GEORGE MASON UNIVERSITY
CHEM 422: Instrumental Analysis

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The objective of this course is to present modern instrumental analytical techniques used for physicochemical analysis. The techniques that you learn in this class are the basis for professional chemists working in industry, research organization, and academia. The course begins with an introduction to basic quantitative chemical processes. The course-outline below is designed to emphasize the most important analytical techniques such as separation chemistry or chromatography, mass spectrometry, dynamic electrochemistry, spectroscopy, and basic electronics. The course is taught from the viewpoint of understanding the quantitative aspects of analytical techniques, theoretical basis of the technique, and a general description of instrumentation. All problems solved and assigned are of quantitative in nature. This course requires that you have taken and passed Organic Chemistry (CHEM 314), Elementary Quantitative Analysis (CHEM 321), and Physical Chemistry I (CHEM 331 or equivalent). In addition, working knowledge with a spreadsheet program such as MS-Excel and word-processing programs are necessary.

Syllabus and schedule

Introduction. ***Chapters 1, 2:***
Analytical process and steps in chemical analysis. Sampling random heterogeneous and segregated heterogeneous materials. Units: M, mM, ppm, ppb, ppbV and their interconversions. Tools of the Trade: Errors and tolerance in general laboratory apparatus. Absolute and relative uncertainties.

Chapter 3: Experimental errors
Significant figure and rules for arithmetic operations (+-, log and antilog) - use scientific notation; know key words (fewest decimal and fewest significant figures). Systematic and random errors. Ways to detect systematic errors (always measure blank). Precision and accuracy. How to calculate relative uncertainty and propagation of errors assuming random errors? Watch the decimal place holder- the real rule for significant figures. Error in final calculation is always expressed with one significant figure. Remember that precision of the error must not be better than precision of the result. Must do the example problems and 'test yourself' questions in this chapter. Similar problems are given in the exam.

Chapter 4: Statistics
Gaussian distribution of random error. Properties of Gaussian distribution. Know the meanings of the terms. Standard deviation of the mean and its significance in reducing error. Confidence interval as range of true mean.

Chapter 4: Statistics- continued
Ways to use t-test- comparing measured and known value, comparing replicate measurements, comparing individual differences, and comparing standard deviations with F-test. Outlier- Grubb test. Method of least squares. Know the meaning and use of errors in slope and intercept. Calibration curves and must know the example in 4.8- calculating concentration error.

Chapter 5: Quality assurance and calibration
Basis of quality: know the terms and meanings- the specification in particular. What are: false positive and negative, sensitivity, and the differences in method blank, reagent blank, field blank, and instrument blank? Calculation of sensitivity, detection limit, and quantitation limit from replicate data or the concentration calibration. The use of standard calibration, standard addition, and internal standard- when and how. Homework projects are assigned. First quiz covers chapter 1-5

Analytical separations, gas chromatography

CHP 22: Introduction to Analytical Separations

Solvent extraction: distribution and extraction of solute between two immiscible phases. Effect of pH on extraction efficiency and partition coefficient. Extractions with metal chelator- know the basic equations involved. Types of chromatography, retention parameters, other basic equations and their applications.

Relation between retention factor and partition coefficient. Column capacity and scaling-up. Properties of Gaussian chromatogram- how to get $w = 4\sigma$ and peak resolution. Memorize simple equations. Diffusion, Fick's first law and its relation to band broadening, and plate height. Factors affecting resolution. Cycling technique to increase resolution. Do examples. Origin of different band broadening processes- van Deemter equation. Origin of band asymmetry- the role of solute overloading and sorption on peak shape. Microscopic description of chromatography.

High-performance liquid chromatography, Other chromatographic methods and capillary electrophoresis

Chapter 23: Gas Chromatography

Basic layout. Know OTC and relative dimensions. Types of stationary phase and separation of solutes based on polarity. Effect of column length, diameter, and film thickness on resolution. Start to think GC separation interms of solute-solvent (stat phase) interactions and the van Deemter equation. Isothermal and temperature programmed separation. Kovat's retention index. Effect of carrier gas, injection techniques, Detectors: Thermal conductivity, flame ionization, and electron capture. Mass spec as selective detector. Solid phase microextraction (SPME).

Chapter 24: Liquid Chromatography

Basic instrumentation and column properties. Nature of silica, end capping of silanol groups, and C_n stationary phase. Theoretical plates and pressure-relation to particle size. Normal phase chromatography and elutropic series. Structure of solvent bonded phase interface. Reversed phase, isocratic and gradient elution. Stationary phase for hydrophilic interaction chromatography (HILIC). Injection and detection in HPLC. Method development and optimization of mixed organic solvents. Project: Simulation of multicomponent chromatogram by spreadsheet.

