84.314
Analytical Chemistry II
(Instrumental Analysis)

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List Price $162
UML Bookstore $231?
Internet as low as $85?
Fifth edition 1998
Sixth ed. just out 2007
Excellent reference book
Website

http://faculty.uml.edu/David_Ryan/84.314/
- Syllabus = course description
- Schedule
- Materials = Lecture Slides,  Handouts, Videos from last year

Skoog – Chapter 1
Introduction

- Basics of Instrumental Analysis
  - Properties Employed in Instrumental Methods
  - Numerical Criteria
  - Figures of Merit
<table>
<thead>
<tr>
<th>Name</th>
<th>Prize Description</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>William H. Bragg</td>
<td>analysis of crystal structure by means of X-rays (physics)</td>
<td>1915</td>
</tr>
<tr>
<td>Francis W. Aston</td>
<td>for his discovery, by means of his mass spectrograph, of isotopes (Chemistry)</td>
<td>1922</td>
</tr>
<tr>
<td>Friderik Pregl</td>
<td>invention of the method of micro-analysis of organic substances (Chemistry)</td>
<td>1923</td>
</tr>
<tr>
<td>Arne Tiselius</td>
<td>his research on electrophoresis and adsorption analysis, especially for his discoveries concerning the complex nature of the serum proteins (Chemistry)</td>
<td>1948</td>
</tr>
<tr>
<td>Felix Bloch, Edward M. Purcell</td>
<td>development of new methods for nuclear magnetic precision measurements and discoveries (Physics)</td>
<td>1952</td>
</tr>
<tr>
<td>Archer J P Martin, Richard L. M Synge</td>
<td>Invention of partition chromatography (Chemistry)</td>
<td>1952</td>
</tr>
<tr>
<td>Jaroslav Heyrovsky</td>
<td>discovery and development of the polarographic methods of analysis (Chemistry)</td>
<td>1959</td>
</tr>
<tr>
<td>Rosalyn Yalow</td>
<td>development of radioimmunoassays of peptide hormones (Physiology or Medicine)</td>
<td>1977</td>
</tr>
<tr>
<td>Kai M. Siegbahn</td>
<td>contribution to the development of high-resolution electron spectroscopy (physics)</td>
<td>1981</td>
</tr>
<tr>
<td>Gerd Binnig, Heinrich Rohrer</td>
<td>design of the scanning tunneling microscope (physics)</td>
<td>1986</td>
</tr>
</tbody>
</table>

### Analytical Methods

#### Classical
- Precipitation
- Extraction
- Distillation

#### Analytical Methods

#### Instrumental
- Physical Properties
- Conductivity
- Electrode Potential
- Light Absorption or Emission
- Mass-to-Charge ratio
- Fluorescence
- Chromatographic
- Electrophoretic

#### Precision Properties
- Gravimetric
- Volumetric
- Conductivity
- Electrode Potential
- Light Absorption or Emission
- Mass-to-Charge ratio
- Fluorescence
- Chromatographic
- Electrophoretic

#### Physical Properties
- Colors
- Boiling or Melting Points
- Solubilities
- Odors
- Optical

#### Classical
- Distillation

#### Analytical Methods

#### Instrumental
### Table 1.1: Chemical and Physical Properties Employed in Instrumental Methods

<table>
<thead>
<tr>
<th>Characteristic Properties</th>
<th>Instrumental Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission of radiation</td>
<td>Emission spectrometry (X-ray, UV, visible, electron, Auger); fluorescence, phosphorescence, and luminescence (X-ray, UV, and visible)</td>
</tr>
<tr>
<td>Absorption of radiation</td>
<td>Spectrophotometry and photometry (X-ray, UV, visible, IR); photoacoustic spectroscopy; nuclear magnetic resonance and electron spin resonance spectroscopy</td>
</tr>
<tr>
<td>Scattering of radiation</td>
<td>Turbidimetry; nephelometry; Raman spectroscopy</td>
</tr>
<tr>
<td>Refraction of radiation</td>
<td>Refractometry; interferometry</td>
</tr>
<tr>
<td>Diffraction of radiation</td>
<td>X-Ray and electron diffraction methods</td>
</tr>
<tr>
<td>Rotation of radiation</td>
<td>Polarimetry; optical rotary dispersion; circular dichroism</td>
</tr>
<tr>
<td>Electrical potential</td>
<td>Potentiometry; chronopotentiometry</td>
</tr>
<tr>
<td>Electrical charge</td>
<td>Coulometry</td>
</tr>
<tr>
<td>Electrical current</td>
<td>Amperometry; polarography</td>
</tr>
<tr>
<td>Electrical resistance</td>
<td>Conductometry</td>
</tr>
<tr>
<td>Mass</td>
<td>Gravimetry (quartz crystal microbalance)</td>
</tr>
<tr>
<td>Mass-to-charge ratio</td>
<td>Mass spectrometry</td>
</tr>
<tr>
<td>Rate of reaction</td>
<td>Kinetic methods</td>
</tr>
<tr>
<td>Thermal characteristics</td>
<td>Thermal gravimetry and titrimetry; differential scanning calorimetry; differential thermal analysis; thermal conductometric methods</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>Activation and isotope dilution methods</td>
</tr>
</tbody>
</table>

### Instruments for Analysis

**Figure 1-3** A block diagram of a fluorometer showing (a) a general diagram of the instrument, (b) a diagrammatic representation of the flow of information through various data domains in the instrument, and (c) the rules governing the data-domain transformations during the measurement process.
Performance Characteristics Of Instruments

**Precision**

- The precision of a measurement system, also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same results.

