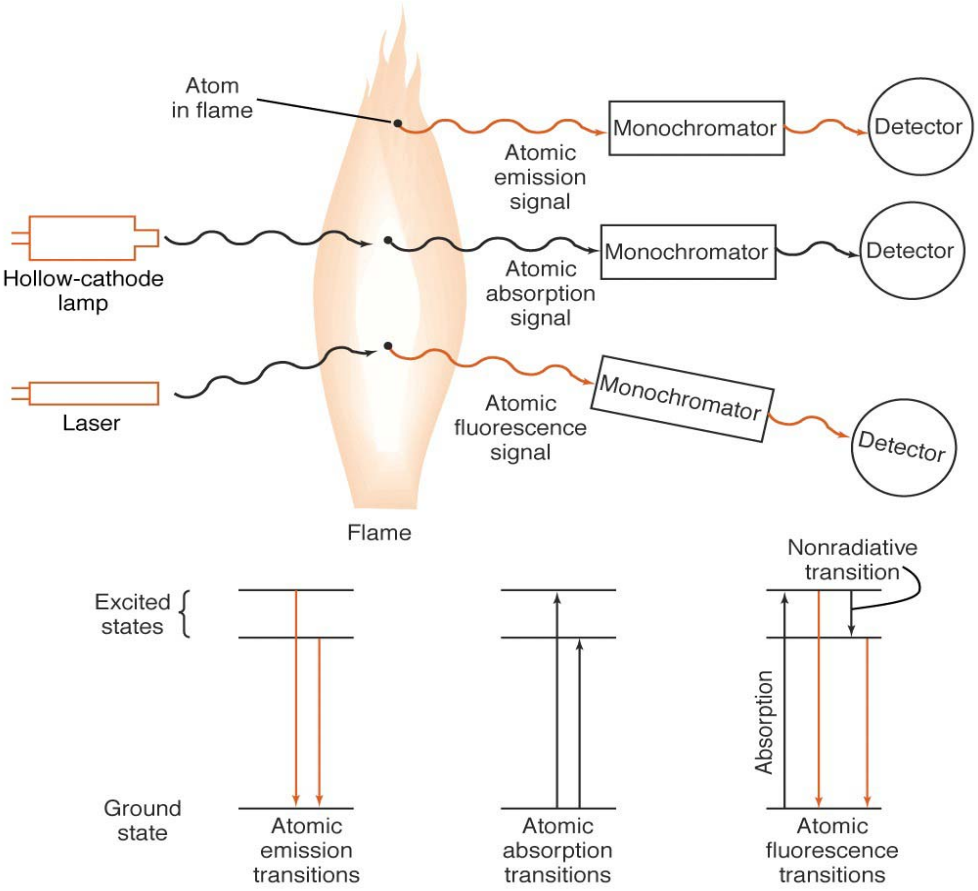
Atomic Spectroscopy



Atomic spectroscopy – need to convert the analyte to free, unbound atoms or ions (atomization).

Atomic Spectroscopy

- Unbound atoms, rather than molecules, are the absorbing species.

- Monochromator in atomic absorption or emission is place after the sample (remove unwanted radiation during atomization process).

- Bandwidths are very narrow (0.002-0.005 nm), often referred to as lines.

Atomization

a. Flame – premix burner (fuel, oxidant and sample mixed before flame introduction)

- Drawn into pneumatic nebulizer by air (oxidant) and creates small droplets (aerosol).

b. Electrothermal – the graphite furnace

- greater sensitivity and less sample

- maintains constant temperature, reducing memory effects

c. Inductively coupled plasma (ICP), 0.001-50 ng L^{-1}

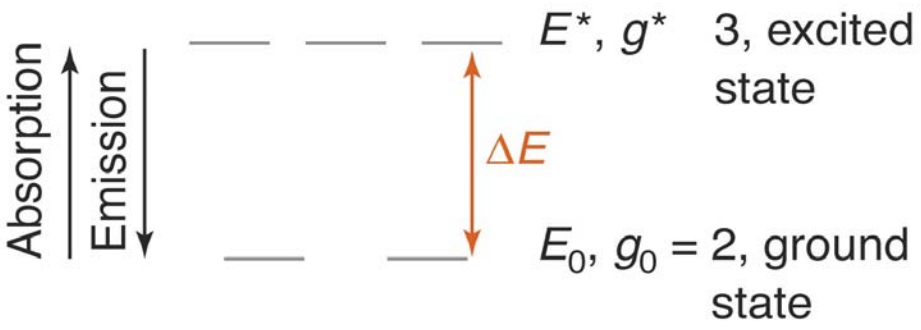
- high temperature, stability and chemically inert Ar environment

Atomization method	**Temperature (K)**	**Measurement Type**
Flame	2300-3400	Abs, emission
Electrothermal	2000-3300	Abs, emission
ICP	6000-8500	emission

Temperature Effects

Boltzmann Distribution – degeneration of energy states (describes the relative populations of diff. states at thermal equilibrium).

