



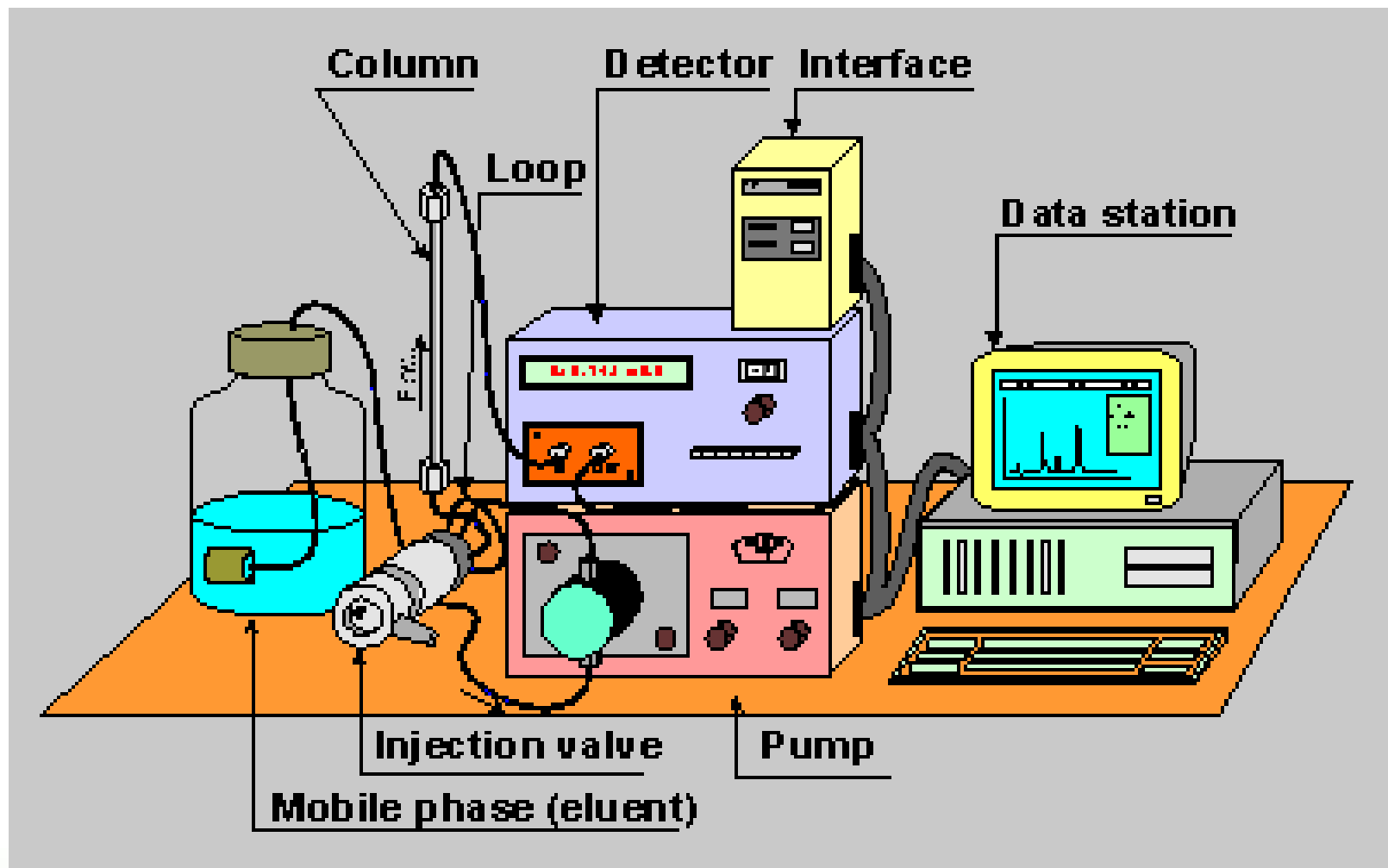
# Chemistry 4631

## Instrumental Analysis

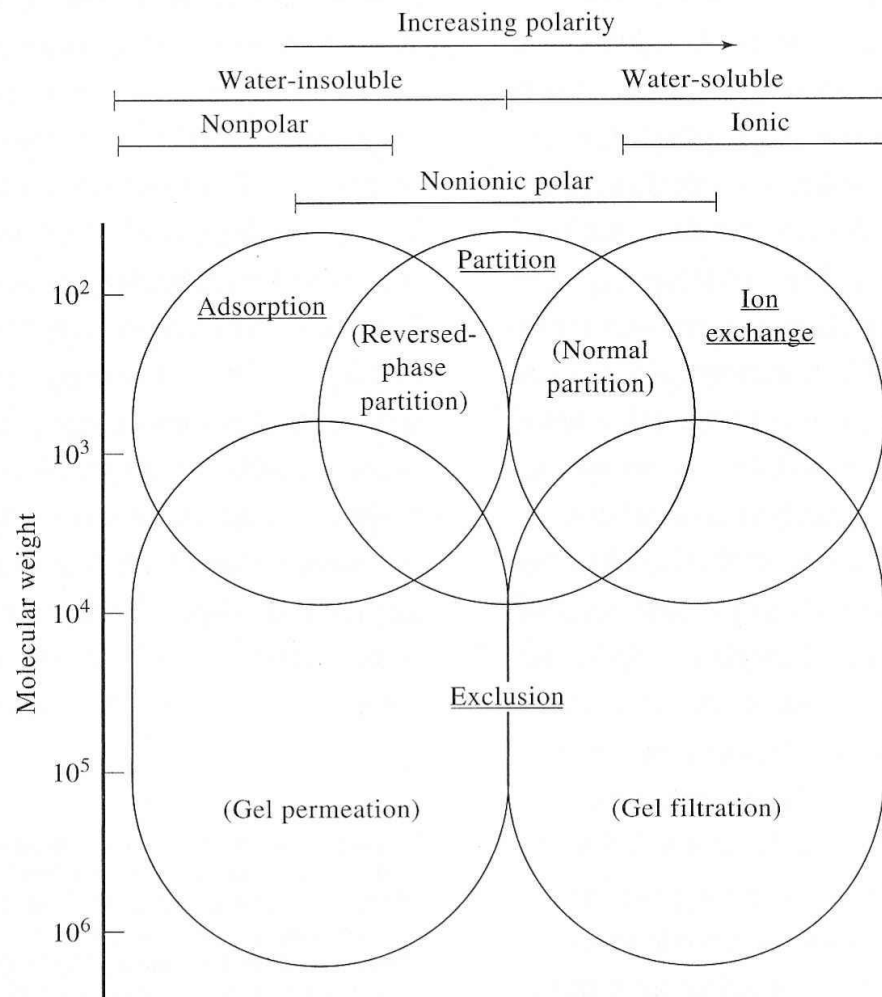
### Lecture 29

# High Performance Liquid Chromatography (HPLC)

## Instrumentation



# HPLC



**Figure 28-1** Applications of liquid chromatography. (From D. L. Saunders, in *Chromatography*, 3rd ed., E. Heftmann, Ed., p. 81. New York: Van Nostrand Reinhold, 1975. With permission.)

# HPLC

## Normal Phase Chromatography

**Normal Phase - a polar stationary phase with a less polar mobile phase.**

**Neutral solutes are separated on the basis of their polarity. More polar solute, longer retention time.**

# HPLC

## Normal Phase Chromatography

### Mechanism of Retention

Dominant retention mechanism is adsorption. Also called adsorption chromatography.

Selectivity depends on relative strength of the polar interaction.

The spatial configuration - how the solute is positioned on the stationary phase is important (sensitive to spatial or steric differences).

# HPLC

## Normal Phase Chromatography

### Stationary Phase for Normal-Phase

Wide range of stationary phase materials have been used:

sucrose

starch

fluorisil

magnesium oxide

cellulose

silica gel

charcoal

alumina

# HPLC

## Normal Phase Chromatography

### Stationary Phase for Normal-Phase

**Most common - silica or alumina that have polar hydroxyl groups on the surface.**

**Silica is preferred - available, low cost, allows higher sample loadings, less likely to catalyze decomposition of sample components.**

**Alumina is used for basic compounds (i.e. amines) which are strongly retained on silica.