwein, Springer-Verlag (1978).
7. Mössbauer Spectroscopy, N.N. Greenwood, T.C. Gibb, Chapman and Hall Ltd. (1971).
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**OC 135: Stereochemistry and Reaction Mechanism ( 4 Credits, 60L)**

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4. Stereochemistry of carbon compound by E. L. Eliel
5. Stereochemistry of organic compound by Nasipuri
6. The Hammett equation – C. D. Johnson, Cambridge University Press (1973)

### **PC 145: Chemical Mathematics and Elements of Computer Programming**

**(4 Credits, 60L)**

#### **Chemical Mathematics**

**(3 Credits, 45 L)**

1. Functions, differential and integral calculus, limits, derivative, physical significance, basic rules of differentiation, maxima and minima, applications in chemistry, exact and inexact differential, Taylor and McLaurin series, curve sketching, partial differentiation, rules of integration, definite and indefinite integrals, integral involving exponential and Gaussian functions (27L)
2. Differential equations  
Separation of variables, homogeneous, exact, linear equations, equations of second order, series solution method. (6L)
3. Probability  
Permutations, combinations and theory of probability (4L)
4. Vectors, matrices and determinants  
Vectors, dot, cross and triple products, introduction to matrix algebra, addition and multiplication of matrices, inverse, adjoint and transpose of matrices, unit and diagonal matrices, (4L)
5. Special functions, Gamma functions, hermite polynomials, Legendre polynomials, Laguerre functions – definitions and recursion relation (no proof required) (4L)

#### **Elements of Computer Programming**

**(1 credit, 15L)**

Hardware and software, binary and decimal numbers, constants and variables, assignment statement, flow chart and their use, IF and GO TO statements, Do loops. Input, output and format statements, Subroutines, function subprograms, Algorithms, Introduction to programming languages (15L)

### **Text Books**

1. The Chemical Maths Book, E. Steiner, Oxford University Press (1996).
2. Maths for Chemists, Volumes 1 and 2, Martin C. R. Cockett and Graham Doggett, Royal Society of Chemistry, Cambridge (2003).
3. Computers and Common Sense *R. Hunt and Shelley*, Prentice Hall, New Delhi (1998)
4. Computer Programming in Fortran-90 *V. Rajaraman*, Prentice Hall, New Delhi (1990)
5. Computer and Chemistry: introduction to programming and numerical methods *T. R. Dickson*, Freeman (1968)
6. Computer programs for chemistry *D. F. Detar* W. A. Benjamin Inc, New York Vol. 1-3 (1968-69)
7. Mathematical Preparation for Physical Chemistry, F. Daniels, McGraw Hill (1972).

## PRACTICALS FOR FIRST YEAR

### IC 128: Experiments in Inorganic Chemistry (4 Credits, 9 weeks)

1. Ore Analysis: At least two of the following:
  - a. Determination of silica and manganese in pyrolusite .
  - b. Determination of copper and iron from chalcopyrite.
  - c. Determination of silica and iron from hematite
  
2. Alloy analysis (At least two of the following )
  - a. Determination of tin & lead from solder.
  - b. Determination of iron & Chromium from mild steel.
  - c. Determination of copper and nickel from cupronickel.
  
3. Inorganic Synthesis and purity determination ( any five )
  - a. Cis-trans potassium di-aquo di-oxalato chromate (III)
  - b. Chloro penta-ammino cobalt (III) chloride
  - c. Nitro penta-ammino cobalt (III) chloride
  - d. Nitrito penta-ammino cobalt (III) chloride
  - e. Bis,2-4 pentanedionato cobalt (II) and cobalt (III)
  - f. Potassium tri-oxalato aluminate
  
4. Ion-exchange chromatography
 

Separation of mixture of Zn(II) and Mg(II) using Ammberlite IRA 400 anion exchanger and quantitative estimation of separated ions Zn(II) and Mg(II)

  - (a) Chelation in Nickel complexes: Preparation of Ni (II) ethylenediamine complexes and studying their absorption spectra.
  - (b) Solution state preparation of  $[\text{Ni}(\text{en})_3]\text{S}_2\text{O}_3$ ,  $[\text{Ni}(\text{H}_2\text{O})_6]\text{Cl}_2$ ,  $[\text{Ni}(\text{NH}_3)_6]\text{Cl}_2$ .  
Record the absorption spectra in solution of all three complexes and analyze it. Arrange the ligands according to their increasing strength depending on your observation
  
5. Instrumental methods of analysis.
  - a. Colorimetry.
    1. Simultaneous determination of Cr & Mn.
    2. Determination of  $K_{eq}$  of M-L Systems such as ,

- Fe (III) - salicylic acid, Fe (III)-Sulphosalicylic acid  
 Fe (III) - b -resorcilic acid by Job's & Mole- ratio method.
- b. Determination of iron by solvent extraction technique in a mixture of  $\text{Fe}^{3+}$  +  $\text{Al}^{3+}$  &  $\text{Fe}^{3+}$  +  $\text{Ni}^{2+}$  using 8- hydroxyquinoline reagent.
  - c. Study of aquation of  $[\text{Fe}(\text{o-phen})_3]$  in acid solution by spectrophotometry.
  - d. Conductometry (Ref.- 5)
    - i. Verification of Debye Hückle theory of ionic conductance for strong electrolytes  $\text{KCl}$ ,  $\text{BaCl}_2$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{K}_3[\text{Fe}(\text{CN})_6]$
    - ii. Structural determination of metal complexes by conductometric measurement
    - iii. To study complex formation between  $\text{Fe}(\text{III})$  with sulfosalicylic acid by conductometry
  - e New Experiments : (any one)
    - i. Data analysis, error analysis, least squares method. Plot of Born Maeyer to determine for 1:1 type molecule to determine internuclear separation. Characterization of metal ligand bonding using IR spectroscopy.
    - ii. Computer Applications: (1) Electronic structure, vibrational characteristics and charge distributions in first row transition metal complexes. (2) Visualizing frontier MO's.
    - iii. Analysis of Electronic spectra of transition metal complexes at least for one system (dn Oh or Td) and calculation of Crystal Field parameters, inter electronic repulsion parameter and bonding parameter.

#### References:

1. Textbook of Quantitative Analysis, A. I. Vogel. 4th edn (1992).
2. Inorganic Electronic spectroscopy: A. B. P. Lever, 2nd edn Elsevier Science Publishers, New York, (1984).
3. Inorganic Synthesis (Vol. Series)
4. Practical Manual made By Department of Chemistry, University of Pune
5. Experiments in Chemistry, D.V. Jahagirdhar, Himalaya Publishing House

#### OC-138: Organic Chemistry practical (Departmental Course) (4 Credits)

1. Practical techniques: Crystallization, fractional crystallization, distillation, fractional distillation, sublimation, thin layer chromatography and column chromatography.
2. Derivatives: Acetyl, 2,4-DNP, anilide, amide, aryloxy acetic acid etc.
3. At least two Oxidation and Reduction reactions
4. Single stage preparations (6 preparations) based on regio-selective and chemo selective principals
5. Two stage preparations (6 preparations)

**Note-i)** Preparations preferred to be club with various technics and ii) Preparation preferred to be on the aromatic substitution, Nucleophilic substitution, Free radical substitution, Addition, Elimination Condensation, Rearrangements, Oxidation, Reduction etc.