- Ground state atoms can absorb light to be promoted to the excited state.
- Excited state atoms can emit light to return to the ground state.



$$\textit{Boltzmann distribution: } \frac{N^*}{N_0} = \frac{g^*}{g_0} e^{-\Delta E / kT}$$

Where T is temperature (K), k is Boltzmann's constant (1.381×10^{-23} J/K)

Ex. Calculate the fraction of sodium atoms in the excited state in an acetylene-air flame at 2600 K.

- lowest excited state = 3.371×10^{-19} J/atom above ground state
- Degeneracy of excited state = 2, ground state = 1

$$\frac{N^*}{N_0} = \left(\frac{2}{1}\right) e^{-(3.371 \times 10^{-19} J)/[(1.381 \times 10^{-23} J/K) \bullet (2600 K)]} = 1.67 \times 10^{-4}$$

- fewer than 0.02% of atoms are in the excited state

The Effect of Temp. on Absorption and Emission

- Excited state population changes by 4% when the temperature rises 10 K….therefore the emission intensity rises by 4%.

Table 21-3 Effect of energy difference and temperature on population of excited states

Wavelength difference of states (nm)	Energy difference of states (J/atom)	Excited-state fraction $(N^*/N_0)^a$	
		2 500 K	6 000 K
250	7.95×10^{-19}	1.0×10^{-10}	6.8×10^{-5}
500	3.97×10^{-19}	1.0×10^{-5}	8.3×10^{-3}
750	2.65×10^{-19}	4.6×10^{-4}	4.1×10^{-2}

a. Based on the equation $N^*/N_0 = (g^*/g_0)e^{-\Delta E/kT}$ in which $g^* = g_0 = 1$.

Read – 21-4 Instrumentation, 21-6 ICP-MS

Table 21-4 Comparison of atomic analysis methods

	Flame absorption	Furnace absorption	Plasma emission	Plasma–mass spectrometry
Detection limits (ng/g)	10–1 000	0.01–1	0.1–10	0.000 01–0.000 1
Linear range	10^2	10^2	10^5	10^8
Precision				
short term (5–10 min)	0.1–1%	0.5–5%	0.1–2%	0.5–2%
long term (hours)	1–10%	1–10%	1–5%	<5%
Interferences				
spectral	very few	very few	many	few
chemical	many	very many	very few	some
mass	—	—	—	many
Sample throughput	10–15 s/element	3–4 min/element	6–60 elements/min	all elements in 2–5 min
Dissolved solid	0.5–5%	>20% slurries & solids	1–20%	0.1–0.4%
Sample volume	large	very small	medium	medium
Purchase cost	1	2	4–9	10–15

SOURCE: Adapted from TJA Solutions, Franklin, MA.

Analytical Separations

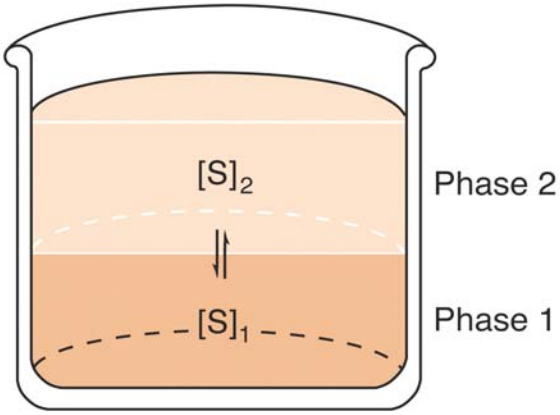
Why do we use analytical separations?

- interferences
- identify
- measure

Gas-Liquid	Gas-Solid	Liquid-Liquid	Liquid-Solid
Distillation	Sublimation	Extraction	Precipitation
Gas Chromatography	Adsorption	Liquid Chromatography	Adsorption
	Molecular sieves		Ion Exchange

<u>Solvent Extraction</u>

- Transfer of a solute from one phase to another.



Distribution is in equilibrium process: $S_{aq} \Leftrightarrow S_{org}$

For which: $K_D = \frac{[S]_{org}}{[S]_{aq}}$, where K_D is called distribution coefficient

(book: partition coefficient)

Knowing K_D can help determine the extent to which a solute is transferred.