**

**In general, both retain more polar compounds strongly.**

# HPLC

## Normal Phase Chromatography

### Stationary Phase for Normal-Phase

Silica adsorption sites (-Si-OH, -OH groups) can be controlled by pretreatment of column.

Usually silica for HPLC treated between 200-300 °C

Drawback of normal phase - lack of separation selectivity between packing materials despite difference in particle shape, size, or surface area.

(Compounds elute in same order regardless of column selected).

So selectivity must be achieved through changing the mobile phase.

# HPLC

## Normal Phase Chromatography

### Mobile phase - solvent strength

Variation in retention is generally achieved by altering the mobile phase.

The interaction of a solvent molecule with an analyte depends on several forces: dispersion, dipole, hydrogen bonding and dielectric interactions (electrical insulator).

The extent of a molecule interacting in these four ways is referred to as the polarity of the compound.

The chromatographic strength of a solvent is directly related to its polarity.

# HPLC

## Normal Phase Chromatography

### Mobile phase - solvent strength

Biggest problem with normal phase is the effect that water has on the activity of polar adsorbents.

Water adsorbs onto the strongest adsorption sites - leaving weaker sites open to retain the sample – decreasing solute retention.

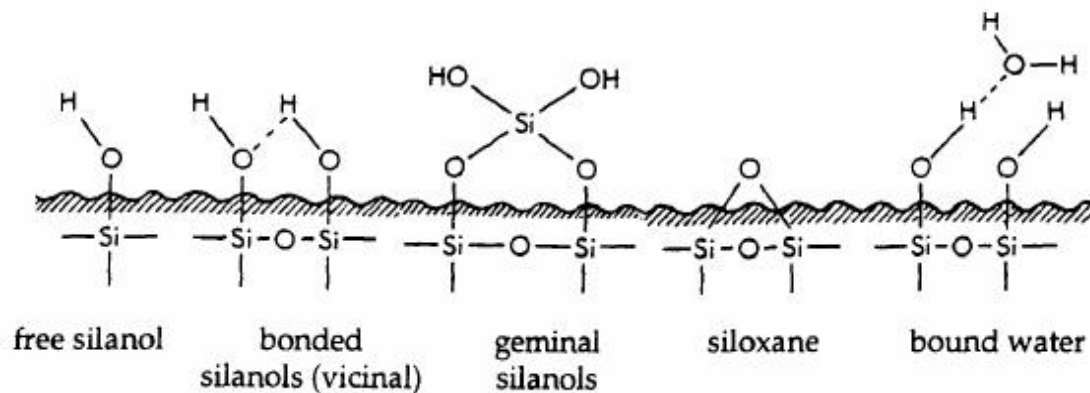
# HPLC

## Normal Phase Chromatography

### Mobile phase - solvent strength

Difficult to control amount of water present in mobile phase - easy to pick up water from atmosphere.