- Table 1.3: Numerical Criteria for Selecting Analytical Methods

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Figure of Merit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Precision</td>
<td>Absolute standard deviation, relative standard deviation,</td>
</tr>
<tr>
<td></td>
<td>coefficient of variation, variance</td>
</tr>
<tr>
<td>2. Bias</td>
<td>Absolute systematic error, relative systematic error</td>
</tr>
<tr>
<td>3. Sensitivity</td>
<td>Calibration sensitivity, analytical sensitivity</td>
</tr>
<tr>
<td>4. Detection limit</td>
<td>Blank plus three times standard deviation of a blank</td>
</tr>
<tr>
<td>5. Concentration range</td>
<td>Concentration limit of quantitation (LOQ) to concentration limit of linearity (LOL)</td>
</tr>
<tr>
<td>6. Selectivity</td>
<td>Coefficient of selectivity</td>
</tr>
</tbody>
</table>

Accuracy of a measurement system is the degree of closeness of measurements of a quantity to its actual (true) value.
Bias provides a measure of the systematic, or determinate, error of an analytical method.

\[ \Delta = \mu - \tau \]

Where \( \mu \) is the population mean for the concentration of an analyte

\( \tau \) is the true value

Sensitivity

Sensitivity of a method or instrument is a measure of its ability to discriminate between small differences.

Two factors limit sensitivity

- The slope of calibration curve
- Reproducibility or precision of the measuring device

\[ S = mC + S_{bl} \]

Detection limit

Minimum concentration or mass of analyte can be detected at a known confidence level

\[ Sm = S_{bl} + ks_{bl} \]

Usually, \( k = 3 \)
Dynamic range

- LOQ limit of quantitation
- LOL limit of linearity
- Dynamic range should be at least a few orders of magnitude

Selectivity

- Selectivity refers to the degree to which the method is free from interference by other species in sample
Calibration of instrumental method

Calibration determines the relationship between analytical response and analytical concentration.

1. external-standard calibration
   - No interference effects
   - Obtain response signal as a function of known analyte concentration

2. Standard- additional methods

   Adding one or more increments of standard solution to sample aliquots
   - \( S_x = K_1 C_x \)
   - \( S_T = K_1 (C_x + C_s) \)
   - \( C_x = C_s S_x / (S_T - S_x) \)
   - When \( S_T = S_x \)
   - \( C_x = -C_s \)
Calibration of instrumental method

- 3. internal-standard method
- Add a constant amount of substance to all samples, blanks, and calibration standard.
- Plot ratio of analyte signal and internal-standard as a function of analyte concentration.

Homework: P23 1-10

Skip the following chapters

- Chapter 2 – Electrical Components and Circuits
- Chapter 3 – Operational Amplifiers in Chemical Instrumentation
- Chapter 4 – Digital Electronics and Microcomputers
Skoog – Chapter 5
Signals and Noise

- Signal to Noise Ratio
  All instrumental measurements involve a signal
  Unfortunately all signals have noise present
  Sometimes the noise is large
  Sometimes it is so small you can't see it
  Noise is constant and independent, small signal
  large noise
  S/N is very important

Current measurements
(a) with noise,
(b) with noise averaged out

Noise is often constant and independent of signal
Signal to Noise Ratio (S/N)

- Parameter describing quality of data
- Often referred to as “figure of merit”

\[ \frac{S}{N} = \frac{\bar{X}}{s} \]

\[ \text{RSD} = \text{relative standard deviation} \]

Impossible to detect a signal when S/N less than 2 or 3

NMR spectra for Progesterone
A) S/N = 4.3
B) S/N = 43

Very little confidence in ability to determine peaks at lower S/N
↓
Detection Limit
Sources of Noise

- **Chemical noise** – temp, pressure, humidity, etc. fluctuations = uncontrolled variables

- **Instrumental noise** – noise from instrumental components
  - Thermal noise (Johnson noise) – thermal motion of electrons in load resistor
  - Voltage fluctuation

\[
v_{\text{rms}} = \sqrt{4kTR\Delta f}
\]

\[\Delta f = \frac{1}{3}t_r\]

Narrow bandwidth to decrease noise, but instrument will be slower
**Instrumental noise**
- Shot noise – movement of electrons across a junction

\[ i_{\text{rms}} = \sqrt{2 ie \Delta f} \]

- Flicker noise – any noise that is inversely proportional to signal \(1/f\)

Significant at low frequency (<100 Hz)
- Environmental noise – composite of many noise sources
  e.g. any electrical device gives off
  EM (electromagnetic radiation)
  ELF radiation = health controversy
  instruments may pick up signals
Environmental noise sources (note frequency dependence)

- **Hardware**
  - Grounding & shielding – Faraday cage
  - Analog filtering – RC filtering
  - Modulation – convert DC signal to high frequency AC then demodulate
  - Signal chopping – rotating wheel to differentiate e.g. IR source from heat
  - Lock-in amplifiers

**Improving S/N hardware & software**
Primitive Faraday Cage for shielding instruments from EM Radiation – must be grounded

Analog Filtering or RC Filtering

Noisy data

RC filter

Filtered data

$v_i$

Time

$v_i$

$R$

$C$

$v_o$

Time
Modulation

Signal chopping in an IR spectrophotometer
Chopper amplifier
Improving S/N hardware & software

- Software
  - Ensemble averaging – adding spectra
  - Boxcar averaging –
  - Digital filtering – moving window, sliding average
  - Correlation methods

Ensemble averaging i.e. adding or averaging signal
Boxcar averaging