#### PC 148: Experiments in Physical Chemistry (4 Credits)

Conductometry:

1. Hydrolysis of  $\text{NH}_4\text{Cl}$  or  $\text{H}_3\text{COONa}$  or aniline hydrochloride
2. Solubility of a sparingly soluble salt.

3. Hydrolysis of ethyl acetate by NaOH.
4. Determination of DG, DH, and DS of Silver Benzoate by conductometry.

Potentiometry:

1. Stability constant of a complex ion.
2. Solubility of a sparingly soluble salt.
3. Determination of dissociation constant of acetic acid.
4. Estimation of halide in mixture.
5. pH metry.
6. Hydrolysis of aniline hydrochloride.
7. Determination of the acid and base dissociation constants of an amino acid and hence the isoelectric point of the acid.
8. To determine the amount of aspirin in the given tablet.

Colorimetry:

1. Analysis of a binary mixture.
2. Copper EDTA photometric titration.
3. Determination of stability constant of ferrisalicylate complex by colorimetric measurements

Radioactivity:

1. Half-life of a radioactive nuclide.
2. Determination of E<sub>max</sub> of beta radiation and absorption coefficients in Al.
3. Counting errors.

Chemical kinetics:

1. Kinetic decomposition of diacetone alcohol by dilatometry.
2. Determination of an order of a reaction.
3. Bronsted primary salt effect.
4. Kinetics of the reduction of methylene blue by ascorbic acid.

Non-Instrumental:

1. Freundlich and Langmuir isotherms for adsorption of acetic acid on active charcoal.
2. Molecular weight by steam distillation.
3. Glycerol radius by viscosity.
4. Partial Molar volume (Pycnometry)
5. Determine the viscosities of mixtures of different compositions of liquids and find the composition of a given mixture.

Computer applications:

1. Least square fitting of experimental data.

*Each candidate should perform a minimum of 20 experiments with at least two experiments from each technique.*

**Text Books**

1. Findlay's Practical Physical Chemistry, B. P. Levitt and J.A. Kitchener 9th Edition, Longmans, London (1972).
2. Experiments in Physical Chemistry by J. M. Newcombe, R. J. Denaro, A. R. Rickett, R.M.W Wilson, Pergamon (1962).
3. Senior Practical Physical Chemistry, 5th Edition, B. D. Khosla, V. S. Garg and A. Khosla, R. Chand (1987).

## SEMESTER II

### IC 220: Coordination & Bioinorganic Chemistry (4Credits, 60L)

#### (a) Coordination Chemistry

1. Concept & Scope of ligand Fields. (1L)
2. Energy levels of transition metal ions, Free ion terms, spin –orbit coupling. (7L)
3. Effect of ligand fields on energy levels of transition metal ions, weak cubic ligand field effect on Russell-Saunders terms, strong field effect, correlation diagrams, Tanabe-Sugano diagrams, Spin-pairing energies. (8L)
4. Electronic spectra of complexes, band intensities, band energies, band width & shapes, spectra of 1st, 2nd & 3rd row ion and rare earth ion complexes, spectrochemical & Nephelauxetic series, charge transfer & luminescence spectra, calculations of Dq, B, 1 parameters. (8L)
5. Magnetic properties of complexes, paramagnetism, 1st & 2nd ordered Zeeman effect, quenching of orbital angular momentum by Ligand fields, Magnetic properties of A,E,T ground terms in complexes, spin free–spin paired equilibria. (6L)

#### (b) Bioinorganic Chemistry

6. Overviews of Bioinorganic Chemistry. (2L)
7. Principles of coordination Chemistry related to Bioinorganic–Proteins, nucleic acids and other metal binding biomolecules (6L)
8. Choice, uptake and assembly of metal containing units in Biology (6L)
9. Control and utilization of metal ion concentration in cells. (6L)
10. Metal ion folding and cross –linking of biomolecules. (6L)
11. Binding of metal ions and complexes to biomolecular active Centers (4L)

#### Books:

1. Ligand field theory & its application: B.N. Figgis & M. A. Hitchman Wiley VCH publ. (2000), Chapters 5, 6, 8,9,11.
2. Principles of Bioinorganic Chemistry: S. J. Lippard & J.M Berg, University science books, Mill Valley, California (1994), Chapters- 1,2,3,5,6,7,8.
3. Inorganic Chemistry: D. F. Shriver & P. W. Atkins, Oxford (1999).
4. Inorganic Electronic spectroscopy: A. B. P. Lever, 2nd edn Elsevier Science Publishers,

New York, (1984).

5. Biological Chemistry of the Elements: R. J. P. Williams & F. R. De Salvia, Oxford University Press-(1991).

6. Bioinorganic Chemistry: Inorganic elements in the Chemistry of life: An introduction and guide: W. Kaim, B. Schwederski, VCH, (1991).

**OC 230 – Synthetic Organic chemistry and Spectroscopy (4 credits, 60L)**

**Oxidation and Reduction: (12)**

Oxidation Reactions:  $\text{CrO}_3$  (Jones reagent) PDC, PCC,  $\text{KMnO}_4$ ,  $\text{MnO}_2$ , Swern Oxidation,  $\text{SeO}_2$ ,  $\text{Pb}(\text{OAc})_4$ , Pd/C,  $\text{OsO}_4$ , m-CPBA,  $\text{O}_3$ ,  $\text{NaIO}_4$ ,  $\text{HIO}_4$ ,  $\text{R}_3\text{SiH}$ ,  $\text{Bu}_3\text{SnH}$ , Reaction of NBS. Reduction viz. Wilkinson's catalyst, metal hydrides,  $\text{NaCNBH}_3$ ,  $\text{NH}_2\text{NH}_2$ , DIBAL, Zn, etc. Stereochemistry involved in hydrogenation, hydroboration, B.V. oxidation,  $\text{KMnO}_4$ ,  $\text{OsO}_4$ ,  $\text{Pb}(\text{OAc})_4$ , oxymercuration, Wilkinson's catalyst,  $\text{O}_3$ ,  $\text{NaIO}_4$ ,  $\text{HIO}_4$  etc.

**Ylids:** Phosphours, sulphur and nitrogen, synthesis and (5)

**Organo-metallic chemistry: (10)**

Li, Zn, Cu, Mg, Al, Si etc., Hydroboration and synthesis of borane reagents and its use in oxidation and protonation.

**Spectroscopy: (18)**

Basics of UV, IR and NMR. Instrumentation and recording of spectra of UV, IR and NMR, Elementary ideas of NMR, integration, chemical shifts etc. Factors affecting chemical shifts, Coupling (First order, analysis), Problems based on UV, IR and NMR.

**Heterocyclic Chemistry: (15)**

Structure, reactivity, synthesis and reactions of pyrrole, furan, thiophene, pyridine, indole, benzofuran, quinolone and isoquinoline.