Generally add small amount of water to mobile phase to give less variation in sample retention from run to run.



# HPLC

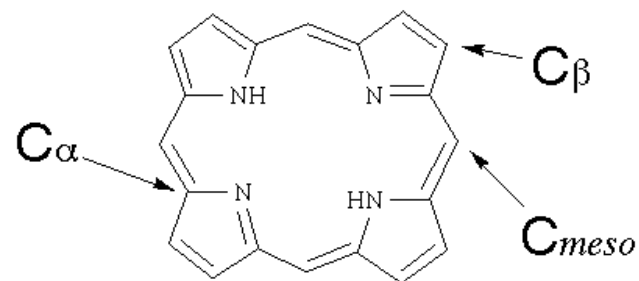
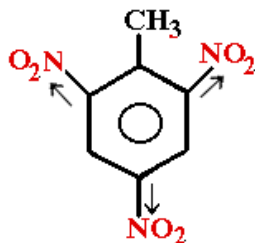
## Normal Phase Chromatography

### Applications

Normal phase used less than other HPLC techniques.

Used for analysis of samples that are soluble in non-polar solvents and for isomer separation.

Examples: fat & water – soluble vitamins  
Less-polar plant pigments – porphyrins  
Pesticides- still better with GC  
Separation of isomers (6 isomers of trinitrotoluene)



# HPLC

## Reverse-Phase Chromatography

Most widely used of LC modes (over 75%)

Uses a non-polar stationary phase with a polar mobile phase.

More polar the solute, the lower the retention time.

# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation

More complex than for normal-phase.

Interaction between solute molecule and non-polar stationary phase is too weak to explain the degree of solute retention observed.

Mechanism - combination of partition and adsorption.

# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation

#### Solvophobic theory

##### Assumes:

- using aqueous mobile phases with low organic modifier
- stationary phase is uniform layer of a non-polar ligand
- solute binds to the stationary phase and reduces surface area of solute exposed to mobile phase. (Solute binds to stationary phase because it is solvophobic)

# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation

#### Solvophobic theory

Retention occurs because of interaction between mobile phase and solute - mobile phase composition influences separation selectivity more than stationary phase (behaves as a solid).

# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation

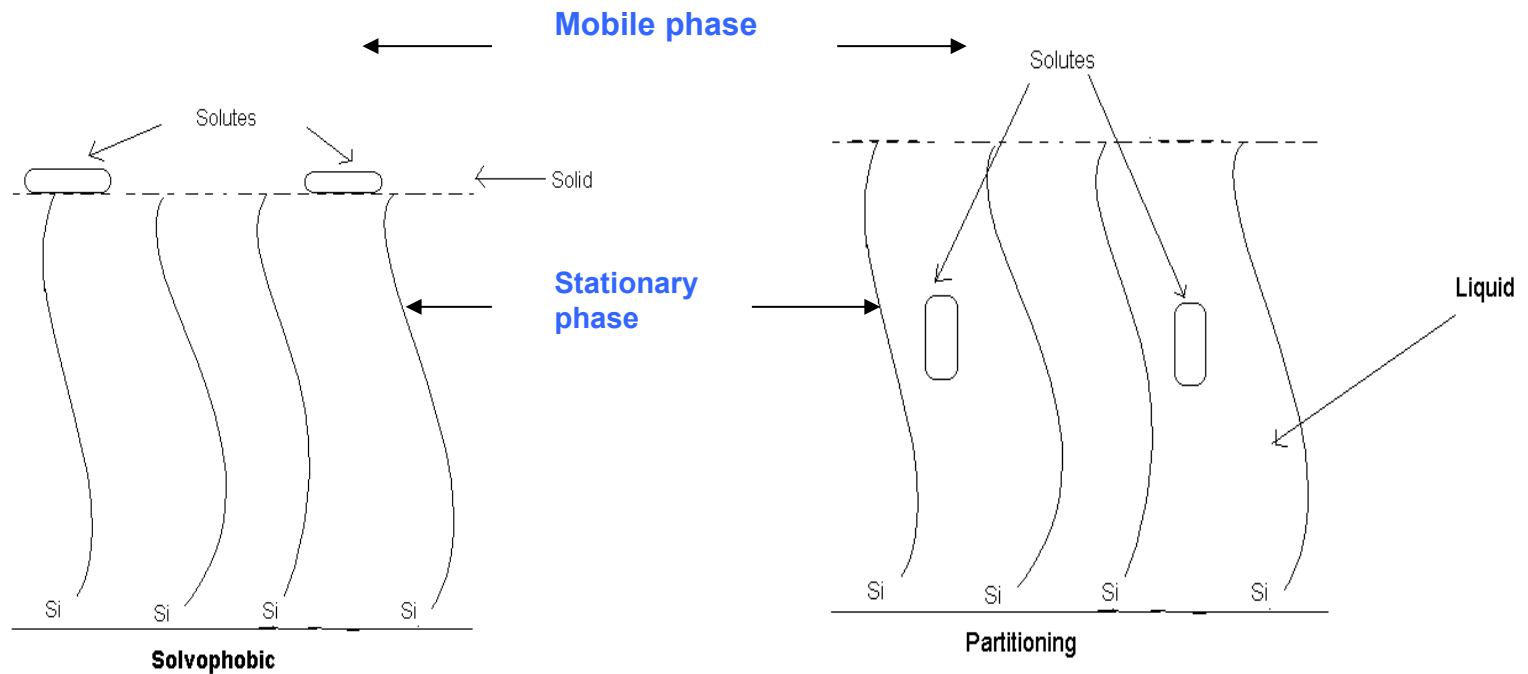
#### Partitioning theory

Solute is thought to fully interact with stationary phase and partitions between mobile phase and stationary phase (behaves as a liquid).

# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation



# HPLC

## Reverse-Phase Chromatography

### Mechanism of separation

#### Partitioning theory

As the chain length of the bonded material increases the retention mechanism is more like partitioning.

Short chain lengths - more like solvophobic (adsorption).

# HPLC

## Reverse-Phase Chromatography

### Stationary Phases - Bonded phase silica columns

Functional group is chemically attached to a silica support (like used for normal phase).

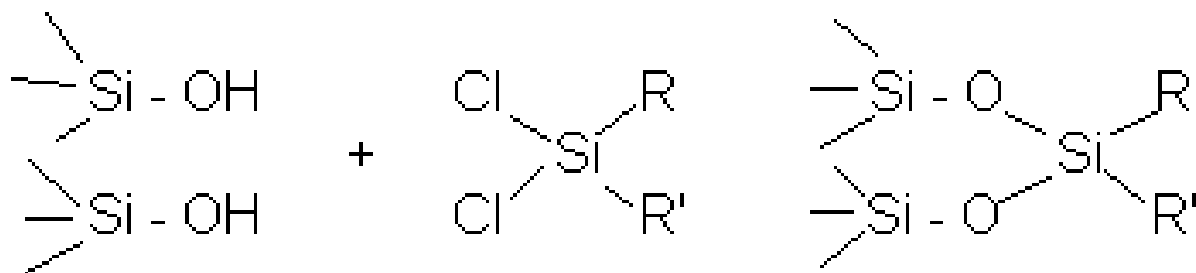
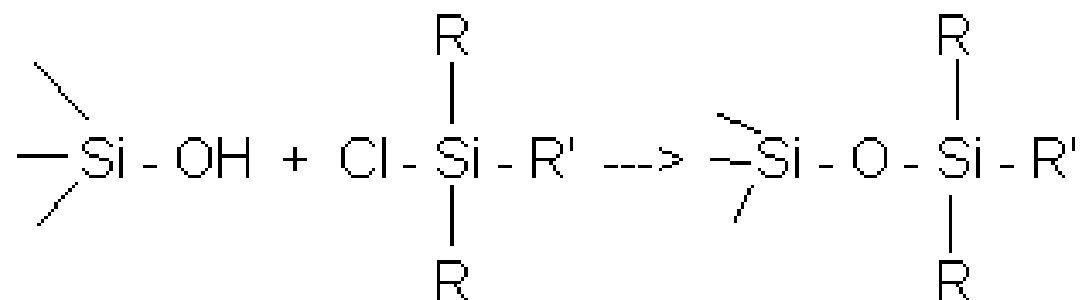
Attaching groups to the silica depends on reaction with the surface silanol groups.

Most common method - reaction of silica with organochlorosilanes to produce siloxane ( $\text{Si-O-Si-R}_3$ ) packings.

# HPLC

## Reverse-Phase Chromatography

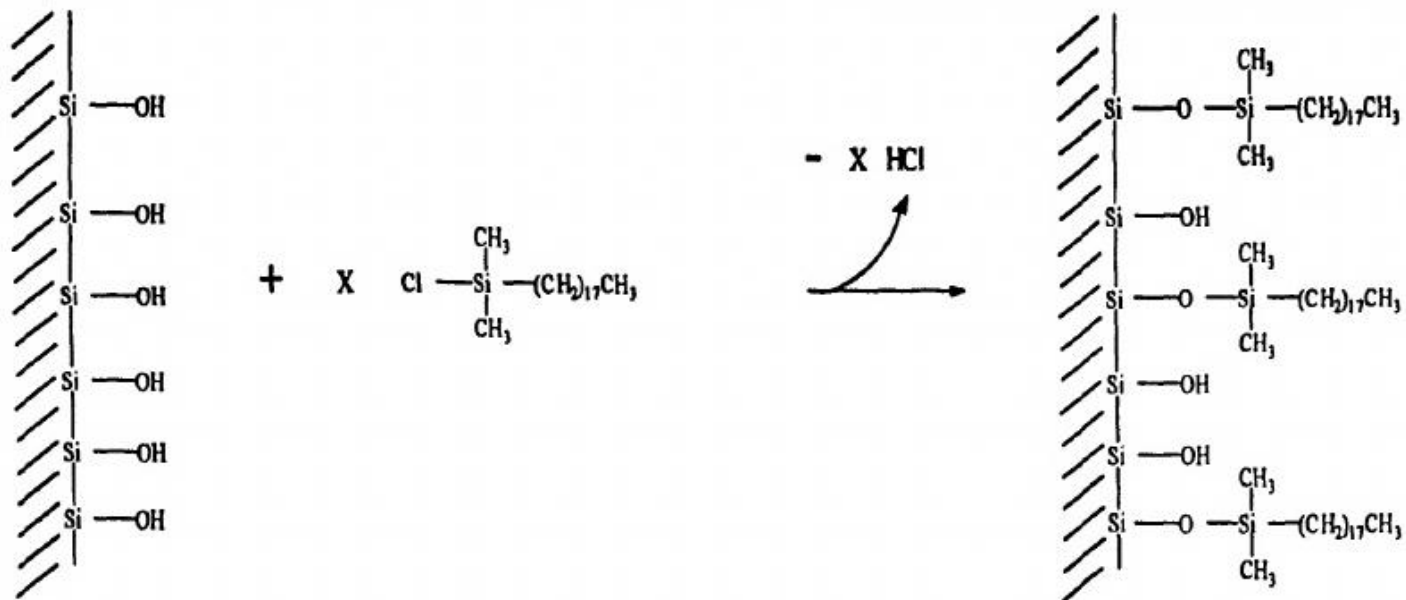
### Stationary Phases - Bonded phase silica columns



