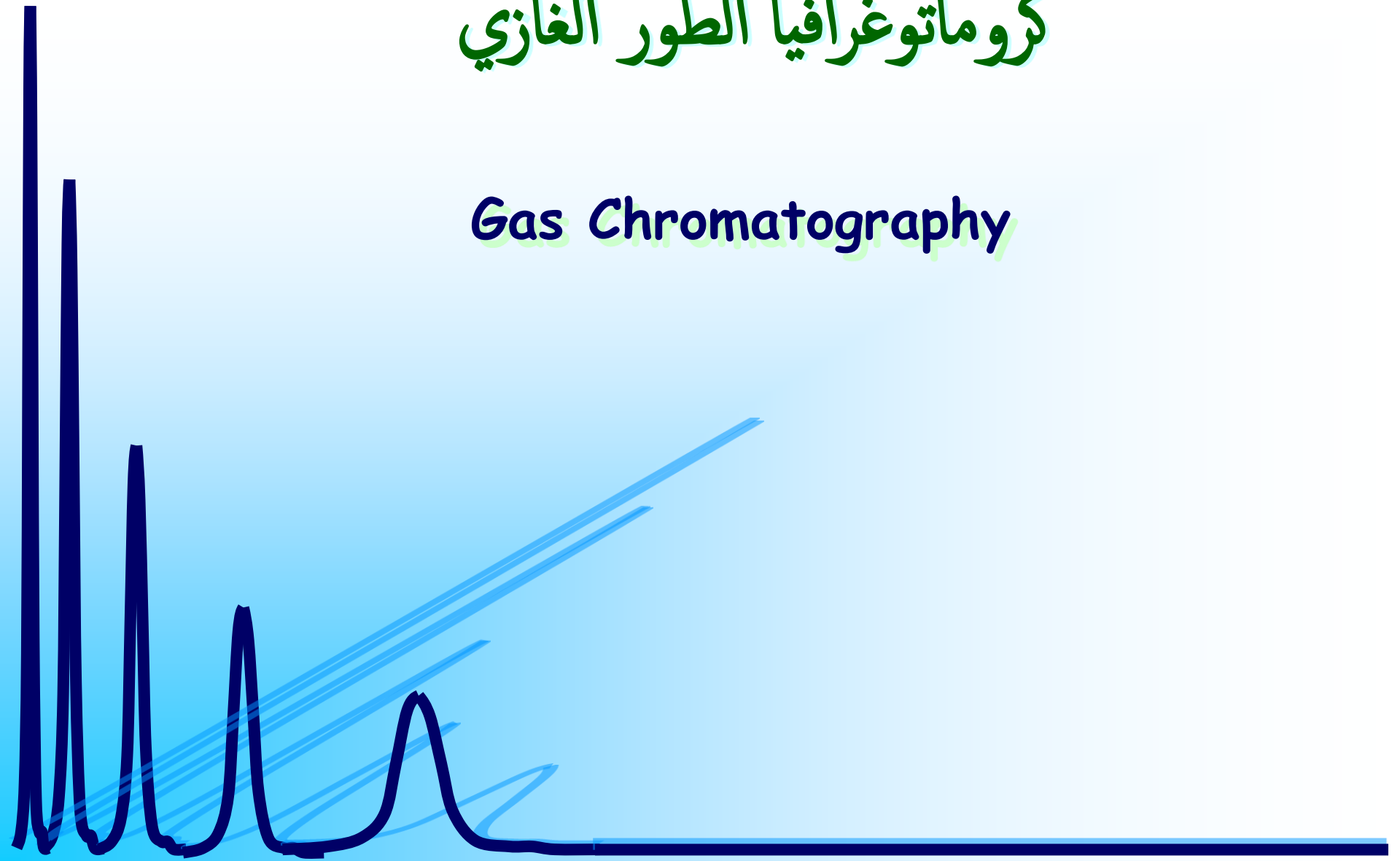

بسم الله الرحمن الرحيم

كروماتوغرافيا الطور الغازي

Gas Chromatography



What is chromatography?

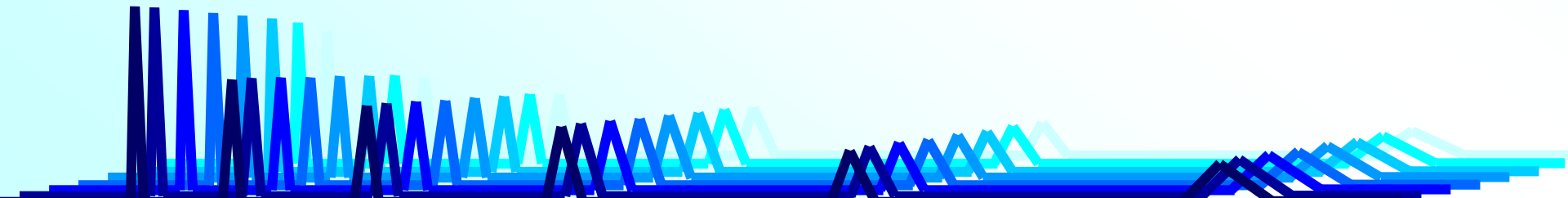
A physical method of separation

No reaction occurs during the separation process

The components partition between two phases:

- the stationary phase which is fixed and does not move
- the mobile phase which moves along the column

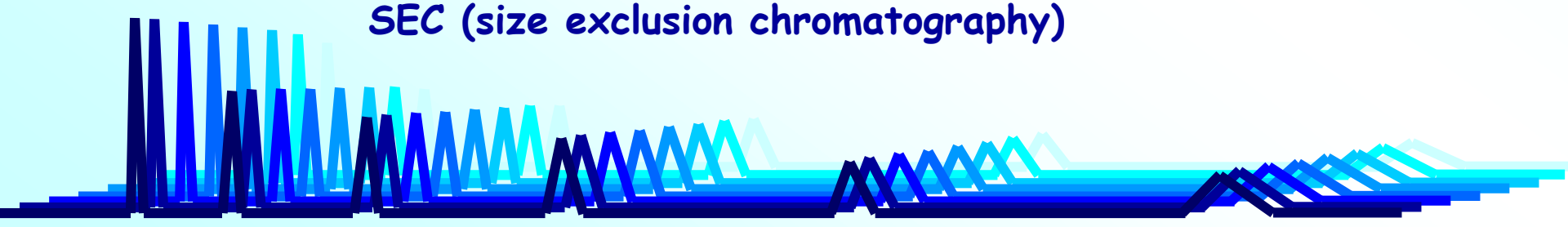
The separation of solutes occurs owing to their different interactions with the two phases



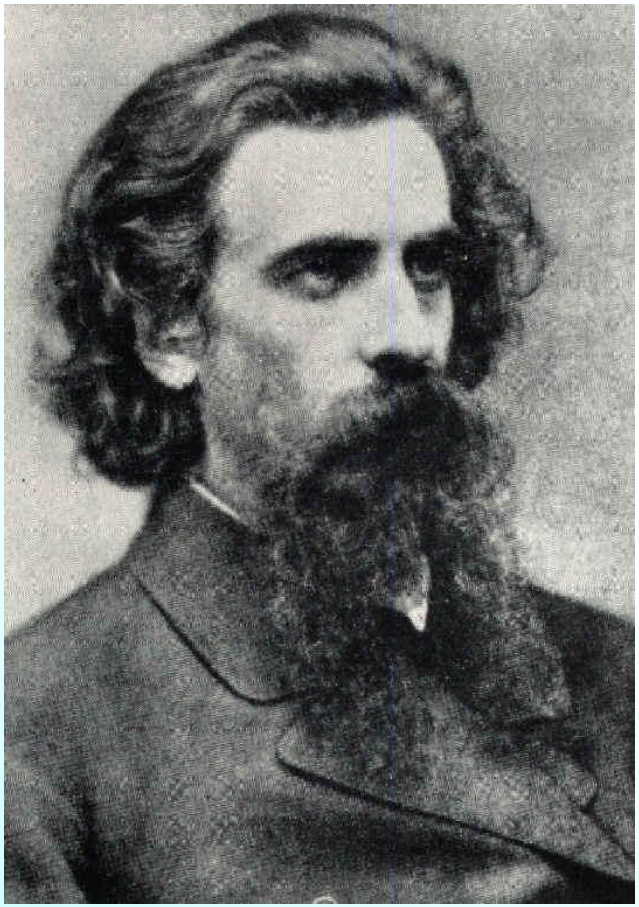
What are the main chromatographic methods?