**Books/References:**

1. Carey and Sundberg. (Ed. IV), Part B – Adv. Organic Chemistry.
2. H.O. House, Synthetic Organic Chemistry.
3. Norman R.O.C. Organic Chemistry.
4. Advanced Organic Chemistry by J. March 6<sup>th</sup> Edition
5. Silverstein and Basser, Spectrometric Identification of Organic Compounds.
6. P.S. Kalsi, Organic Spectroscopy.
7. J. Bellamy, Infrared spectra of Complex molecules.
8. I Fleming, Organic Spectroscopy.
9. J. Clayden, N. Greeves et. al Organic Chemistry
10. Pavia Spectroscopy of Organic Compounds
11. Heterocyclic Chemistry – J. A. Joule, K. Mills and G. F. Smith

**PC 240: Chemical Bonding and Molecular Spectroscopy (4 Credits, 60 L)**

**Chemical Bonding (2 Credits, 32 L)**

1. Recapitulation, quantization, Postulates of Quantum mechanics, Schrödinger equation, particle in a box, particle in 3-D box, degeneracy, hydrogen-like atoms (no derivation), atomic orbitals. (12 L)
2. Variational method, many electron atoms, orbital angular momentum, electron spin, wave functions of many electron atoms, Pauli exclusion principle, spin-orbit interaction, fine structure, vector atom model, spectral terms. (5 L)

3. Molecular orbital theory, Born-Oppenheimer approximation, H<sub>2</sub> molecule, homo and hetero-nuclear diatomic molecules, MO diagrams of simple triatomic molecules. (5 L)
4. Valence bond theory of simple molecules, quantitative treatment of hydrogen molecule and related systems, hybridization, comparison of VBT and MOT. (4 L)
5. Hückel theory of conjugated hydrocarbons, Electron densities, Bond orders and free valence indices, Illustrations (6 L)

#### **Text Books**

1. Quantum Chemistry, I. Levine, 5th Edition, Prentice Hall (1999).

#### **Reference Books**

1. Valence, C. A. Coulson, ELBS (1974).
2. Introduction to Quantum Mechanics- with Applications to Quantum Chemistry, L. Pauling and E. B. Wilson, Dover Publishers (1999).
3. Orbitals in Chemistry, V. Gil, Cambridge University Press (2000).

#### **Molecular Spectroscopy (2 Credits, 28 L)**

1. Recapitulation, regions of electromagnetic spectrum, width and intensity of spectral lines. (2 L)
2. Rotational spectra: classification of molecules based on the moment of inertia, Schrodinger equation of rigid rotor, diatomic molecules, effect of isotopic substitution, centrifugal distortion, linear triatomic molecules, symmetric top molecules, stark effect. (5 L)
3. Infrared spectra: quantum mechanical harmonic oscillator, diatomic molecule, Morse potential, overtone and hot bands, polyatomic molecules, skeletal and normal vibrations (6 L)
4. Vibrational rotational spectra, fine structure in diatomic molecules, break down of the Born-Oppenheimer approximation, effect due to nuclear spin, parallel and perpendicular vibrations. (4 L)
5. Raman Spectra: classical and quantum theory of Raman effect, stokes and antistokes lines, polarizability ellipsoid, rotational Raman spectra, selection rule, vibrational raman spectra, rule of mutual exclusion, elucidating structure from the combined infrared and Raman spectra, rule of mutual exclusion (6 L)
6. Electronic spectra: Born-Oppenheimer approximation, molecular progression, term symbols, Franck-Condon principle, dissociation energies, oscillator strength, rotational fine structure, fortrat parabola, predissociation, photoelectron spectroscopy (5 L)

#### **Text Books**

1. Fundamentals of Molecular Spectroscopy, C. M. Banwell and E. McCash, Tata McGraw Hill, 4th Edition (1994).
2. Molecular Spectroscopy, J. Machale, Prentice Hall, NJ, USA (1999).
3. Vibrating Molecules, P. Gans, Chapman and Hall, UK (1971).

#### **Semester III**

#### **Compulsory courses**

**AC 350: Principles of Analytical Chemistry (4Credits) (60L)**

**Section I: (30L)**

- a. Analytical Science – an overview: (4L)  
History of analytical chemistry, basic concepts, classification of analytical methods, types of instrumental methods, instruments for analysis and its different domains.
- b. Automated Methods of Analysis (6L)  
Specification and performance of automated methods, automation strategy, automation laboratory analyzers, automated laboratory apparatus; continuous flow analysers, flow injection analysers, sequential injection analysers, discrete analysers, centrifugal analysers, automatic chemical analysers, laboratory robots, process control and its analysers.
- c. Sample dissolution methods for elemental analysis: (4L)  
Dissolution of inorganic samples by using acids as solvent, fusion process, and miscellaneous procedures, Dissolution of organic samples by dry and wet ashing, methods, special methods. Use of dissolution assemblies in analysis
- d. Electrical circuits: (8L)  
Semiconductors and semiconductor devices, Current-voltage curves for semiconductor diodes. Transistor and its types, power supplies and regulators, read out devices. Operational amplifiers and microprocessors in chemical instrumentation, Logic devices and Computers
- e. Heterogeneous Catalysis and its applications: (8L)  
Basic principles of heterogeneous catalysis, different types of reactions, characterization of heterogeneous catalysis, catalytic converters, zeolites, photocatalysis, commercial applications of heterogeneous catalysis. Experimental techniques used in surface analysis of heterogeneous catalysis.

**Text Books:**

1. Principles and Practice of Analytical Chemistry, F. W. Fifield and D. Kealey, 5th edn., Blackwell Science, Chapt. 1, pp 12-13, 331- 379, 385-411, 415-458 (Chapt. 7.4) and 463-471, (2000)
2. Fundamentals of Analytical Chemistry, D. A. Skoog and D. M. West, 4th edn., CBS College Publishing, New York, Chapt. 1, pp 12-13, (1982)
3. Introduction to Instrumental Analysis, R. D. Brown, McGraw Hill, (1987).
4. Instrumental Methods of Analysis, H. H. Willard, L. L. Meritt and J. A. Dean, Affiliated East-West Press, Chapt. 1 and 2, (1977)
5. Heterogenous Catalysis: Principles and Applications by G.C. Bond, Clarendon Press-Oxford, 1974.

**References:**

1. Instrumental Analysis, D. A. Skoog, F. James Hollier and S. R. Crouch, 6<sup>th</sup> edn., Thomson Brooks/Cole Publishers (2007).

2. Sample Pre-treatment and Separation, R. Anderson, ACOL Series, N.B. Chapman (Ed.), John Wiley & Sons for ACOL, Chapt. 3 and 4, pp 66-118, (1991)

**Section II:** (30L)

- a. Calibration: (6L)  
Construction of calibration curves, comparison with single standard, matrix matching, standard addition and internal standard methods, calibration of glassware, buoyancy errors, numerical, Reference Materials (RMs): Analytical standards, primary and secondary standards, high purity reference materials and certified reference materials (CRMs), Uses
- b. Optimization and Experimental Design: (12L)  
Accuracy, precision, classification of errors, minimization of errors, significant figures and computation, mean deviation and standard deviation, Detection, reduction and compensation of errors, propagation of intermediate error, confidence level, confidence limit when sigma is known and when sigma is unknown, statistical treatment of random error, properties of Gaussian distribution, Test of significance, F test, Q test, Construction and interpretation of graphs, fitting the least squares lines, correlation coefficient and coefficient of determination, detection limits, statistics of sampling, numerical, Sampling, the basis of sampling, sampling procedure
- c. Systematic approach of solving problems: (8L)  
pH scale and its significance, pH at elevated temperatures, pH for aqueous solutions of very weak acid and base, pH for salts of weak acid and weak bases, polyprotic acids. Buffer solutions, buffer capacity, applications of buffers, Physiological buffers, buffers for biological and clinical measurements. Problems based on solubility, common ion effect, systematic approach to solving equilibrium problems, buffer problems, problems based on titrimetric (redox, complexometric and precipitation), gravimetric and instrumental method of analysis (Spectrophotometric, Amperometric, Potentiometric)
- d. Process Analysis, Quality Assurance and Quality Control: (4L)  
Introduction, Hazards, Safety, continuous or regular monitoring, measurement systems. Quality characteristics of chemical analysis, errors occurring at the start, during or by the end of analysis, interpretation and presentation of results, Shewhart Chart, CUSUM chart and EWMA chart; QA schemes, Internal QC, Accuracy and external quality assessment