# HPLC

## Reverse-Phase Chromatography

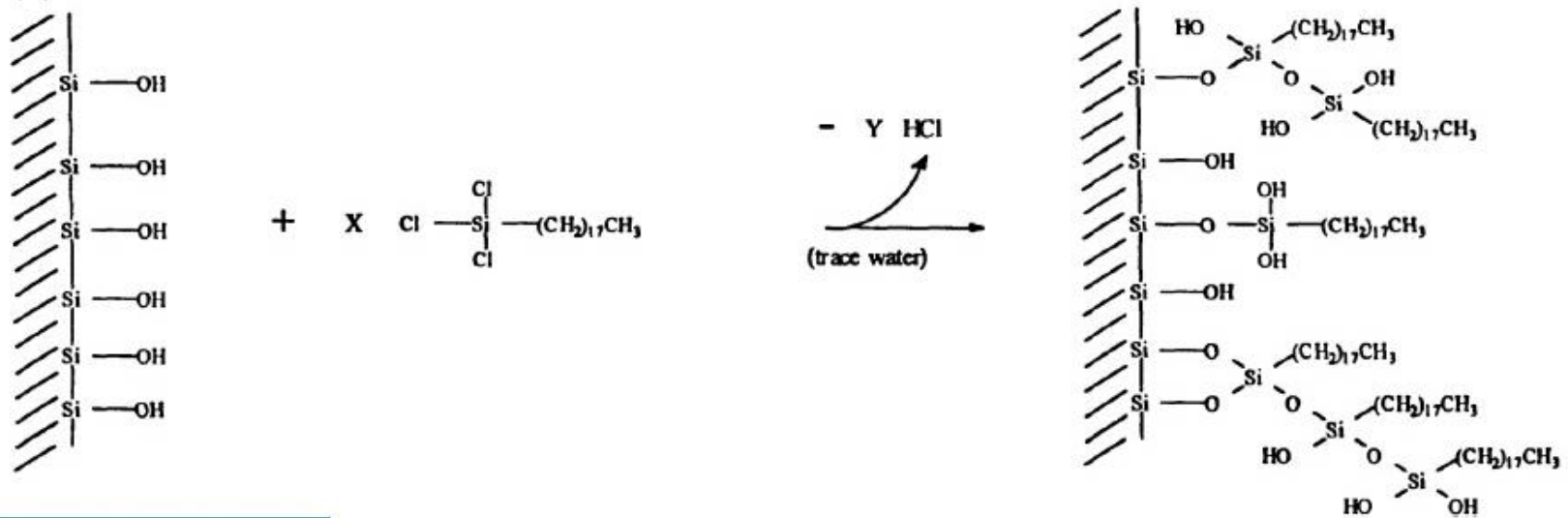
Stationary Phases - Bonded phase silica columns  
monomeric type



# HPLC

## Reverse-Phase Chromatography

### Stationary Phases - Bonded phase silica columns polymeric type



# HPLC

## Reverse-Phase Chromatography

### Stationary Phases - Bonded phase silica columns

Amount of material bonded to the silica is described by the term carbon load - amount of carbon as a weight % of bulk silica packing.

Example: Monofunctional C<sub>18</sub> - carbon load = 7-15 % (w/w)

Monofunctional preferred - easier to control - less batch to batch variation.

Higher the carbon load, more hydrophobic the column.

# HPLC

## Reverse-Phase Chromatography

Stationary Phases - Bonded phase silica columns

Identify the column by the nature of the bonded R' group. C<sub>18</sub> - most common.

Others – C<sub>8</sub>, phenyl, C<sub>6</sub>, C<sub>4</sub>, C<sub>2</sub>, CN, NH<sub>2</sub>, and NO<sub>2</sub>.

Retention increases exponentially as alkyl chain length increases.

# HPLC

## Reverse-Phase Chromatography

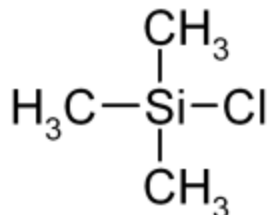
### Stationary Phases - Bonded phase silica columns

Not all silanol groups are functionalized.

These residual acidic silanol groups can cause tailing of basic compounds.

So usually after functional groups are added - an end-capping procedure is done.

This procedure uses chlorotrimethylsilane to cap open groups.



# HPLC

## Reverse-Phase Chromatography

### Stationary Phases - Bonded phase silica columns

Stability of bonded phases are largely limited by the silica support - mobile phase pH must be kept between 2-8.

Below pH 2 - hydrolysis of the bonded functional groups - decreasing retention.

Above pH 8, silica dissociates and the support starts to dissolve - creating voids in the packing material decreasing column efficiency.

# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent classification

Classification scheme developed by Snyder uses a triangle - the apexes represent solvent properties such as proton donor, proton acceptor, dipole interaction.

There are eight groups of solvents.

# HPLC

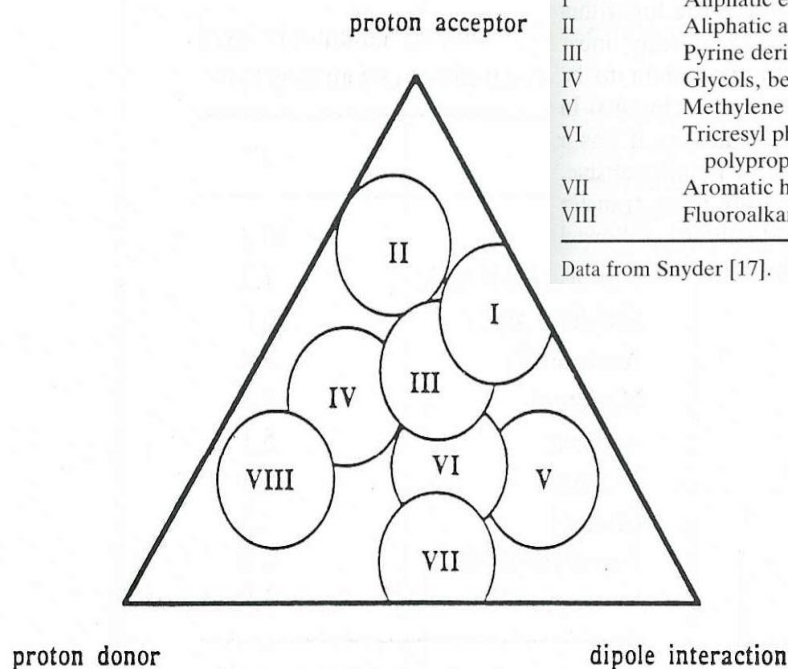
## Reverse-Phase Chromatography

### Mobile Phases - Solvent classification

**Table 6.6** Classification of solvents according to their groups.

Group	Solvents
I	Aliphatic ethers, hexamethylphosphoric acid amide, trialkyl amines
II	Aliphatic alcohols, methanol
III	Pyridine derivatives, amides, glycol ethers, sulfoxides, tetrahydrofuran
IV	Glycols, benzyl alcohol, acetic acid, formamide
V	Methylene chloride, ethylene chloride
VI	Tricresyl phosphate, aliphatic ketones and esters, polyethers, dioxane, sulfones, nitriles, polypropylene carbonate, acetonitrile
VII	Aromatic hydrocarbons, nitro compounds, aromatic ethers
VIII	Fluoroalkanols, <i>m</i> -cresol, chloroform, water

Data from Snyder [17].



**Fig. 6.15.** The solvent classification triangle which illustrates the eight selectivity groups determined by polarity and selectivity. Modified with permission from Snyder (1974) *J. Chromatogr.*, **92**, 223.

# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent Strength

Expressed as a function of polarity.

Solvent polarity parameter –  $P'$

Lower the value of  $P'$  - stronger the solvent.

Water is generally used as the base solvent and mobile phase strength determined by mixing water with another solvent (organic modifier).

# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent classification

The eluotropic series are common solvents placed in order of relative chromatographic polarity.

- Water is generally used as the base solvent and mobile phase strength determined by mixing water with another solvent (organic modifier).



# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent strength

Generally solute retention decreases by a factor of 2 for every 10% volume addition of solvent to water.

Example:

50:50 H <sub>2</sub> O/ CH <sub>3</sub> OH	nitrobenzene	$t_r = 2$ min
45:55 H <sub>2</sub> O/ CH <sub>3</sub> OH	nitrobenzene	$t_r = 1$ min
55:45 H <sub>2</sub> O/ CH <sub>3</sub> OH	nitrobenzene	$t_r = 4$ min

# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent strength

Methanol is most widely used organic modifier since it has low u.v. cut-off (205 nm), reasonable eluting strength and is inexpensive.

Acetonitrile has a lower u.v. cut-off (190 nm), better mass transfer properties, more expensive.

Tetrahydrofuran next most used.

# HPLC

## Reverse-Phase Chromatography

### Mobile Phases - Solvent strength

To find optimal mobile phase strength start with solvent-rich mobile phase (more organic modifier) and decrease organic modifier content until desired retention is obtained.

Once a binary mixture of a desired strength is found - selectivity can be altered by changing the organic modifier - while still maintaining a constant eluotropic strength.

Example: 3 mobile phases: 30:70 CH<sub>3</sub>OH/H<sub>2</sub>O or 22:78 ACN/H<sub>2</sub>O or 16:84 THF/H<sub>2</sub>O - all give equal retention but different selectivity.

There are many different equations to calculate this but a simple rule to remember is:

$$\phi_{\text{ACN}} = 0.77 \phi_{\text{CH}_3\text{OH}}$$

$\phi_{\text{M}}$  – represents the mobile phase volume fraction.

$$\phi_{\text{THF}} = 0.66 \phi_{\text{CH}_3\text{OH}}$$

# HPLC

## Reverse-Phase Chromatography

For HPLC, the separation is described by 4 major concepts:

- Capacity, efficiency, selectivity and resolution
- Capacity and selectivity of a column are controlled by the manufacturer.
- Efficiency and resolution are controlled by the user.