Their classification is based on the nature of mobile phase:

- gaseous mobile phase:
  - GLC (partition chromatography)
  - GSC (adsorption chromatography)
- liquid mobile phase :
  - LLC (partition chromatography)
  - LSC (adsorption chromatography)
  - IEC (ion exchange chromatography)
  - SEC (size exclusion chromatography)



History

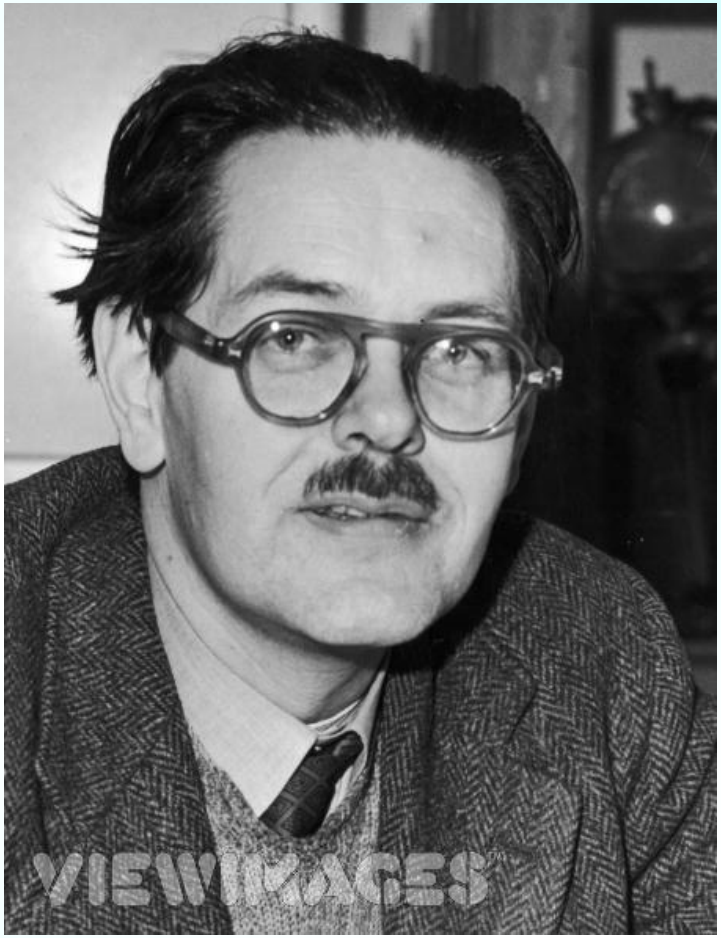


- Russian Scientist Mikhail Semenovich Tswett is credited for the discovery of chromatography (1903).

- German student Fritz Prior is credited for developing gas chromatography (1947).

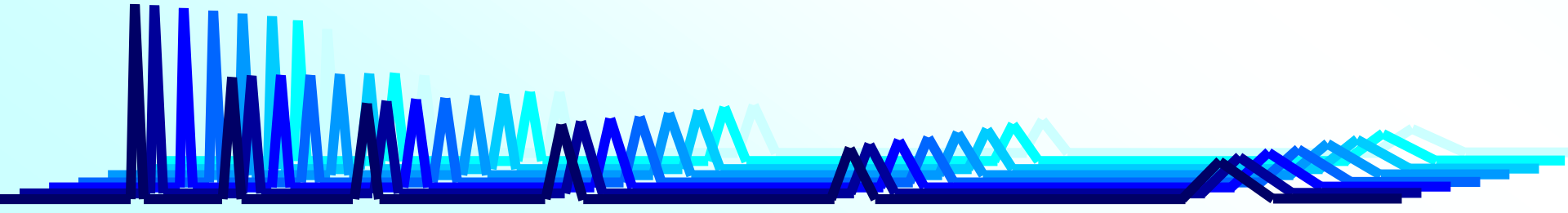
Gas Chromatography

- The father of modern gas chromatography is Nobel Prize winner John Porter Martin, who also developed the first liquid-gas chromatograph (1950).



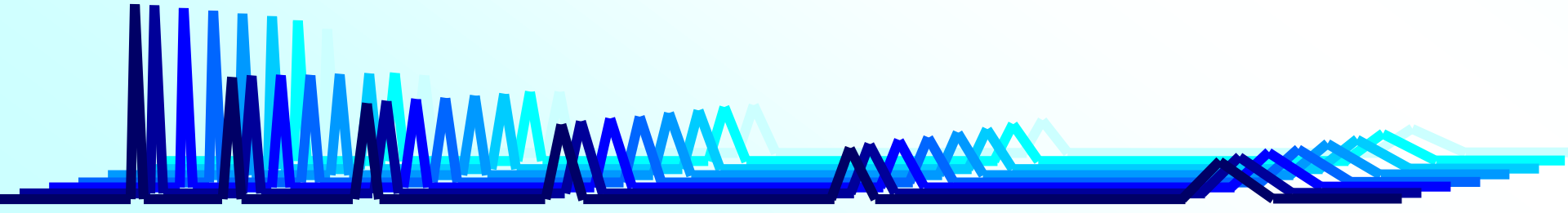
Gas chromatography principle

- Sample is vaporised and injected onto the head of a chromatographic column.
- Elution is produced by the flow of an inert gaseous mobile phase.
- Separation is based upon the partition of the analyte between a gaseous mobile phase and a liquid phase immobilised on the surface of an inert solid (GLC) at a temperature above boiling point of analyte (for various analytes: temperature programming).
- Mobile phase does not interact with molecules of the analyte.
- Eluted analytes are detected by a detector and recorded by the data system
- GC columns are either packed (with silica particles coated in stationary) or capillary in nature.



Chromatographic terminology:

- **Solute**: constituent of a mixture to be separated by chromatography
- **Mobile phase** : fluid medium which pushes the solutes along the column
- **Stationary phase**: solid or liquid which interacts with the solutes and retains them allowing their separation
- **Support**: inert solid substrate coated with the liquid stationary phase
- **Coating**: the support with the liquid stationary phase which fill the column in partition chromatography or the solid adsorbant in adsorption chromatography
- **Chromatographic column**: the tube of variable diameter and length made with metal or glass, containing the coating
- **Elution**: transfer of the solutes in the mobile phase along the column
- **Retention**: delaying the solutes movement by their interactions with the stationary phase
- **Chromatogram**: curve obtained on the recorder giving the detector response as a function of time

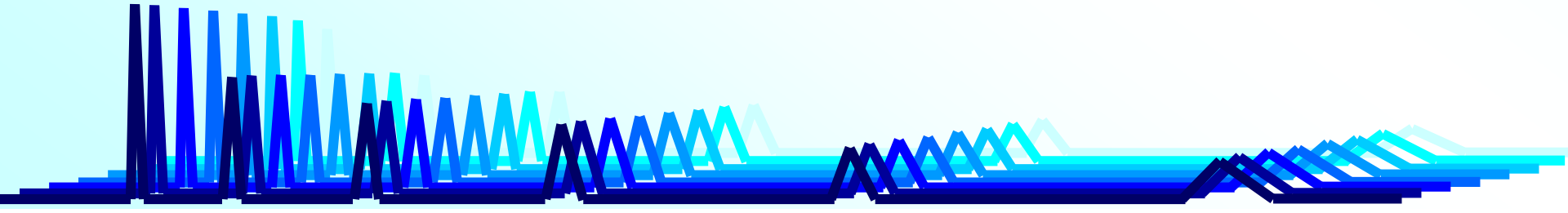


How does the separation process occur?

- Solutes are forced by the mobile phase to move through the stationary phase along the column

- Each species is specifically retained by the stationary phase because of interactions such as:

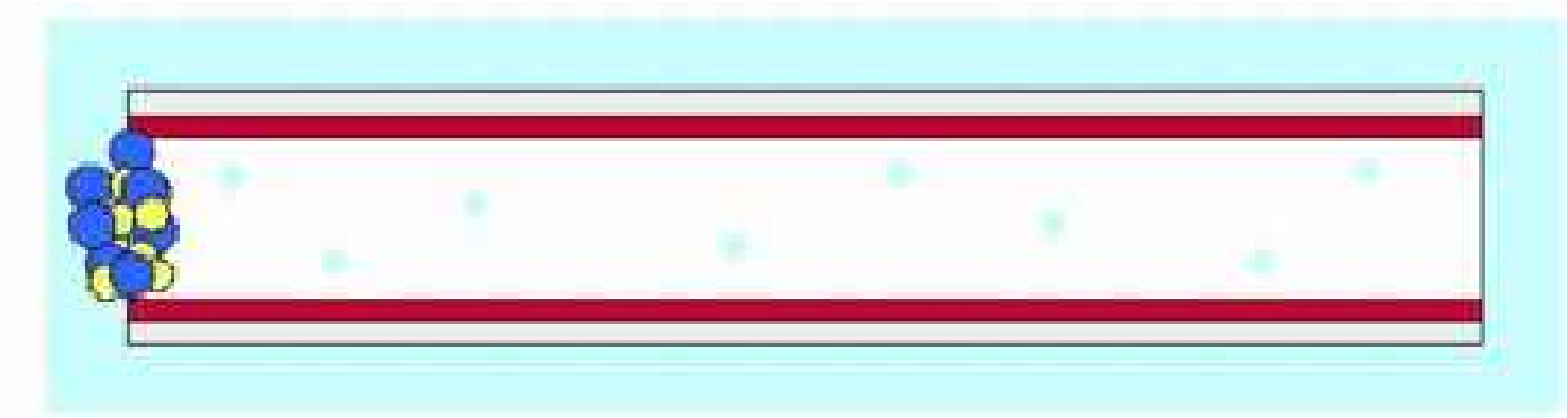
1. adsorption on the solid surface
2. relative solubility in the liquid stationary phase
3. polar interactions