**References:**

1. D. A. Skoog, D. M. West and F. J. Holler, Fundamentals of Analytical Chemistry, 2<sup>nd</sup> Ed., Saunders College Publishing, 1991

2. R. A. Day and A. L. Underwood, Quantitative Analysis, 6<sup>th</sup> Ed., Prentice-Hall of India Pvt. Ltd., 1993
3. Gas Chromatography, Open Book Learning Series
4. Larry Hargis, Analytical Chemistry. Principles and techniques
5. Encyclopedia of Analytical Chemistry, Vol.
6. M. Valcarcel, Principles of Analytical Chemistry, Springer
7. Modern Analytical Chemistry, David Harvey

**AC-351: Spectroscopic Methods of Analysis**

**(4Credits)(60L)**

- a. UV-Visible: **(6L)**  
Introduction to spectroscopy, Beer-Lambert's Law, chromophoric Groups, factors affecting wavelength and molar extinction co-efficient, application to structural problems and uses in industry instrumentation
- b. IR: **(10L)**  
Introduction, basic principles, factors affecting IR group frequencies, Applications to structural problems and uses in industry, instrumentation
- c. Raman: **(8L)**  
Raman Spectroscopy Principle instrumentation applications
- d. <sup>1</sup>H NMR: **(20L)**  
Recapitulation of basic principle, Fourier Transform technique, Pulse sequence, relaxation processes. Use of Integration in the quantitative determination of isomers, Factors affecting chemical shifts (inductive, resonance and anisotropic effect with examples), chemical shift of different types of protons (alkane, alkene, alkyne and allene), aromatic protons and effect of substituent, different types of spin coupling, first order analysis of spectra, Ramsay mechanism of spin coupling, roofing effect with example, different spin systems (AB, AM, AX, ABX/AMX spin systems with examples), calculations of line intensities and chemical shifts in AB spin system, factors affecting coupling constants (dihedral angle, Karplus equation-graph, electronegativity, bond order, hybridization, bond angle with examples), non equivalence due to restricted rotations, rate processes. Effect of high field NMR for simplification of spectra, Shift reagents, Spin decoupling and Nuclear Overhauser effect with examples
- e. <sup>13</sup>C NMR: **(16L)**  
Elementary ideas, instrumental difficulties, FT technique advantages and disadvantages, Proton Noise Decoupling technique advantages and disadvantages, off-resonance technique, Chemical shifts of solvents, factors affecting chemical shifts, analogy with <sup>1</sup>H NMR, calculations of chemical shift of hydrocarbons, effect of substituents on chemical shifts, different types of carbons (alkene, alkyne and allene), chemical shift of aromatic carbons and effect of substituent. Chemical shifts of carbonyl, nitrile, oxime carbons

**References:**

- 1 Introduction to Spectroscopy – D. L. Pavia, G.M. Lampman, G. S. Kriz, 3<sup>rd</sup> Ed. (Harcourt college publishers)

2. Spectrometric identification of organic compounds R. M. Silverstein, F. X. Webster, 6<sup>th</sup> Ed. John Wiley and Sons.
3. Spectroscopic methods in organic chemistry – D. H. Williams and I. Fleming McGraw Hill.
4. Absorption spectroscopy of organic molecules – V. M. Parikh
5. Nuclear Magnetic Resonance – Basic Principles- Atta-Ur-Rehman, Springer-Verlag (1986)
6. One and Two dimensional NMR Spectroscopy- - Atta-Ur-Rehman, Elsevier (1989)
7. Organic structure Analysis- Phillip Crews, Rodriguez, Jaspars, Oxford University Press (1998)
8. Organic structural spectroscopy- Joseph B. Lambert, Shurvell, Lightner, Cooks, Prentice-Hall (1998)
9. Organic structures from spectra- Field L. D., Kalman J.R. and Sternhell S. 4<sup>th</sup> Ed. John Wiley and sons Ltd.
10. NMR spectroscopy of Organic compounds. Jackmann and Sternhell S
11. Instrumental methods of chemical analysis- *Chatwal and Anand*
12. Introduction to Instrumental Analysis- *R. D. Braun*, Pharmamed Press, Indian Reprint (2006)
13. Principles of Instrumental Analysis, 5<sup>th</sup> edition- *D. A. Skoog, F.J. Holler, T. A. Nieman*, Philadelphia Saunders College Publishing (1988)

**Elective courses (any two from the following)**

**AC-355: Introduction to Biomolecules and Analysis of Clinical and Consumer products (4Credits)(60L)**

- a. Protein structure and analysis:  
Definition of protein and peptides; structure of protein; types of protein s;  
Physical and chemical properties of protein; Analysis of proteins: Total protein, albumin and globulin from serum samples.
- b. Hormone analysis:  
Introduction; Classification and general characteristics of hormones;  
Determination of cortisol from blood and urine samples; determination of oestrogens from urine samples
- c. An overview of Carbohydrates and Lipids.
- d. Nucleic acids (DNA and RNA):  
Structure, physical and chemical properties
- e. Enzymatic and Immunochemical Analysis
- f. Mineral metabolism, Electrolyte analysis
- g. Body fluid analysis
- h. Therapeutic drug monitoring
- i. Scope of Clinical chemistry:  
Philosophy of clinical analysis, Practical aspects of analysis: sample types, collection of specimens (samples) like blood, urine, faeces; Cleaning of glass apparatus; Storage of clinical samples.
- j. General techniques for analysis:

Brief principle and applications of following techniques: colorimetric, spectrophotometric, turbidimetric, fluorimetric, flame photometry, autoanalysis, paper electrophoresis, gel-electrophoresis, chromatography; Units of expressing biochemical values

### **Food Product Analysis**

- a. Moisture content, ash, fibre, nutrients, antinutrients, toxicants, microorganism spoilage (rancid taste), colour, preservatives
- b. Analysis of amino acids, proteins, carbohydrates, lipids and fats
- c. Analysis of edible oils, dairy products, pickles etc., fruit and vegetable products
- d. Food additives and Food colours
- e. Food adulteration
- f. Sensory / organoleptic evaluation of food
- g. ISO 9000 and Food industry

### **Consumer Product Analysis**

- a. Consumer products and their chemical speciation (as well as qualitative and quantitative analysis)
- b. Cosmetics – Face powders, hair preparations, Antiperspirants and deodorants, Perfumes, Toothpastes
- c. Food pigments

### **References:**

1. B. M. Mittal and R. N. Saha, Handbook of Cosmetics, Vallabh Prakashan, New Delhi, 1<sup>st</sup> edn., 2000.
2. S. Nanda and R. K. Khar, Cosmetic Technology, Birla Publication Pvt. Ltd., 1<sup>st</sup> edn., 2006.
3. Principles of Biochemistry, Lehninger C Rs. Publ. (1982).
4. Biochemistry, L. Stryer, W.H. Freeman, San Francisco, A. Townshend, Ed., Encyclopedia in Analytical Science, Academic Press (1995)
5. R. L. Na, Academic Press, Calcutta