# HPLC

## Reverse-Phase Chromatography

### Capacity Factor

For effective LC separations, a column must have the capacity to retain samples.

Capacity factor –  $k'$  - of a column is a direct measure of the strength of the interaction of the solute with the packing material.

$$k' = \frac{t_r - t_m}{t_m} = \frac{V_r - V_m}{V_m}$$

$t_r$  – ret. time of the analyte

$t_m$  - ret. time of unretained solute (marker compounds NaI)

# HPLC

## Reverse-Phase Chromatography

### Capacity Factor

Capacity factor of a column is mostly a function of the packing material but can be manipulated to some degree by varying the solvent strength.

Higher  $k'$  - the greater the ability of the column to retain solutes, longer analysis time.

$k'$  values range 1-10

Usually  $k'$  between 2-5 represents a good balance between analysis time and resolution.

$k'$  - too low - solutes not resolved

$k'$  - too high - analysis time too long

# HPLC

## Reverse-Phase Chromatography

### Selectivity

Selectivity or separation factor,  $\alpha$ , describes the separation of two peaks relative to each other.

$$\alpha = \frac{k_2'}{k_1'} = \frac{t_{r_2} - t_m}{t_{r_1} - t_m}$$

Selectivity is a function of packing material.

Value of  $\alpha$  ranges from unity (1) when  $t_{r_2} = t_{r_1}$ ,  $\alpha \geq 1$ .

Easy way to increase  $\alpha$  is to change the composition (components) of the mobile phase.

# HPLC

## Reverse-Phase Chromatography

### Resolution

Resolution,  $R$  or  $R_s$ - degree of separation between neighboring solute peaks.  $R_s$  is affected by selectivity ( $\alpha$ ), efficiency ( $N$ ), and capacity ( $k'$ ) of the column.

$$R = \frac{1}{4} \frac{\alpha - 1}{\alpha} (N^{1/2}) \frac{k'}{1 + k'}$$

$$R_s = \frac{2(t_{r_2} - t_{r_1})}{wb_1 + wb_2}$$

# HPLC

## Reverse-Phase Chromatography

### Resolution

When the two peaks are just resolved at the baseline  $R = 1.5$ .

Increasing efficiency (double theoretical plates, longer columns) only gain 1.4 in resolution since  $R \propto N^{1/2}$ .

Better to change selectivity,  $\alpha$ , by varying the mobile phase or capacity factor,  $k'$  by varying mobile phase strength

# HPLC

## Reverse-Phase Chromatography

Efficiency – can be defined as “mechanical separation power”

Determined by the column length and the particle size

Efficiency (N) describes peak broadening as a function of retention, and is described in terms of number of theoretical plates. More efficient the column - the less band spreading.

$$N = 16 \left( \frac{t_r'}{W} \right)^2 \qquad n = 5.54 \left( \frac{t_r'}{W_{1/2}} \right)^2$$

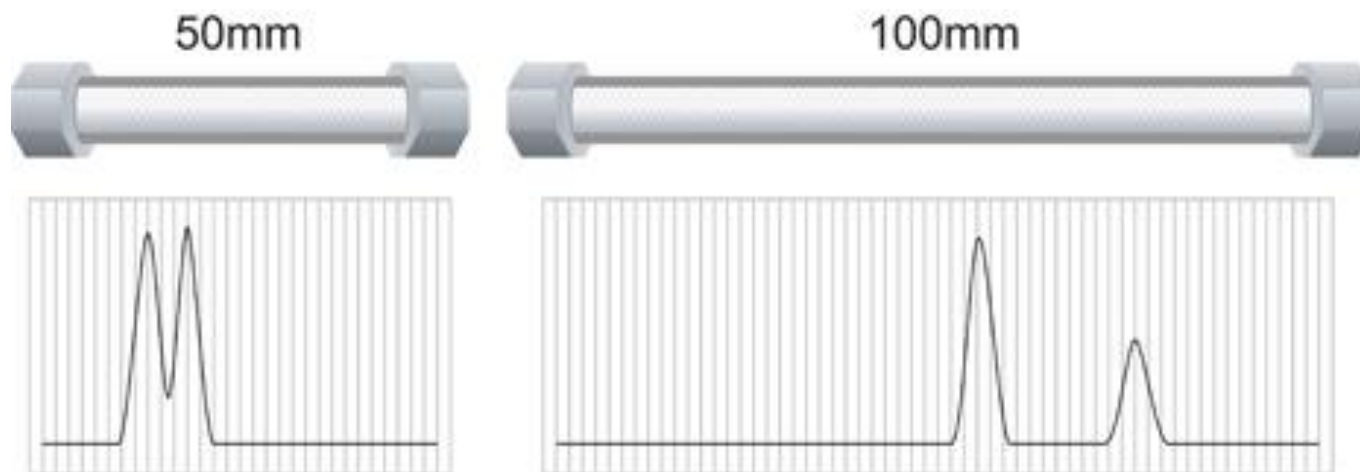
Typical ODS-C18 column ~ 12.5 cm long and 5 um packing  
N ≈ 6250    H = 0.02 mm

# HPLC

## Reverse-Phase Chromatography

### Efficiency

For a given particle size, more mechanical separation power is gained by increasing column length. However, the trade-offs are longer chromatographic run times, greater solvent consumption, and higher backpressure. Shorter column lengths minimize all these variables but also reduce mechanical separation power.