Solute elution:

It can be explained by different competitive interactions which occur inside the column:

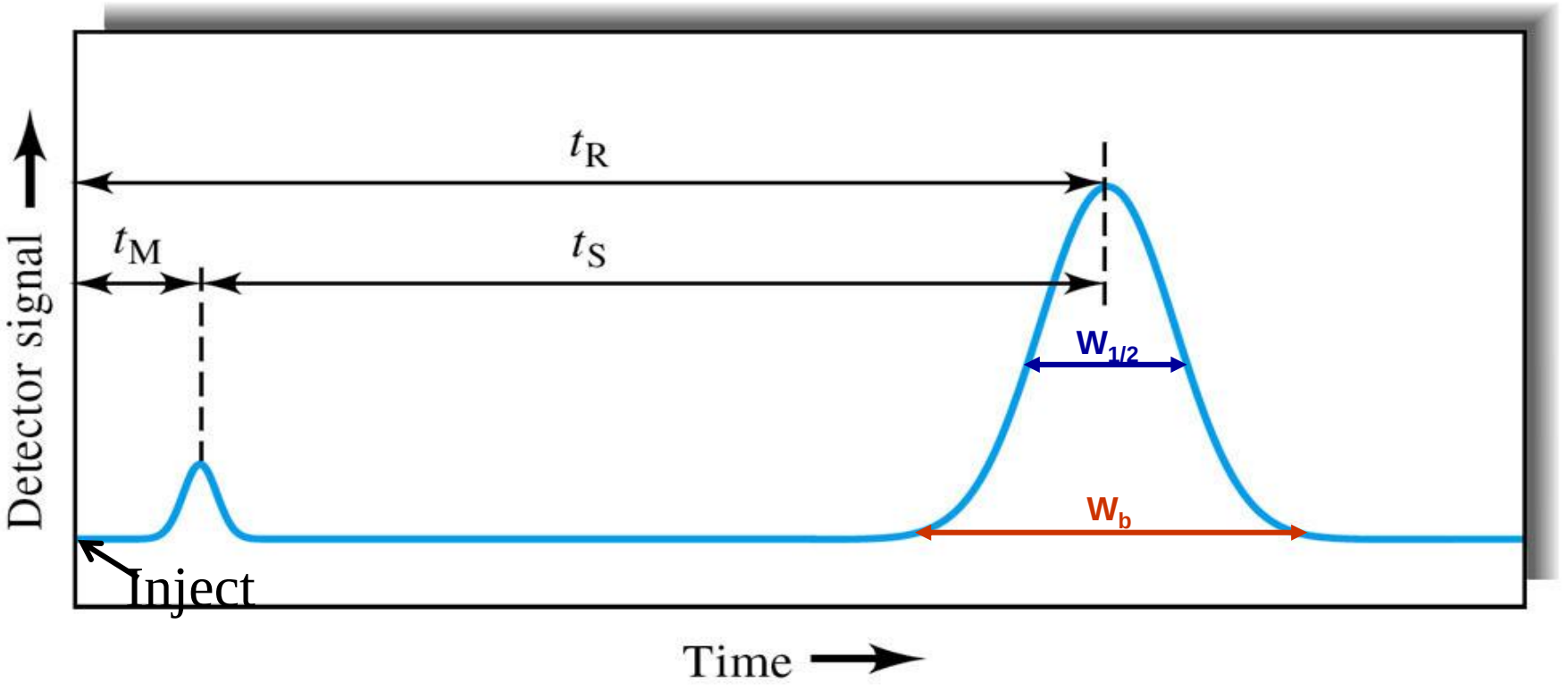
- solute volatility (vapor pressure)
- solute solubility in the liquid stationary phase and/or solute adsorption on the solid surfaces



Theory of Chromatography

Typical response obtained by chromatography: chromatogram

concentration versus elution time



where:

t_R = retention time

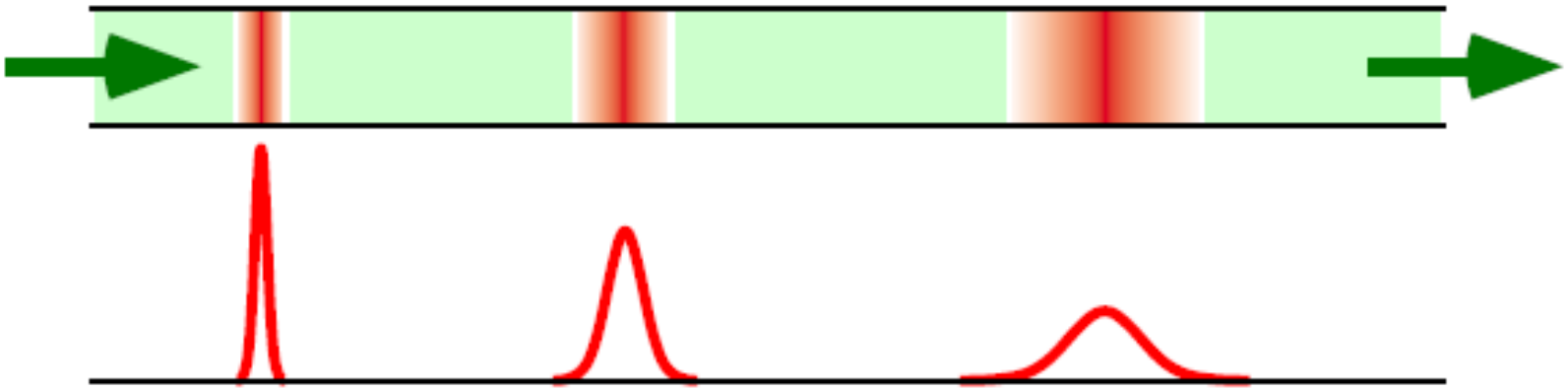
t_M = void time (dead time, non-retained solute)

W_b = baseline width of the peak in time units

$W_{1/2}$ = half-height width of the peak in time units

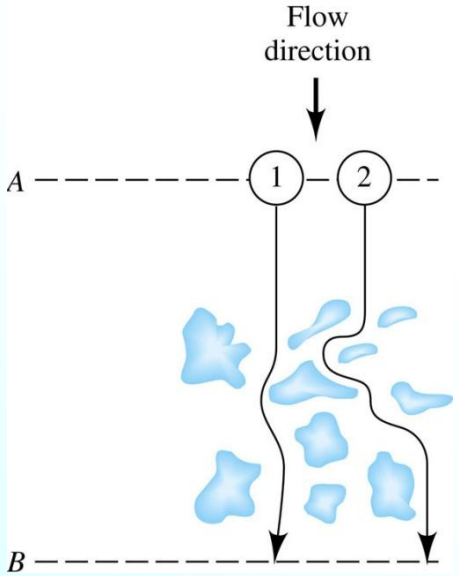
Why do bands spread?

a. Eddy diffusion
b. Mobile phase mass transfer
c. Stagnant mobile phase mass transfer
d. Stationary phase mass transfer
e. Longitudinal diffusion



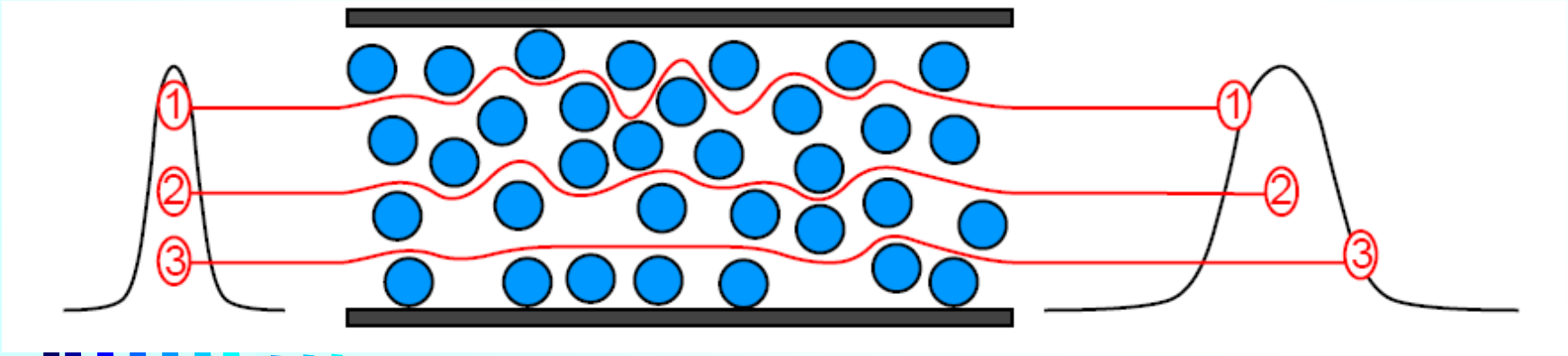
Eddy diffusion:

a process that leads to peak (band) broadening due to the presence of multiple flow paths through a packed column.