Chapter 25: Ion Exchange and Capillary Electrophoresis

Ion exchanger, common active groups, selectivity, Donnan equilibrium and ion exclusion principle. Chelating resins, simultaneous separation of anions and cations one column by zwitter-ion stationary phase HIILC. The function and mechanism of of suppressor column in conductivity detection. IC without suppression, indirect UV detection, ion pair chromatography and the role of surfactants. Molecular exclusion chromatography and separation of proteins. Hydrophobic interaction chromatography. Capillary zone electrophoresis: the origin of electrophoresis and elecctroosmosis, H, N, and R_s in CZE in terms of voltage and ion mobility. Sample injection and stacking in CZE. Micellar CZE and separation of neutral species. Lab on a chip.

Midterm exam:

Basic electronics and operational amplifiers

Voltage divider, Low-pass and high-pass RC filter transient response to a pulse, concept of impedance, gain vs. frequency response of RC filters, and 3dB point. Operational amplifiers as analog interface to sensors. Properties of ideal opamp. Follower as impedance driver, inverting, noninverting, adder, 3 bit R-2R digital to analog converter, subtractor, current-to-voltage converter, integrator, and differentiator circuits. Example circuits to interface sensors (pH, FID, PMT, current multiplier, photodiode etc). Please check posted materials and handouts.

Electrochemical sensors and electroanalytical techniques *Chapter 14: Electrodes and Potentiometry*
Basic Galvanic cell, standard cell potential, reference electrodes (NHE, SSC), and reference potential. Construction of a glass-pH sensor and the origin of response. Origin of junction potential and how to minimize it. Drift in pH electrode. Membrane and solid state based ISE. Mechanism of response of F- ISE. Principle of compound electrode for CO_2(g), SO_2(g). Principle of field effect transistor based ISE. Please check example problems.

Chapter 16: Electroanalytical Techniques
Fundamentals of electrolysis, effect of voltage on current, origin of activation potential, ohmic potential, and overpotential, and concentration polarization. Controlled potential electrolysis. Difference between two electrode and three electrode cells. Constant current coulometry and electrogeneration of reagents. Amperometry, ion flux and current. Principle of glucose sensor and the role of mediator. How to derive diffusion current from concentration profile? Voltammetry: Faradaic and charging current and their role in pulse voltammetry. How to use cyclic voltammetry to characterize a redox couple?

Mass spectrometry: Chapter 21
Process of obtaining molecular mass by EI and CI. Basic instrumentation. Effect of electric and magnetic field on charged particles (equations). Fragmentation patterns of simple molecules. Resolution. Molecular ions and isotope patterns: m+./m+1 in relation to isotope abundance. Isotope ratio mass spec and its use in carbon dating. Ring and double bond equation. Identifying molecular ion peaks and number of carbons. Types of MS: Quadrupole MS, time of flight with reflectron, and ion trap. Ion mobility MS, electrospary ionization for LC-MS. How to get protein molecular mass from EI spectra.

Spectrophotometry: Application, Instrumentation , Atomic Spectroscopy
Electronic and vibrational transitions to explain UV, VIS, emission, absorption, fluorescence, and luminescence spectra. Singlet and triplet states. Electronic states of formaldehyde. Derivation of Beer's law and its limitations. Equations for luminescence.
Additivity of Beers Law. Isosbestic point and significance. Scatchard equation and application. Luminescence quenching and application. Principle of ELISA and Flow Injection.
Basic spectrometer: parts and functions. Principle of grating as monochromtaor: bandwidth, resolution, and dispersion. PMT as detector. Principle of FTIR. Noise and ways to reduce noise by moving averaging, ensemble averaging, and beam chopping. S/N ratio calculation.

Final exam:

Example computer projects: Signal and noise estimation, Parameter estimation by using linear regression: sensitivity and detection limit, Parameter estimation by using multiple linear regression: absorbance of a mixture, Parameter estimation by using non-linear data fitting: van-Deemter equation, Filtering noisy signal: Moving average smoothing, median or spike filter, signal-to-noise, signal detection limit

Attendance in the class is mandatory. Quizzes will cover the class materials. Quiz date is announced in class. No make-ups will be considered except under rare circumstances. Students with a physical handicap requiring assistance should privately contact the instructor.

METHODS OF INSTRUCTION

Smart classroom facilities and 'Chalk-Talk' are the primary methods of instruction. Exams and quizzes are based on examples, "Ask yourself question" and HW problems. Class notes, handouts, papers, and other resources are posted on the web (Blackboard) on a regular basis. Students with valid gmu email address registered for this class can access these resources.

GRADING SCHEME

Homework, class quiz, and computer projects 40%, Midterm 20% , and Final examination 40%

REQUIRED TEXT

Daniel Harris, Quantitative Chemical Analysis, 9th Edition, ISBN-10: 142925436X, ISBN-13: 9781429254366