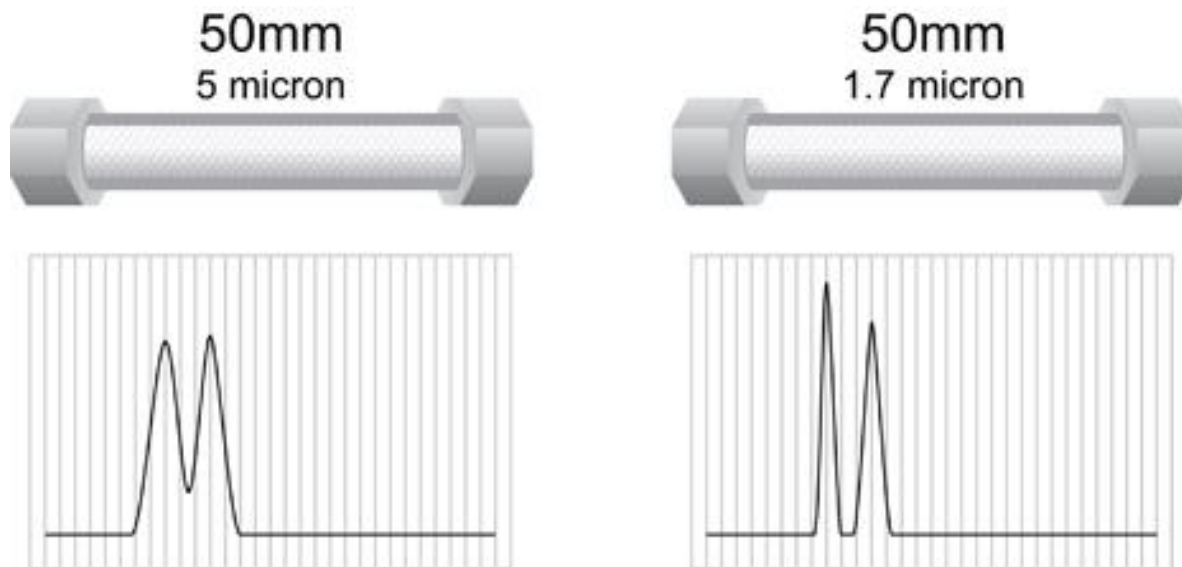
# HPLC

## Reverse-Phase Chromatography

### Efficiency

A column of the same length and i.d., but with a smaller particle size, will deliver more mechanical separation power in the same time.

However, its backpressure will be much higher.



# HPLC

## Reverse-Phase Chromatography

### The Fundamental Resolution Equation

$$R_s = \frac{\sqrt{N}}{4} \frac{(\alpha - 1)}{\alpha} \frac{k}{(k + 1)}$$

- $\alpha$  = Selectivity (influenced by mobile and stationary phase)
- $N$  = Column Efficiency (influenced by length and particle size)
- $k$  = Capacity Factor (retention) (influenced by stationary and mobile phase)

# HPLC

## Reverse-Phase Chromatography

### Applications

With RPLC best separations are of neutral solutes that are soluble in water or other relatively polar solvents with molecule weights less than 2000-3000.

Hydrocarbons was the first group separated with reverse phase.

Non-polar solutes or fatty acids resolved on the basis of their carbon chain length.

# HPLC

## Reverse-Phase Chromatography

### Applications

Largest HPLC reverse phase industry is pharmaceutical for drug analysis.

Clinic labs - analysis of plasma and urinary catecholamines with EC detection.

Also amino acids, proteins, peptides.

Analysis of food - beverage, agriculture, carbohydrates, food additives, aflatoxins, sweeteners.

Environmental samples - pesticides, pollutants

# Assignment

- Read Chapter 27
- HW16 Chapter 27: 1-5, 11-19 & 21-23
- HW16 Chapter 27 Due 4/13/26
  
- Read Chapter 28
- Homework Chapter 28: 2-12, & 15
- HW17 Chapter 28 Due 4/20/26

# Assignment

- Bibliography

## **Journal**

Author, A. B.; Author, C. D. *J. Abbrev.* **19XX**, vol, xx-yy.

NOTE: No punctuation in journal abbreviations except periods. No conjunctions, articles, or prepositions in journal abbreviations. No comma or semicolon before or after journal titles.

## **Book without editors:**

Author, A. B.; Author, C. D. *Book Title*; Series Name and number; Publisher: City, STATE (2 letters), year; Vol. 1, pp xx-yy.

# Assignment

- Bibliography

**Book with editors, no authors named:**

*Book Title*; Editor, A. B.; Editor, C. D., Eds.; Series Name and number; Publisher: City, STATE (2 letters), year; Vol. 2, pp xx-yy.

**Book with editors and authors named:**

Author, A. B. In *Book Title*; Editor, C. D.; Ed.; Series Name and number; Publisher: City, STATE (2 letters), year; Vol. 3, pp xx-yy.

# Assignment

- Bibliography

## **Patent**

Author, A. B. U.S. Patent 3,123,456, year.

## **Thesis**

Author, A. B. Ph.D. thesis, Institution Name, City,  
STATE, year.

NOTE: Do not include the title of the thesis.

# Assignment

- Bibliography

## Websites

### Basic Format:

Author, A. A. (if any). Title of Site. URL (accessed date), other identifying information. (No need to include URL of subscription sites).

ChemFinder.Com. <http://chemfinder.cambridgesoft.com> (accessed July 14, 2004).

The Combined Chemical Dictionary database, web version 2004 (1); CRC Press: Boca Raton: FL (accessed July 16, 2004).