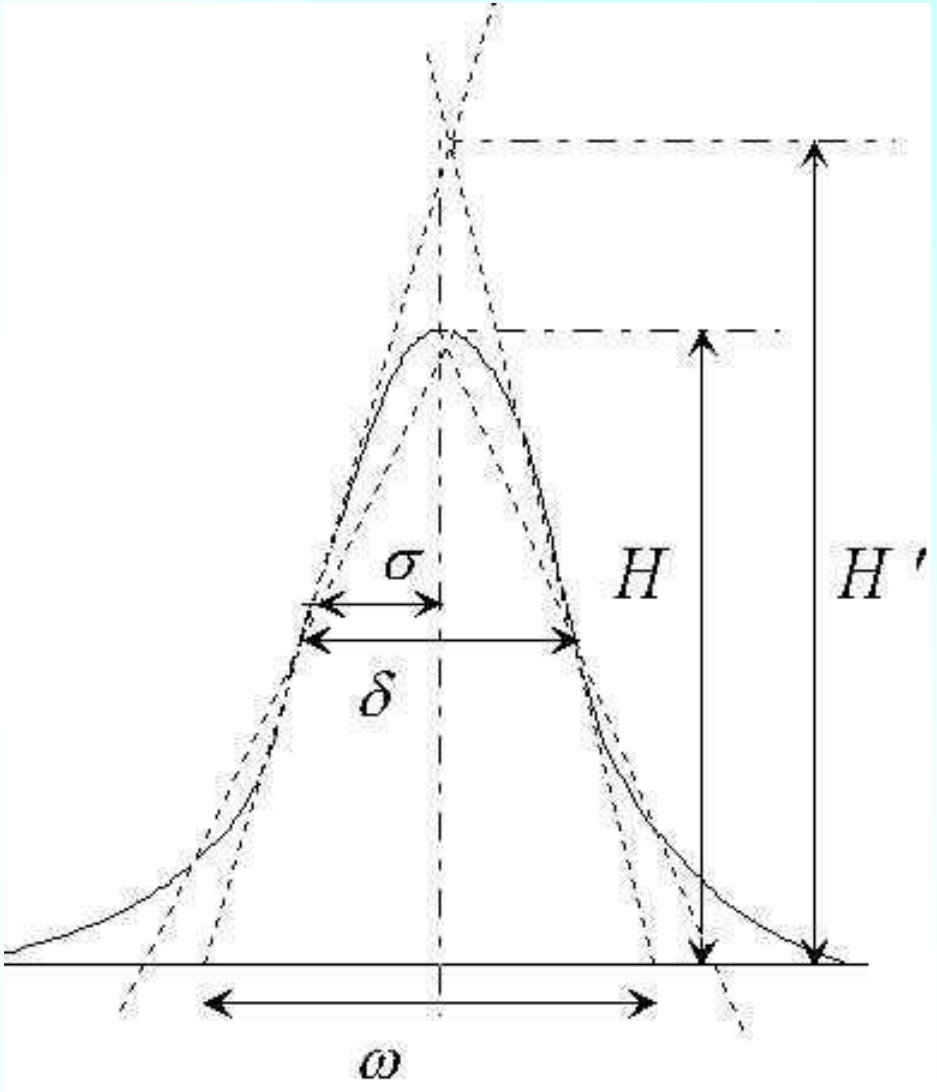
As solute molecules travel through the column, some arrive at the end sooner than others due to the different path traveled around the support particles in the column that result in different travel distances.

Longer path arrives at end of column after (1).



Chromatographic peak:

- supposed gaussian
- σ: standard deviation
- δ: width at half-height ($W_{1/2}$)
- ω : baseline width
- Since is often difficult to accurately evaluate the beginning and end of the peak, most equations use the width at half-height δ which can be easily measured on the chromatogram



Some fundamental equations:

- **Corrected retention time:**

$$t'_R = t_R - t_M$$

- **Capacity ratio: corresponds to a relative retention:**

$$k = t'_R / t_M = (t_R - t_M) / t_M$$

- **Column selectivity:**

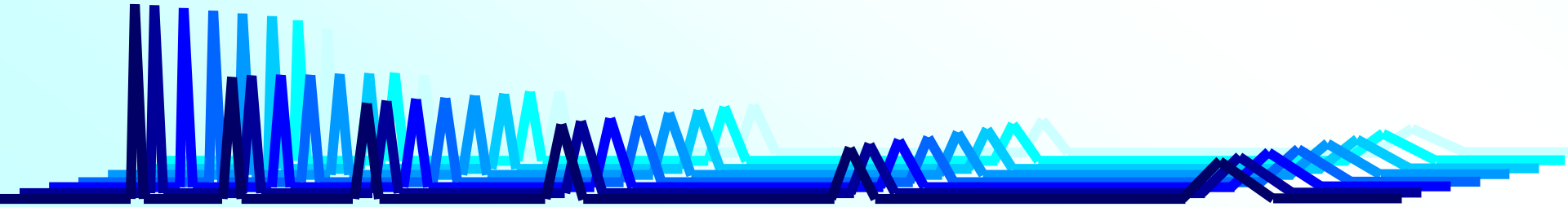
$$\alpha = t'_{R2} / t'_{R1} = k_2 / k_1 \quad (\alpha > 1 \text{ because } t'_{R2} > t'_{R1})$$

- **Resolution between two neighboring peaks:**

$$R_S = 2\,(t_{R2} - t_{R1}) / (\omega_2 + \omega_1) = 1{,}18\,(t_{R2} - t_{R1}) / (\delta_2 + \delta_1)$$

- *For two neighboring peaks, a resolution R_S higher than 1 means a complete separation (for R_S = 1, the overlapping peak surface is 2%)*

- *When R_S is less than 0.8, the separation between the two peaks is considered to be incomplete*



Column efficiency:

The chromatographic peaks being supposed gaussian, the peak broadening can be related to the separation and the column efficiency which is evaluated by the number of theoretical plates of the column N.

For a gaussian peak, N can be calculated by one of the following equations:

$$N = (t_R / \sigma)^2$$ (σ: standard deviation of the peak)

$$N = 16\,(t_R / \omega)^2$$ (ω: width at baseline)

$$N = 5{,}54\,(t_R / \delta)^2$$ (δ: width at half- height)

In order to compare columns having different lengths, one calculate the height equivalent to a theoretical plate HETP:

$$H = L / N$$ (L : column length)

H may vary from centimeters (packed columns) to several microns (high resolution capillary columns)

Van Deemter Equation:

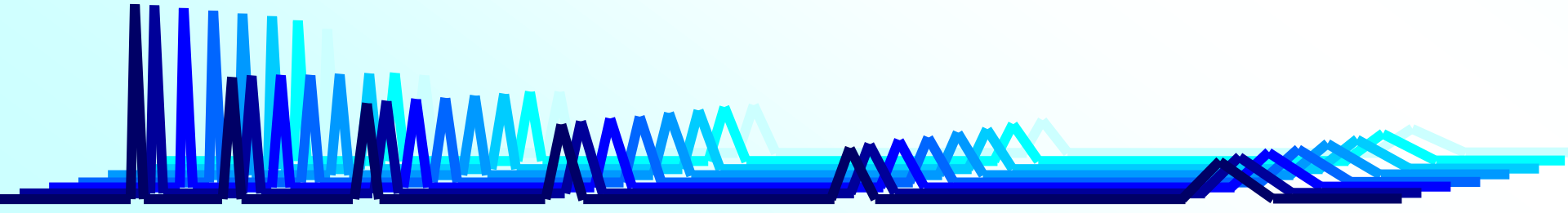
It gives the dependance of the height equivalent to a theoretical plate as a function of several parameters:

$$H = 2\lambda d_p + \frac{2\gamma D_g}{u} + \frac{8}{\pi^2}\frac{k d_f^2}{(1+k)^2 D_l} u$$