Let m = amount of solute (S) in mmoles, q = fraction of S remaining in the aqueous phase at equilibrium:

$$[\mathrm{S}]_{\mathrm{aq}} = \frac{(\text{fraction remaining})\,(\text{total amount})}{\text{volume aq phase}} = \frac{qm}{V_{aq}}$$

$$[\mathrm{S}]_{org} = \frac{(\text{fraction transferred})\,(\text{total amount})}{\text{volume org phase}} = \frac{(1-q)m}{V_{org}}$$

$$K_D = \frac{(1-q)m/V_{org}}{qm/V_{aq}} = \frac{(1-q)V_{aq}}{qV_{org}}$$

$$q = \frac{V_{aq}}{K_D V_{org} + V_{aq}}$$

The fraction of solute transferred to the organic phase is 1-q, or:

$$= 1 - \frac{V_{aq}}{K_D V_{org} + V_{aq}}$$

Fractions remaining after two extractions:

$$q \text{ x } q = \left(\frac{V_{aq}}{K_D V_{org} + V_{aq}} \right)^2$$

The fraction remaining in the aqueous phase after *n* extractions w/ V_{org} portions of organic solvent:

$$q^n = \left(\frac{V_{aq}}{K_D V_{org} + V_{aq}} \right)^n$$

The percentage of solute transferred to the combined organic phases after *n* extractions:

$$\% E = (1 - q^n) \times 100$$

or

$$\% E = \left[1 - \left(\frac{V_{aq}}{K_D V_{org} + V_{aq}} \right)^n \right] x100$$

Ex: If the K_D for a metal chelate partitioning between water and chloroform is 6.4, calculate the fraction of chelate extracted when 25.0 mL of 4.3×10^{-2} M ML is shaken with 10.0 mL portion of chloroform.

Fraction remaining after 1 extraction:

$$q = \frac{25.0mL}{(6.4)(10mL) + 25.0mL} = 0.281$$

$$= 1 - q = 1\text{-}0.281 = 0.719$$

After two successive 10.0 mL portions of chloroform:

$$q^2 = \left[\frac{25.0mL}{(6.4)(10mL) + 25.0mL} \right]^2 = 0.0790$$

$$\text{the fraction extracted} = 1 - q^2 = 1 - 0.0790 = 0.921$$

pH Effects

- neutral species more soluble in an organic solvent
- charged species more soluble in an aqueous solution

Consider: basic amine with neutral form (B), has a K_D between aqueous phase 1 and organic phase 2. Conjugate acid, BH^+, is only soluble in aqueous phase 1. Also consider its acid dissociation constant as K_a

$$\textit{Distribution ratio (coefficient)} = D = \frac{C_{org}}{C_{aq}}$$

$$D = \frac{[B]_{org}}{[B]_{aq} + [BH^+]_{aq}}$$

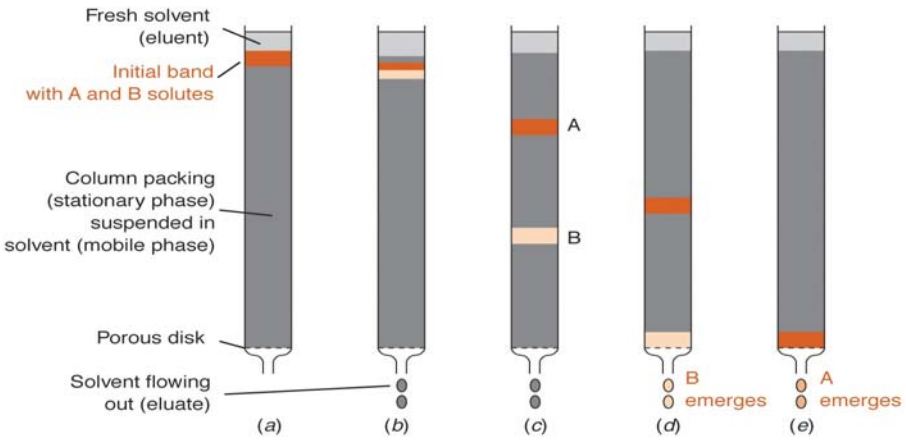
Substituting $K=[B]_{org}/[B]_{aq}$ and $K_a= [H^+][B]_{aq}/[BH^+]_{aq}$

$$\textit{Distribution of base between 2 phases}: \quad D = \frac{K \bullet K_a}{K_a + [H^+]} = K \bullet \alpha_B$$

Where α_B= fraction of weak base in neutral form, B, in aq phase

Chromatography

-same principle as extraction, but one phase is held in place while the other moves past it.



eluent $\rightarrow$ column $\rightarrow$ eluate

Mobile phase – the solvent moving through the column (liquid or gas)

Stationary phase – stays place inside the column (viscous liquid bound inside column)

Types of Chromatography

-read pg. 555-556 Harris

Chromatogram

- Retention time (t_r) = time needed after injection of the mixture onto the column until it reaches the detector.