### **AC-356 : Modern Analytical Techniques**

**(4Credits)(60L)**

- a. Radioanalytical methods:
  1. Neutron Activation Analysis : Principle, Different steps involved in NAA, radiochemical and instrumental NAA, applications, advantages and disadvantages **(6L)**
  2. Radiometric titrations: Principle, Radiometric titrations based on precipitate formation, complex formation and neutralization reactions **(5L)**
  3. Isotope Dilution Analysis: Principle and types: Direct, Reverse and Double Isotope dilution analysis **(5L)**
  4. Radioimmuno assay: Principle, methodology and applications **(5L)**
- b. Atomic Absorption Spectroscopy: **(6L)**  
Principle, instrumentation, interference in spectral analysis, applications, advantages and disadvantages
- c. Inductively coupled plasma atomic emission spectroscopy: **(6L)**

Principle, various stages involved in the analysis, instrumentation, applications, advantages and disadvantages

- d. Thermal Methods of Analysis: (6L)  
TGA, DTA, DSC and Thermometric Titration: Principle, instrumentation and applications
- e. Mass spectrometry: (6L)  
Theory, instrumentation-basic components, ionization sources, analyzers, resolution, chemical analysis, advanced techniques-GC/MS
- f. X-Ray Methods: (15L)  
X-ray methods: Generation and properties of X-rays, X-ray absorption, X-ray absorptive apparatus, radiography and radiotherapy, applications, X rays fluorescence, fundamental principles, instrumentation, quantitative analysis, X-ray emission, fundamental principles, X ray diffraction, powder diffractometer, applications in material science, electron microprobe, XPS: Principle, instrumentation and applications

**AC 357: Fluorescence spectroscopy and its applications in chemistry and biology (4 credits 60 lectures)**

- a. Phenomena of Fluorescence, Jablonski Diagram, Characteristics of Fluorescence Emission, Instrumentation for Fluorescence Spectroscopy, lasers as excitation sources, time-resolved fluorimetry, Dynamics of Solvent and Spectral Relaxation, Solvent and Environmental Effects, Quenching of Fluorescence, Mechanisms and Dynamics, Fluorescence Anisotropy, Energetics and dynamics of bimolecular processes like excimer and exciplex formation, resonance energy transfer
- b. Fluorescence Correlation Spectroscopy, Protein Fluorescence, Single Molecule Fluorescence Spectroscopy and Microscopy, Multiphoton Fluorescence Spectroscopy and Microscopy, Fluorescence Lifetime Imaging Microscopy (FLIM)
- c. Applications: Microscopy (optical, phase-contrast, confocal, FLIM). Applications in biology and analytical chemistry.
- d. Fluorescence based sensors – Mechanisms of Sensing, Sensing by Collisional Quenching, Energy-Transfer Sensing, Two-State pH Sensors, Photoinduced Electron Transfer (PET) Probes, Probes of Analyte Recognition, Glucose-Sensitive Fluorophores, Protein Sensors, GFP Sensors, In-Vivo Imaging, Immunoassays, metal enhanced fluorescence, Green Fluorescent proteins, Sensing in cellular environment

**References**

1. Fundamental of Photochemistry, K. K. Rohatgi-Mukherjee, New Age International (P) Ltd., New Delhi, 1986.

- Principles of Fluorescence Spectroscopy, 3rd Ed., J. R. Lakowicz, Springer, New York, 2006.
- Fundamentals of Photoinduced Electron Transfer, G. J. Kavarnos, VCH publishers Inc., New York, 1993.
- Molecular Fluorescence: Principles and Applications, B. Valeur, Wiley-VCH Verlag GmbH, Weinheim, 2002.

**AC-358: Analytical Chemistry Practicals I (4Credits)**

**Part A (Any 10 experiments)**

- Determination of gamma energy of a given source using scintillation counter coupled with single channel analyser.
- Determination of Manganese content of steel sample by neutron activation analysis technique
- Determination of half life of radioisotopes in a given mixture
- Determination of isobestic point of a given dye molecule by spectrophotometric method.
- Determination of Molecular weight of a given polymer by turbidimetry.
- Determination of Molecular weight of a given polymer by end group analysis
- Kinetics of condensation polymerization by dilatometry.
- Estimation of Zn and Cd from their mixture by polarographic technique.
- Determine the molecular weight of a given polymer from viscosity measurements.
- Estimate the amount of halide from solution by differential potentiometry method.
- Determine the critical micelle concentration of a given surfactant by conductometry.
- Determine the concentration of Riboflavin in the given sample by spectrophotometry.
- Determine the activity coefficient of an non-electrolyte by freezing point depression method.
- Determine the activity coefficient of an electrolyte by freezing point depression method.
- Determine the molality of the solution of a substance in water and hence it's molecular weight by freezing point depression method.

**Part B (Any ten experiments)**

- Determination of glucose from blood serum (Enzyme method)
- Determination of total serum cholesterol (cholesterol & HDL).
- Estimation of urea from blood sample.
- Determination of glucose from blood serum by Folin –Wu – method
- Estimation of Vitamin C.
- Assay of Thiamine
- Estimation of amino acids by ninhydrin method.
- Estimation of Ketone bodies
- Estimation of Creatine / Creatinine in urine
- Estimation of free fatty acids in oil by titration method.
- Growth curve of E.coli.
- Minimum inhibitory concentration (MIC) of drugs using E.coli.

13. Isolation of plasmid DNA.
14. Agarose gel electrophoresis of DNA.
15. Separation of proteins by polyacrylamide gel electrophoresis.

### **AC-359: Analytical Chemistry Practicals II**

**(4Credits)**

#### **Part A**

1. Estimation of Tannin from tea
2. Isolation of caffeine from tea
3. Quantitative analysis of mixture by gas Chromatography [e. g. Chloroform and carbon tetrachloride / methanol and ethanol]
4. Preparation of sulphanilamide from acetanilide and assay its purity
5. Preparation of methyl salicylate and assay its purity
6. Isolation of Lycopene from tomato /  $\beta$ -Carotene from carrots and assay its purity
7. Preparation, purification and assay of aspirin.

#### **Part B**

1. Alloy [e.g. iron, chromium and nickel from Stainless steel]
2. Ore [e.g. acid-insoluble matter (combined oxides), iron and titanium from Ilmenite]
3. Cement [ e.g. silicon, aluminium, iron from Portland cement ]
4. Consumer products (e.g. Inorganic Pigment [e.g. chromium from Zinc chrome]; Pharmaceutical product [magnesium from tablet of "Milk of magnesia" / calcium from calcium-supplementary tablet / aluminium from alum]; Fertilizer [NPK Fertilizer for phosphorus]
5. Ion exchange chromatography [separation and estimation of mixture of zinc (II) and magnesium (II)]
6. Thermogravimetry [Determination of percentage of  $MgCO_3$  in Dolomite]
7. Flame Photometry [Determination of the percentage of sodium in the sample of dairy whitener]
8. Cyclic voltametry [Study of cyclic voltammogram of  $K_3[Fe(CN)_6]$ ]
9. Determination of moisture content in food sample using Karl-Fischer Titrator
10. Determination of Phosphate in Detergents by Spectrophotometry
11. Determination of phosphoric acid in cola beverages by pH titration.
12. Photometric Titrations: (a) Cu Vs EDTA (b) Fe Vs EDTA using salicylic acid
13. Potentiometric Titrations: (a) FAS Vs  $K_2Cr_2O_7$  (b) FAS Vs.  $KMnO_4$
14. Conductometric Titrations: (a) NaOH Vs. HCl (b) NaOH Vs. Boric acid
15. Synthesis of semiconducting nano oxides such as NiO, ZnO
16. Table work for IR-spectra, NMR, UV-Visible spectra