- **H** : height equivalent to a theoretical plate
- **λ** : factor characteristic of the packing column
- **d_p** : diameter of the packing particules
- **γ** : factor depending on the irregularity of interparticles space
- **D_g** : diffusion coefficient of the solute in gas phase
- **D_l** : diffusion coefficient of the solute in liquid phase
- **u** : linear velocity of the carrier gas
- **k** : capacity ratio of the studied solute
- **d_f** : thickness of the liquid stationary phase film

For packed columns, the Van Deemter equation shows three terms:

- $2 \lambda d_p$: term **A**, characteristic of the packing material
- $\frac{2 \gamma D_g}{u}$: term **B**, characteristic of the gas mobile phase
- $\frac{8}{\pi^2} \frac{k d_f^2}{(1+k)^2 D_l} u$: term **C**, characteristic of the liquid stationary phase

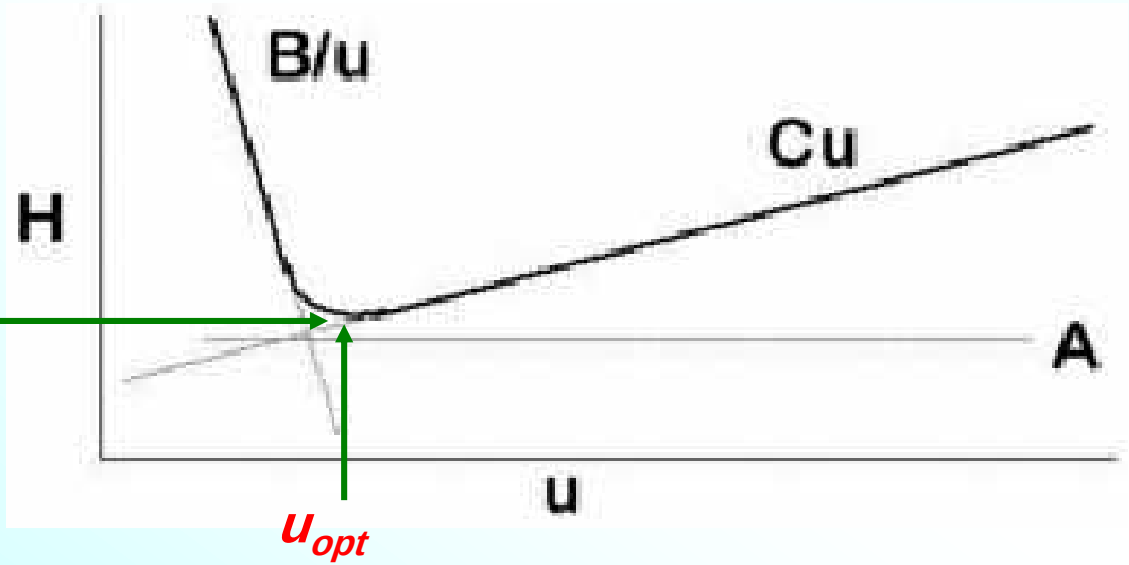


Van Deemter curve:

It allows the determination of the minimum HETP value H_{min} which corresponds to the maximum column performance obtained with the optimum velocity u_{opt}

$$H = A + B / u + C u$$

For a packed column, this curve is as follows:



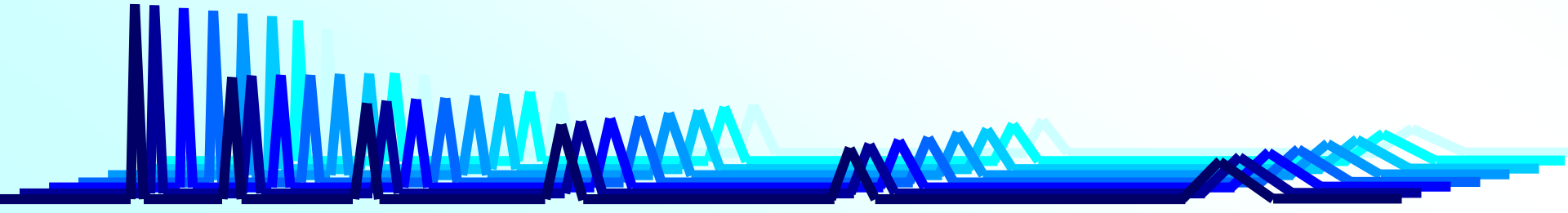
Van Deemter curve:

- It is not necessary to determine the optimum HETP for each component of the analysed mixture, we can consider a medium solute in the chromatogram to evaluate the optimum velocity

- It is often advised to select a carrier gas flowrate slightly greater than the optimum value:

  - *it allows the obtention of shorter retention times and reduction of the analysis duration*
  - *without greatly affecting the column performance*