- Retention volume (V_r) = vol of mobile phase required to elute a solute from the column.

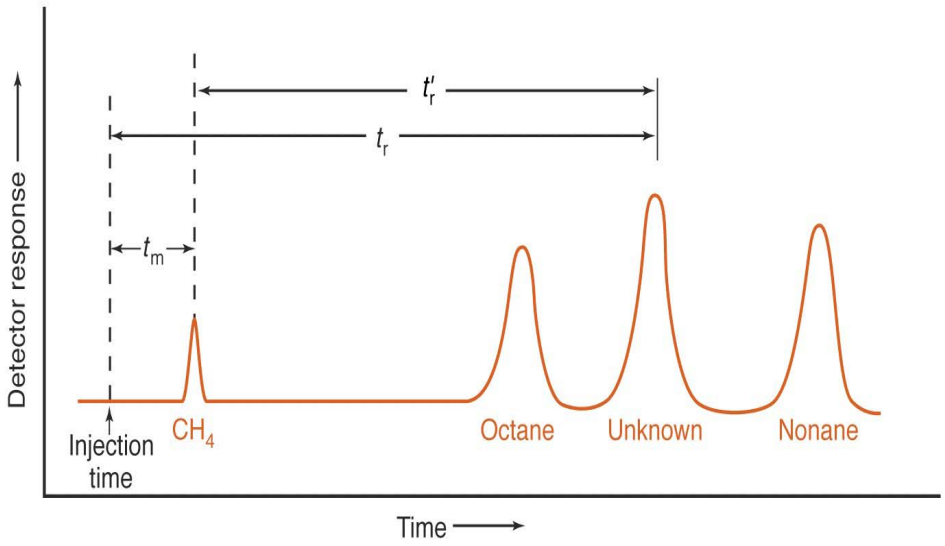
- Adjusted retention time (t'_r) = additional time required for solute to travel the length of column, beyond the time required by unretained solvent.

Adjusted retention time: $t'_r = t_r - t_m$

For any two components 1 and 2, the *relative retention*, α, is the ratio of their adjusted retention times:

Relative retention: $$\alpha = \frac{t'_{r2}}{t'_{r1}}$$

where $t'_{r2} > t'_{r1}$, so $\alpha > 1$ – the greater the relative retention, the greater the separation between two components.



For each peak in the chromatogram, the *capacity factor*, k', is defined:

$$k = \frac{t_r - t_m}{t_m}$$

Ex. A mixture of benzene toluene and methane was injected into a GC. Methane = 42 s, benzene = 251 s, toluene = 333 s. Find the adjusted retention time and capacity factor for each solute and the relative retention.

Adjusted:
Benzene: $t'_r = t_r - t_m = 251-42=209s$

Toluene: $t'_r = 333-42 = 291s$

Capacity factors:

Benzene: k'= $\frac{t_r - t_m}{t_m} = \frac{251-42}{42} = 5.0$

Toluene: k'= $\frac{t_r - t_m}{t_m} = \frac{333-42}{42} = 6.9$

Relative retention:

$\alpha = \frac{t'_r\,(toluene)}{t'_r\,(benzene)} = \frac{333-42}{251-42} = 1.39$

Efficiency of separation

-farther the elution time between peaks, the better the separation

-the wider the peaks, the poorer the separation

Resolution:

$$= \frac{\Delta t_r}{w_{av}} = \frac{\Delta V_r}{w_{av}} = \frac{0.589\Delta t_r}{w_{1/2av}}$$

where Δt_r or ΔV_r is the separation between peaks and w_{av} = average width of the two peaks in corresponding units

Ex. A peak with a retention time of 407 s has a width at the base of 13s. A neighboring peak is eluted at 424 s with a width of 16 s. Find the resolution of these two components.

$$\textit{Resolution}: \frac{\Delta t_r}{w_{av}} = \frac{424 - 407}{1/2(13 + 16)} = 1.17$$

Chapter 23, sections 1-4, up to plate theory