### **Semester IV**

#### **Compulsory courses**

**AC-450: Polymers and Agrochemicals****(4Credits)(60L)**

- a. Brief history of macromolecular sciences: **(5L)**  
Basic concepts of polymer science, classification of polymers, Chemical Bonding in polymers, stereochemistry of polymers
- b. Kinetics of polymerization: **(6L)**  
Addition and condensation polymerization with specific examples  
Copolymerization: Classification of copolymers, Kinetics and mechanism of copolymerization and determination of its composition
- c. Structure and Properties: **(8L)**  
Crystalline melting point, The glass transition temperature (T<sub>g</sub>), States of aggregation, states of phase, Factors influencing T<sub>g</sub>. Determination of T<sub>g</sub> by dilatometry, calorimetry. Heat distortion temperature, Properties involving large deformations, melt viscosity, tensile strength, stress, strain, crazing, shear banding, solubility and related properties, electrical and related properties.
- d. Molecular weight of polymer: **(6L)**  
Number average and weight average molecular weight and degree of polymerization,  
Measurement of molecular weight of polymers: End group analysis, Colligative property measurement, Light scattering, Solution viscosity and molecular size and GPC.
- e. Characterization of polymers: **(5L)**  
Chemical analysis of polymers, IR and Raman spectroscopy, X-ray diffraction analysis, Thermal analysis TG-DSC, Thermomechanical analysis

**References:**

1. Text book of Polymer Science, Fred W. Billmeyer Jr., Third edition, 2000.
2. Polymer Science, V. R. Gowarikar, N. V. Vishwanathan and Jaydev Sreedhar, Reprint edition, 2002.
3. Introduction to Polymer Science and Chemistry by Manas Chanda, Taylor and Francis Pub.
4. Chemistry of Pesticides, N. M. Melnikov, Residue Reviews, Vol. 36, Springer Verlag, New York, 1971.

**Analysis of Agrochemicals: (30L)**

- a. Introduction, Classification, mechanism of action and synthesis.
- b. Insecticides: DDT, BHC, Aldrin, Endosulfon, Malathion, Parathion.
- c. Herbicides: 2,4-dichloro phenoxy acetic acid, dalapon, paraquat, Banalin, Butacarb
- d. Fungicides: Boardeaux mixture, Copper oxychloride, Zineb,, Benomyl(Benlte)
- e. Analysis of pesticide residue and toxicological effects.

**Books:**

1. Text Book of Polymer Science by F. W. Bilmayer
2. Polymer Science by Gowarikar

3. Introduction to polymer science and chemistry by Manas Chanda, Taylor and Francis Pub.
4. Chemistry of pesticides, N.M. Melnikov, Residue Reviews, Vol.36, Springer Verlag, New York, 1971.
5. Future for insecticides, R. C. Netealr, J. J. Mckalvery, Jr. John Wiley & Sons, New York, 1976.
6. Pesticide processes Encyclopedia, Marshal Sitting Hoyes Data Corporation, U.S.A., 1977.

### **AC-451: Electrochemistry and Pharmaceutical analysis (4 Credits)(60L)**

#### **Section-I Electrochemistry:**

**2 credits, 30 lectures**

- a. Introduction and over view of electrochemical processes: **(6L)**  
Origin of electrode potential, Electrochemical cell and EMF and free energy of the electrochemical reactions, half reaction and reduction potentials, formal potentials, reference electrodes, liquid junction potential.
- b. Ion-ion interactions: **(6 L)**  
Ideal solution, deviation from ideality, Activity and activity coefficient, Debye-Huckel Theory, limited and extended law (derivation expected), applications of Debye Huckel Theory.
- c. Kinetics of Electrode reactions: **(6 L)**  
Butler Volmer Model for electrode kinetics, standard rate constants and transfer coefficients, equilibrium condition and exchange current, current over potential equation. Butler equation.
- d. Introduction to Electroanalytical Techniques: **(6 L)**  
  
Cyclic Voltammetry, Chronoamperometry, scanning electrochemical Microscopy (SECM), Electrochemical Impedance spectroscopy.
- e. Important Electrochemical devices: **(6 L)**  
Batteries, Fuel cells, photoelectrochemical and dye sensitized solar cells and electrochemical super capacitors and ion-selective electrodes.

#### **Books:**

Electrochemical Methods second edition, A.J. Bard and L.R. Faulkner, John Wiley and Son (2001).

Electrode Potentials Richard G. Compton and Giles H.W. Sanders, Oxford University Press, Walton Street, Oxford, 1998.

Modern Electrochemistry Vol 1:, 2nd Edition by John O'M. Bockris, Amulya K.N. Reddy, Plenum Press N.Y. 1998.

Modern Electrochemistry Vol 2B: by John O'M. Bockris, Amulya K.N. Reddy, Plenum Press N.Y. 1998.

#### **Section II Pharmaceutical Analysis**

- a. Role of FDA in Pharmaceutical Industries: (2L)**  
 Definitions of Drug, Substandard Drugs, Role of FDA, Introduction to New Drug, Development of New Drugs- Selection of Area, Phase I, Phase II, Phase III Application to FDA for formulation and marketing for new drug. Stability studies and Shelf life fixation.
- b. Physical Test, Determinations and Limit tests: (3 L)**  
 Disintegration Test for Tablets and Capsules, Dissolution Test for Tablets and Capsules, moisture / water content by Karl-Fischer titration, limit tests for arsenic, heavy metals, iron, lead, sulphate, chloride, Ash, sulphated ash,
- c. Standardization and quality control of different raw materials: (2L)**  
 Analysis of raw materials with respect to identification, other or related substances, loss on drying, and Assay as per IP, i) adrenaline, ii) Niacinamide iii) Cephalexin, iv) ferrous fumarate, v) isoniazid and vi) paracetamol.
- d. Pharmacodynamic analysis: (5L)**  
 Pharmacodynamics, concept and application of therapeutic drug monitoring (TDM). Pharmacokinetics consideration for adverse effect and drug interaction. Clinical pharmacokinetics of selected drugs.
- e. Pharmacokinetics**
1. Introduction to Pharmacokinetics-Dosage form, excipients, routes of administration, dosage regimen (defining the starting dose), (2L)
  2. Pharmacokinetic properties-ADME, metabolite pathways for known drugs, (2L)
  3. Pharmacokinetics and drug design, pharmacokinetic models (one compartment, two compartment and multi compartment models), rates of reaction (zero-order and first-order reaction), (3L)
  4. pharmacokinetic analysis: elimination rate constant, volume of distribution, rate of elimination, half life of the drug, clearance and its significance, salt effect, bioavailability, numerical problems, Intravenous infusion (IV bolus), extravascular administration (oral), single oral dose, multiple oral doses, non-linear pharmacokinetics, (4L)
  5. Drug metabolism, stereochemistry of drug metabolism, biological factors affecting metabolism, Phase I and Phase II metabolic reactions, (4L)
  6. Analytical methods – development, validation and clinical applicability, Phase I trials- design and endpoints (a case study) (3L)