Gas chromatography equipment



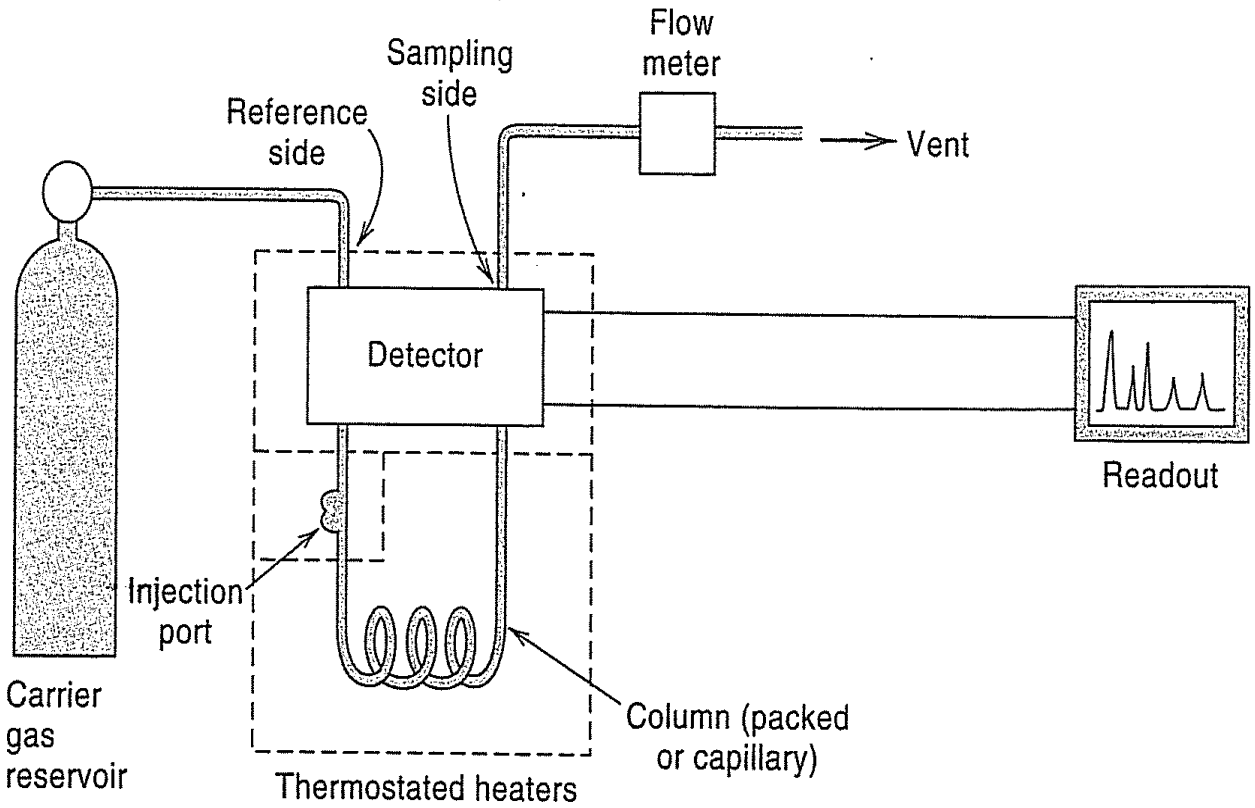
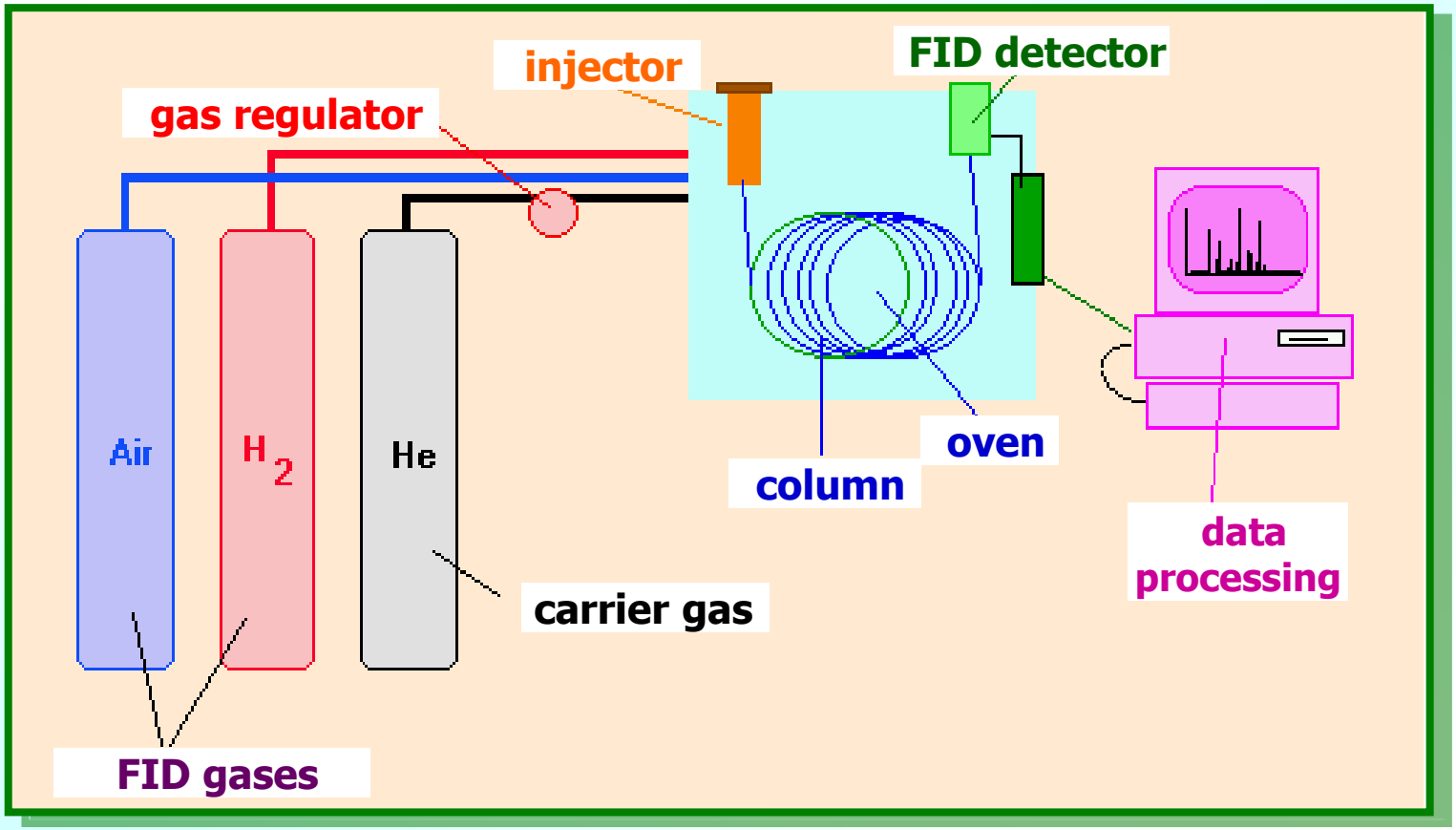
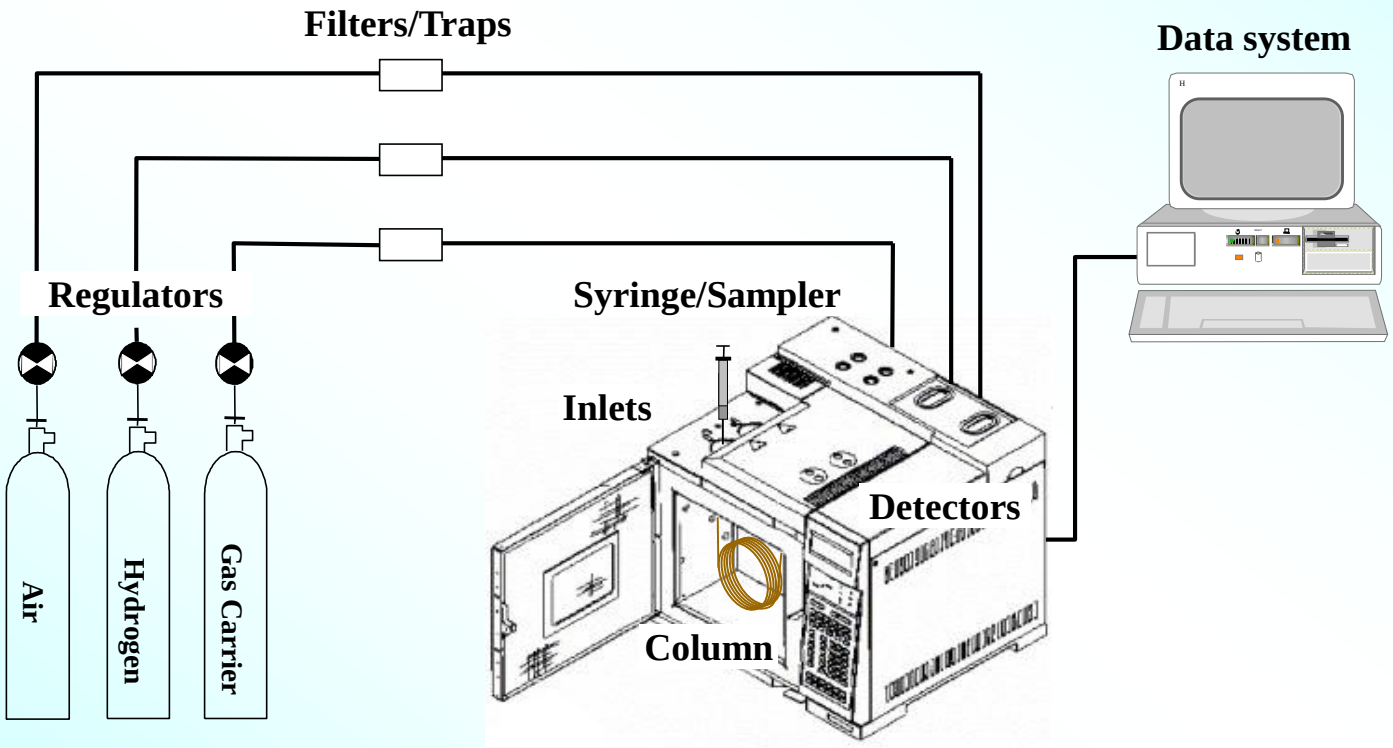


Fig. 20.1. Schematic diagram of gas chromatograph.

Main parts of a gas chromatograph

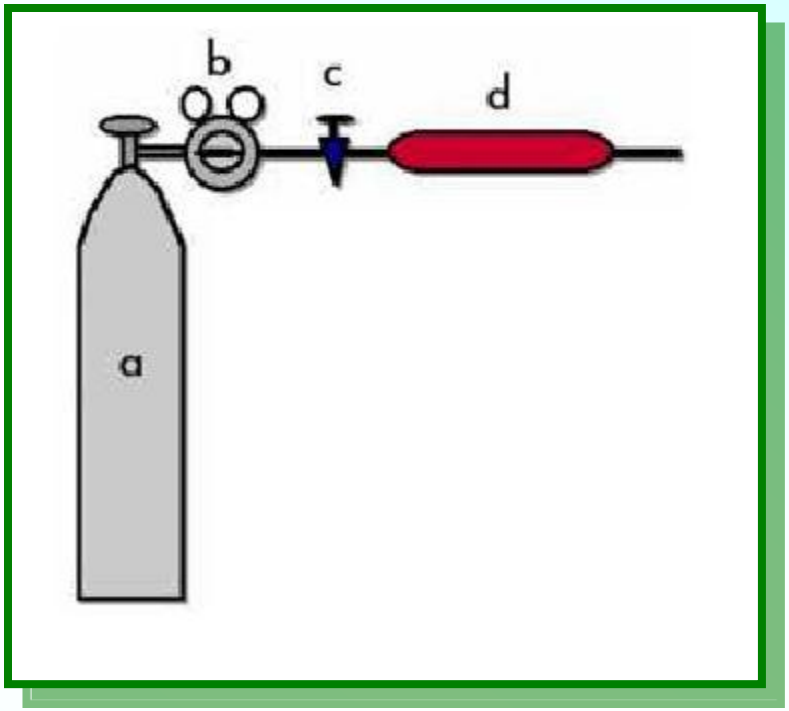


Main parts of a gas chromatograph



Gas supply:

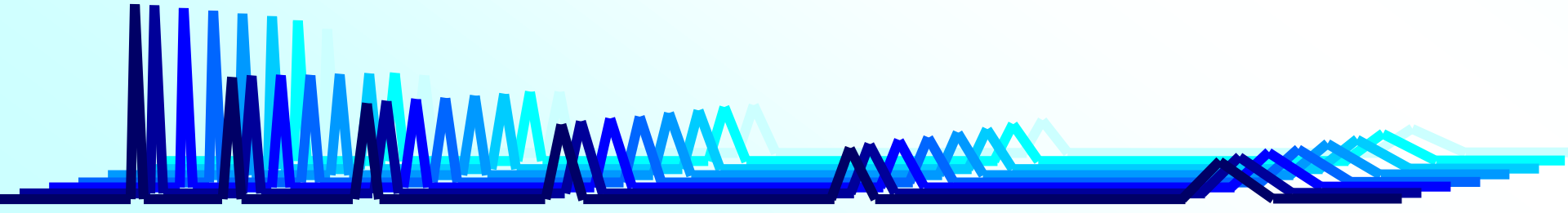
- a : compressed gas cylinder
- b : double stage pressure regulator
- c : valve
- d : gas filter (to eliminate impurities such as: water, oxygen, hydocarbons,…)



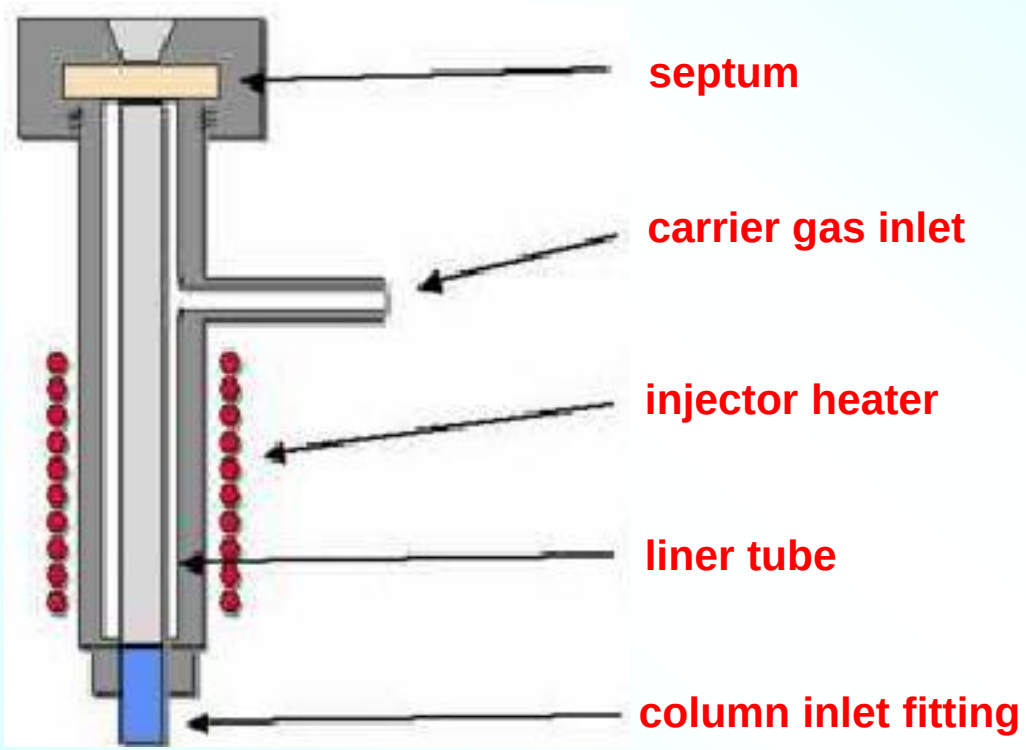
Sample injection:

It allows a rapid and simple introduction of the sample to be analysed in the gas chromatograph. There are two main injection systems, depending on the nature of sample:

- **injection port:** for introduction of liquids and solutions
- **sampling loop injection:** for introduction of gas samples



Injection port

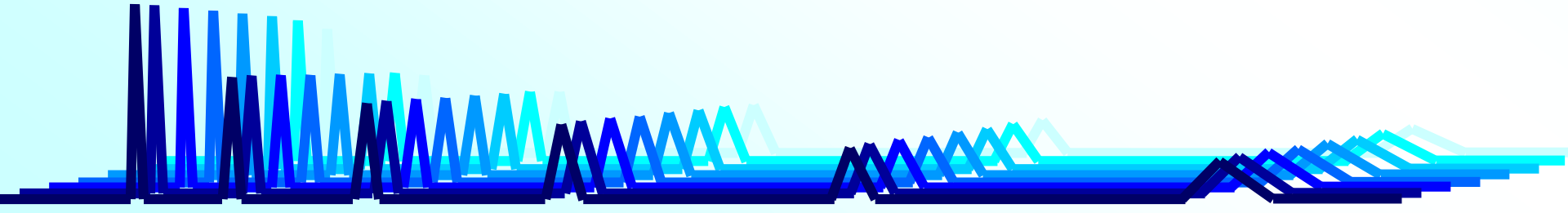


Injection port for liquid samples:

- allows the rapid introduction and volatilisation of the liquid sample in the chromatograph
- injection port temperature: must be high enough to quickly evaporate the sample without thermal degradation
- the injection temperature is 20° higher than the boiling point of the less volatile constituent of the mixture
- to avoid condensation of the sample in the injection port, the injector temperature must be higher than column temperature:

$T_{injector} > T_{column}$ (about 50°C)

- the volume of the injection port must allow the volatilisation of the liquid sample and avoid the excessive dead volume

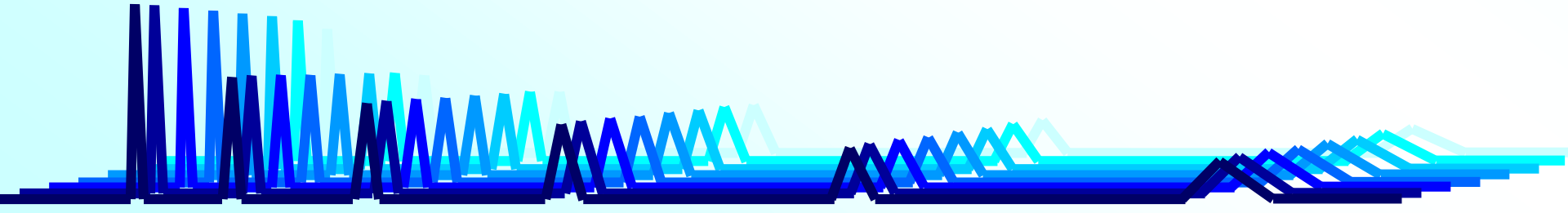


The syringe

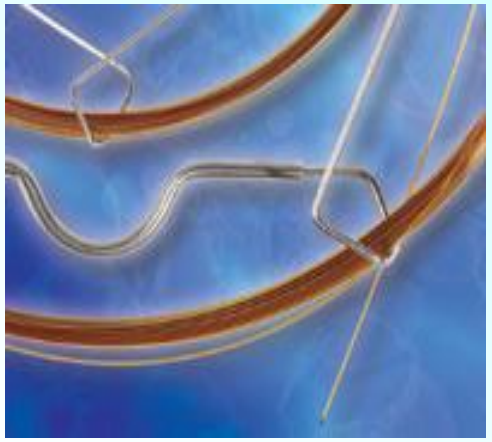
- it is used to introduce an accurate volume of the liquid or gas sample in the injector
- several syringe models are available: from 1 μl to several cm^3, with various options: fixed or removable needle, adaptor, sharp or round needle…

Columns

- Heart of the separation process.
- Vast number of materials have been evaluated.
- It is usually best to refer to various catalogs as an up to date reference.
- Can be classified by tubing diameter and packing type.



Columns in gas chromatography



Packed columns

- 2 to 4 mm I.D. and 1 to 4 meters long.
- Packed with a suitable adsorbent.
- Mostly used for gas analysis.
- Peak broadening due to zone (eddy) diffusion resulting from multitude of pathways a molecule can pass through column.

Capillary columns

- 0.1 mm to 0.5 mm I.D. and 10 m to 100 m long
- Stationary phase is coated on the internal wall of the column as a film 0.2 mm to 1 mm thick
- Sharper peaks – no Eddy diffusion.
- Up to 500,000 theoretical plates – excellent separations.
- Most popular type of column in use.