**References and Books:**

- 1) Indian Pharmacopeia Volume I and II.
- 2) Practical Pharmaceutical chemistry third edition volume 1. By A.H.Beckett &J.B.Stenlake
- 3) Remington's Pharmaceutical sciences.
- 4) Ansel's Pharmaceutical Analysis

- 5) Screening methodology in Pharmacology –II by Turner and Hebborn  
 6) In vitro testing by John M. Fraizer  
 7) General and Applied toxicology by Bryan Ballantyne, T. Marrs and P. Turner

**Elective courses (any one from following two)**

**AC-455: Industrial Products and Forensic Analysis (4Credits)(60L)**

**Section I:**

- a. Analysis of steel and ferrous materials (10L)  
 Sampling, analysis of steel and ferrous alloy: carbon, silicon, manganese, phosphorous, sulphur, selenium, copper, nickel, chromium, vanadium, tungsten, molybdenum, cobalt, aluminium, titanium, nitrogen, lead, niobium, iron, Instrumental methods of analysis of steel by XRF, SEM-EDS and OES
- b. Analysis of cement and building materials (3L)  
 Types of cement, sampling, analysis of cement and building materials: silicon dioxide and other metal oxides, sulphide- sulphur, loss on ignition, insoluble residue, XRF and potentiometric methods for cement analysis
- c. Analysis of ceramic materials (2L)  
 Analysis of quartz, analysis of clays and feldspar, analysis of glasses and ceramics, volatile residue and their various metal oxides
- d. Surfactants and detergents (5L)  
 Soaps: General scheme of analysis, alcohol soluble and insoluble material, moisture, active ingredients, total fatty acids, fatty anhydride, combined alkali, unsaponifiable and unsaponified matter, iodine value, free glycerol.  
 Detergents: Unsulfonated or unsulfated material, Ester  $\text{SO}_3$ , combined alcohols, total combined  $\text{SO}_3$ , organic builders, alkalinity, silicates.
- e. Fertilizers: (5L)  
 Moisture, ash content, pH, oil content, main components, nitrogen, ammoniac nitrogen, nitrate nitrogen, phosphate, total phosphate, soluble, citrate soluble, water soluble phosphoric acid, potassium, citrate soluble and water soluble potassium, silicic acid, lime, calcium, magnesium, alkalinity, manganese etc. flame photometric, absorbance methods.
- f. Medicinal and pharmaceutical products (5L)  
 General physical methods, Chromatographic methods and spectroscopic methods for the analysis of drugs, quantitative analysis of drugs in formulations using various techniques

**Books:**

1. "Standard methods of Chemical Analysis", Vol. 2, (Part A & B), F. J. Welcher, 5th edn., Von Nostrand & Robert E. Krieger Publishing Co. New York, (1975 and 2000)
2. "Quantitative Inorganic Analysis" A. I. Vogel, English Language Book Society, London, (1975)

**Reference Books:**

1. "Materials Science & Engineering, William D. Callister Jr., John Wiley and Sons, Inc. New York.,(1991).
2. "Encyclopaedia of Analytical Science", A. Townshend (Ed.), Academic Press (1995).
3. "Practical Pharmaceutical Chemistry, A. H. Beckett and J. B. Stenlake, CBS Publishers, New Delhi, 1st Indian edn., pp 16-76 and 309-348, (1986).

**Section II: (30L)**

- a. Forensic analysis: (4L)  
Overview, Destructive and Nondestructive techniques, Data interpretation
- b. Blood Analysis: (3L)  
Blood preservation and ageing effects, Analysis of blood components and exogenic substances, blood stain analysis
- c. DNA Profiling: (3L)  
DNA and its polymorphism, DNA typing procedures-RFLP, PCR, MVR-PCR, Dot-blot, AMP-FLP, STR methods, applications, interpretation and practical use
- d. Determination of alcohol in body fluids: (3L)  
Legal background, sampling and sample preservation, alcohol content analysis by GC, IR and enzymatic methods
- e. Fingerprint analysis: (3L)  
Latent fingerprints; optical, physical, physico-chemical & chemical detection methods; fingerprints in blood, fingerprint detection sequences
- f. Hair analysis: (3L)  
Structure and composition of hair, morphological examination, Chemical analysis of hair components and components remaining on or in hair
- g. Systematic Drug Identification: (3L)  
Classification and categories of compounds involved, analytical strategy-TLC, LC, GC-MS, etc., requirements for identification, possibilities & limitations of selected techniques
- h. Materials of interest for Forensic studies: (8L)  
Explosives: Types, analytical methods for identification of low and high explosives in post-blast debris.  
Fibres: Fibres encountered at crime scene, identification of types, dye extraction and analysis, colour matching, analysis for metals, additives and contaminants-SEM-EDX, XRD, XRF.  
Paints, Varnishes and Lacquers: Formulation of paints, types of sample, Sample pre-treatment prior to analysis, colour measurements, Analysis by SEM, TEM, TLC/HPTLC, PyrGC, IR, Raman, UV-Vis-Flu, XRF, AES, TG-DTA. Glass: As forensic evidence, measurement of physical properties, elemental analysis-XRD, NAA, etc., interpretation of results, casework examples.

Arson Residues : nature of arson evidence, chemical evidence, properties of liquid accelerants, sampling and sample pre-treatment, laboratory examination of suspect arson evidence, evidential value.

Gunshot Residues: Composition of sources, detection on hands & its limitations, determination of muzzle-to-target distance, elemental & inorganic analysis, numericals on estimation of energy released by combustion reactions, etc.

**References:**

1. 'Forensic Chemistry' by Suzanne Bell, Pearson Prentice Hall Publishers, 2006
2. Encyclopaedia of Analytical Chemistry, Volume 3, Academic Press, 1995

**AC- 456 Recent advances in analytical chemistry (4Credits)(60L)**

Advanced Separation methods

- a. HPLC, GC and applications, Ultrahigh pressure liquid chromatography, Hydrophilic interaction liquid chromatography, Chiral separations, Affinity Chromatography, Size Exclusion chromatography, Ion chromatography, Headspace GC, Pyrolysis GC, Electrokinetic Chromatography (8L)
- b. Green Chromatographic techniques: Separation and Purification of organic and Inorganic analytes: Saving solvents in chromatographic purifications: The counter current Chromatography technique, Ion size exclusion chromatography on hypercrosslinked polystyrene sorbents, Supercritical fluid chromatography-green techniques in GC and its applications (5L)
- c. Theory of electrophoresis, capillary electrophoresis, electro-osmotic flow, SDS-PAGE, vertical and horizontal electrophoresis and their applications, 2D Gel electrophoresis. Agarose gel electrophoresis and its applications. Isoelectric focusing its theory and applications. Micellar electrokinetic chromatography, Fingerprinting and large-scale preparative electrophoresis. Applications in Nucleic acids, Clinical and capillary zone electrophoresis of carbohydrates. (5L)

Electroanalytical methods:

- a. Controlled potential Techniques: Polarography, Pulse voltammetry, Normal pulse, differential pulse, square wave and staircase voltammetry, Stripping Analysis- Anodic stripping voltammetry, potentiometric stripping analysis, cathodic stripping voltammetry, abrasive stripping voltammetry and applications. (4L)
- b. Potentiometry: Principles and Ion selective electrodes, glass electrodes, liquid membrane electrodes, solid state electrodes, On line, On site and in vivo potentiometric measurements. examples and problems (6L)
- c. Coulometry and amperometry (4L)
- d. Electrochemical sensors:

Electrochemical biosensor: enzyme based electrodes and their analytical significance, Glucose, ethanol, urea electrodes and toxin (enzyme inhibition) biosensors, Tissue and bacteria electrodes, Affinity biosensors, Immunosensors, DNA hybridisation biosensor, receptor based sensors, electrochemical sensors based on molecularly imprinted polymers. gas sensors, CO<sub>2</sub> sensors and Oxygen electrodes, solid state devices: Ion selective field effect transistors, microfabrication of solid state sensor assemblies, microfabrication techniques, examples and problems **(8L)**

Microfluidic devices: Fabrication and operation of a Lab on a Chip. **(2 L)**

### Spectroscopic methods

- a. Recent advances in sensor development based on silver halide fibres for Mid IR spectrometric analysis, fiber optic probes, imaging and selected applications, Near-IR Spectroscopy and its applications, Evanescent wave spectroscopy, Two-Dimensional Correlation Spectroscopy, Spectroscopy of Cold Molecules in matrices: Study of conformational changes **(6 L)**
- b. SERS (Surface enhanced Raman Spectroscopy), Single-Molecule SERS, and TERS (Tip-enhanced Raman Spectroscopy), Femtosecond spectroscopy and investigation of ultrafast dynamics in condensed matters, Linear and non-linear Terahertz spectroscopy and Applications to biological and pharmaceutical sciences **Laser spectroscopy for nano-materials, Recent Advances in Resonance Raman Spectroscopy, Laser Applications to spectroscopy of unstable species Photoacoustic Spectroscopy, Application of Raman spectroscopy in Art and Cultural Heritage materials (10L)**
- c. Auger electron spectroscopy and X-Ray Photoelectron spectroscopy **(2L)**

### References:

1. Principles of Analytical Chemistry, Douglas Skoog, F.J. Holler and S.R.Crouch, 6th edition, Thomson Brooks/Cole, 2007
2. Molecular and Laser Spectroscopy Advances and Applications, 1st Edition, Editor V.P. Gupta, Elsevier
3. Green Chromatographic techniques: Separation and Purification of organic and Inorganic analytes, Editors: Inamuddin, Dr., Mohammad, Ali (Eds.)
4. Analytical Electrochemistry, By Joseph Wang, 3<sup>rd</sup> edition, Wiley
5. Fundamentals and applications of chromatography and related differential migration methods - Part A: Fundamentals and techniques, Editor: E. Heftmann
6. Frontiers of Molecular Spectroscopy, edited by Jaan Laane
7. Handbook of Advanced Chromatography /Mass Spectrometry Techniques, edited by Michal Holcapek, Wm. Craig Byrdwell

## **PC-446 Nanoscience and Nanotechnology**

**(4Credits)**

- a. Introduction to Nanotechnology: **(2L)**  
Introduction to the nanoworld, A new realm of matter that lies between chemistry and solid state physics, historical perspective of nanomaterials, classification of nanomaterials
- b. Metals: **(4L)**  
Structure and bonding, Properties, Reduction of Size, Size dependent properties, Applications, Synthesis of metal nanoparticles and structures
- c. Chemical and catalytic aspects of nanocrystals: **(2L)**  
Nanomaterials in catalysis, recent progress-Metals
- d. Self Assembly and Self Organization: **(2L)**  
The advantages of self assembly, Intermolecular interactions and Molecular recognition, Self assembly monolayers (SAMs)
- e. Energy and Power: **(5L)**  
Energy needs for future mobile devices, Basics of Battery and Power source Technology, Energy harvesting-Nanotechnology in portable systems
- f. Flat Panel displays: **(3L)**  
The emergence of flat panel displays, New technologies for flat panel displays, Displays as an Intuitive human interface
- g. Memory technologies for the future: **(1L)**  
Flash memory, Future options of memory technologies and their comparisons
- h. Seeing beyond the hype: **(1L)**  
What the internet teaches us about the development of nanotechnology
- i. Size and shape effect on biomedical applications of nanomaterials: **(4L)**  
Role of size and shape of nanomaterials in biomedical applications, Nanoparticles selection based on size, shape and surface, Targeted drug delivery by nanoparticles, The role of blood vessel, The significance of size, shape and surface characteristics of nanoparticles in biomedical applications, Comparison between nanorods and nanospheres, Thermotherapy or hyperthermia of tumors, Biomedical applications of Quantum dots, Carbon nanotubes and Silver nanoparticles
- j. The optical and electron microscopy, Elementary principles of phase contrast microscopy, Fundamental properties of different types of electron microscopy **(3L)**
- k. SEM and TEM: **(3L)**  
Importance of use of electrons, Electron sources: Electron Gun, Characteristics of Electron beam, Measurement of gun characteristics Scattering and diffraction, Elastic and inelastic scattering, Diffraction in TEM, Diffraction from crystals and small

- l. Lasers, apertures and resolution: (3L)  
Electron lenses, Apertures and diaphragms, The resolution of electron lenses, Lens Defects: Aberration: Spherical and chromatic astigmatism
- m. Pumps and Holders: (3L)  
The vacuum, Diffusion, Turbomolecular ion and cryogenic pumps, Leak detection, contamination, Hydrocarbon and water, plasma cleaner, Different types of holders
- n. Specimen preparation: SEM and TEM (2L)
- o. Imaging: (4L)  
Amplitude contrast, mass thickness contrast, z-contrast, Phase contrast images, Bright and Dark field surface imaging, Secondary electron and back scattered electron imaging, Detectors: Electron detection and displays, Semiconductor detectors, scintillator,- PMT, TV cameras, CCD detectors, Faraday cup, Everhart-Thornley detector, SE and BSE detectors
- p. Analysis of Samples: (2L)  
Qualitative and quantitative analysis using SEM and TEM
- q. Other Techniques: (4L)  
X-ray spectrometry, EELS, EDX, X-ray emission spectroscopy, AFM

**References:**

1. Nanoscale Materials in Chemistry, *Editor: Kenneth J. Klabunde*, Publisher: John Wiley & Sons
2. Introduction to Nanoscale Science and Technology, *Edited by: Massimiliano Di Ventra, Stephane Evoy and James R. Heflin, Jr.* Publisher: Springer
3. Nanotechnologies for Future Mobile Devices, *Edited by: Tapani Ryhanen, Micco A. Uusitalo, Olli Ikkala and Asta Korkkainen.*, Publisher: Cambridge University Press.
4. Biomedical Engineering-Technical Applications in Medicine, *Edited by: Radovan Hudak, Marek Penhaker and Jaroslav Majernik*, Publisher: InTech, Croatia.
5. Physical Principles of Electron Microscopy: An introduction to TEM, SEM and AFM, *Ray F. Egerton*, Springer.
6. Handbook of Instrumental Techniques for Analytical Chemistry, *Frank Settle* Pearson Education (Singapore).
7. Transmission Electron Microscopy: A text book for Material Science, *David B Williams and C. Barry Carter*, Springer.
8. High Resolution Electron Microscopy, *John C. H. Spence*, Oxford Science Publications

**AC-457: Project**

**(4Credits)**