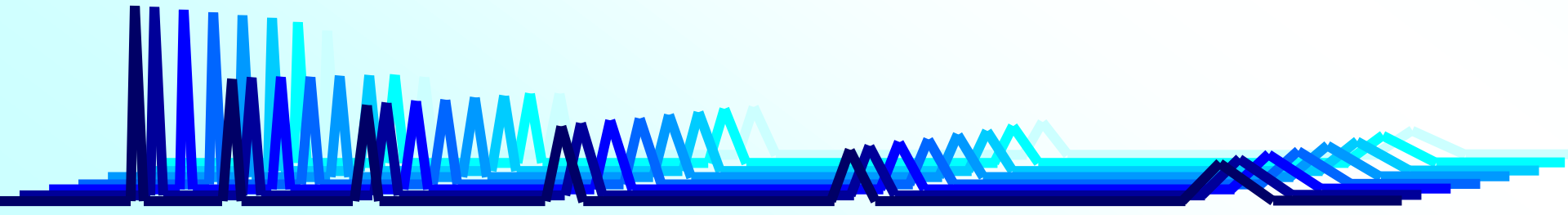
Temperature programming

The column sits in an oven.

If the temperature is held constant during the entire analysis it is isothermal.

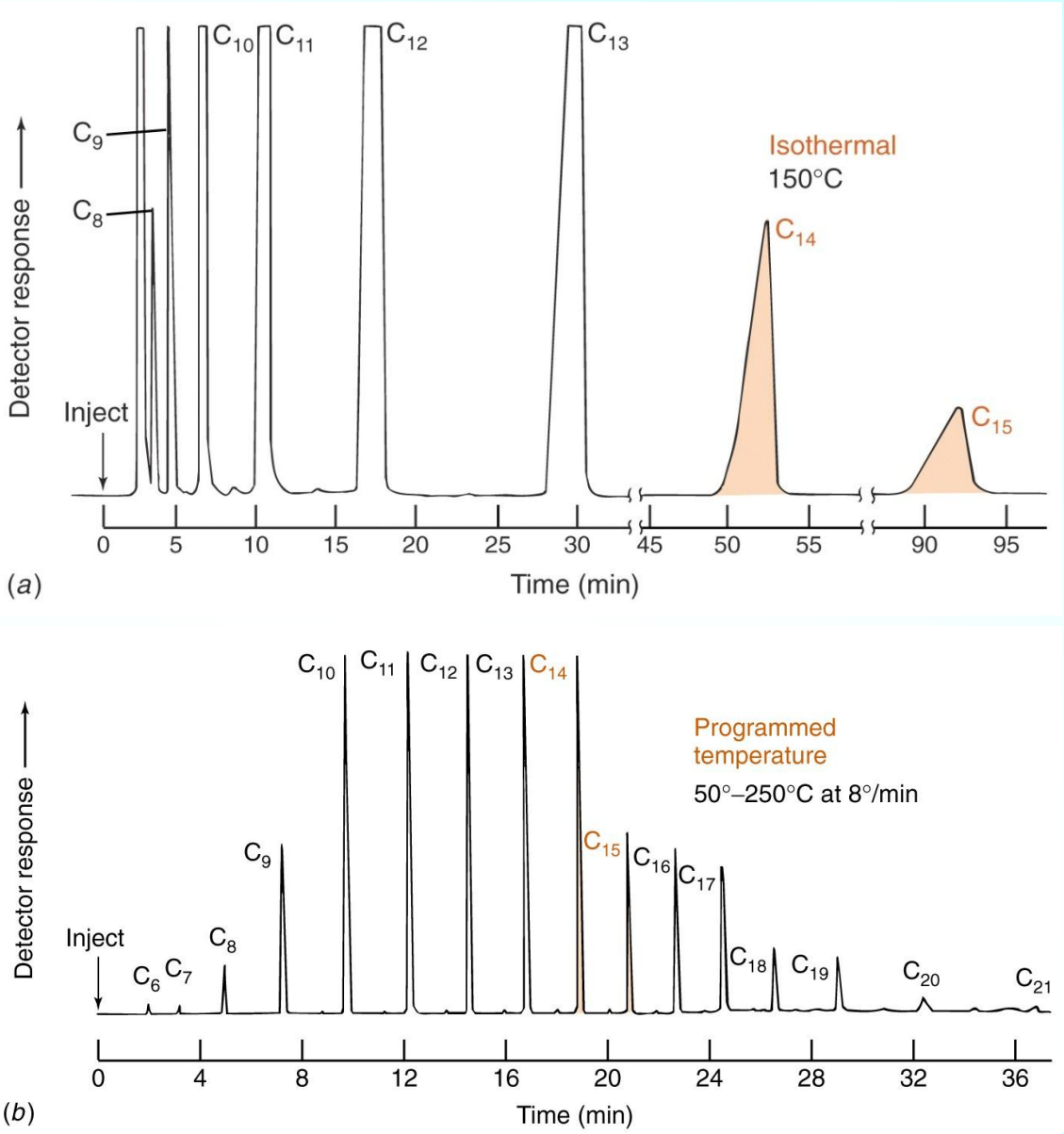
If you vary the temperature during the analysis, you typically use a temperature program.

Why bother?

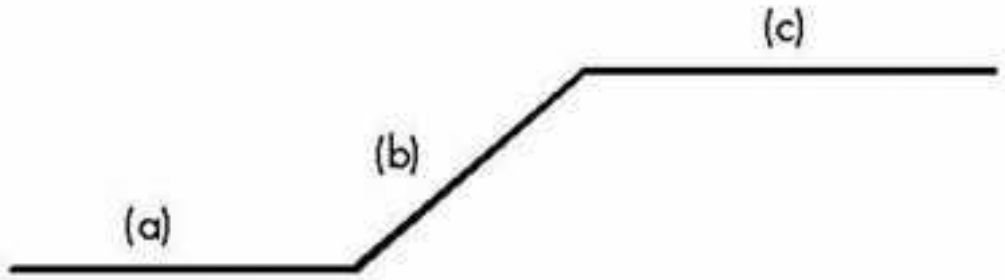


Comparison of isothermal and programmed temperature separation

Temperature gradient improves resolution while also decreasing retention time



A temperature program



a - initial temperature and time

b - ramp (°C/min)

c - final hold time and temperature

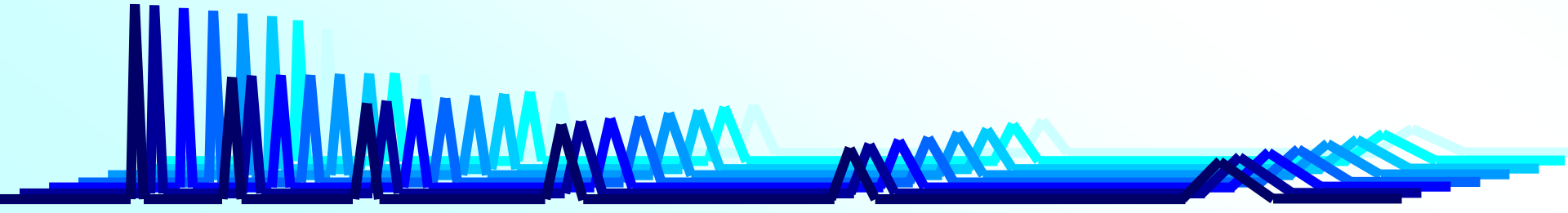
Some GCs will allow for a more complex program.

Detectors

Each can be roughly classified based on

Destructive	vs.	nondestructive
General	vs.	some discrimination
	vs.	very discriminating

Let's start by reviewing some general concepts such as detection limit and sensitivity.



Characteristics of ideal GC detector

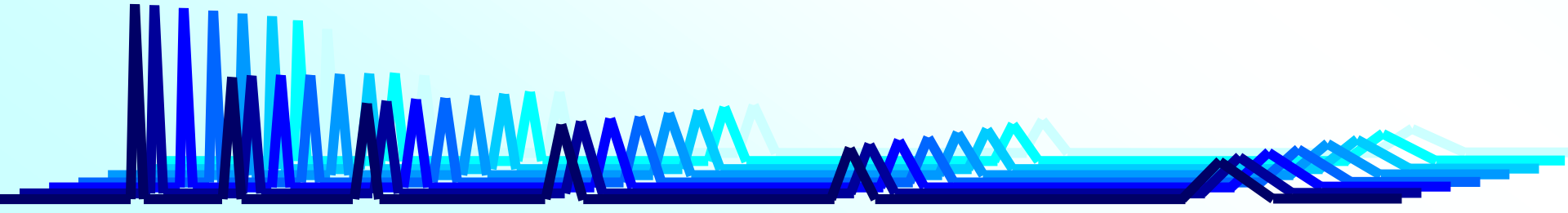
- Good stability and reproducibility.
- Linear response to analytes that extends over several orders of magnitude.
- Similarity in response toward all analytes.
- Temperature range from room temperature to 400°C.
- A short response time that is independent of flow rate.
- Non-destructive.
- High reliability and ease of use.
- No one detector exhibits all of these characteristics

Thermal conductivity detector

- General purpose
- Nondestructive
- Limit of detection ~ 400 pg/ml carrier
- Linear range ~ 10^6

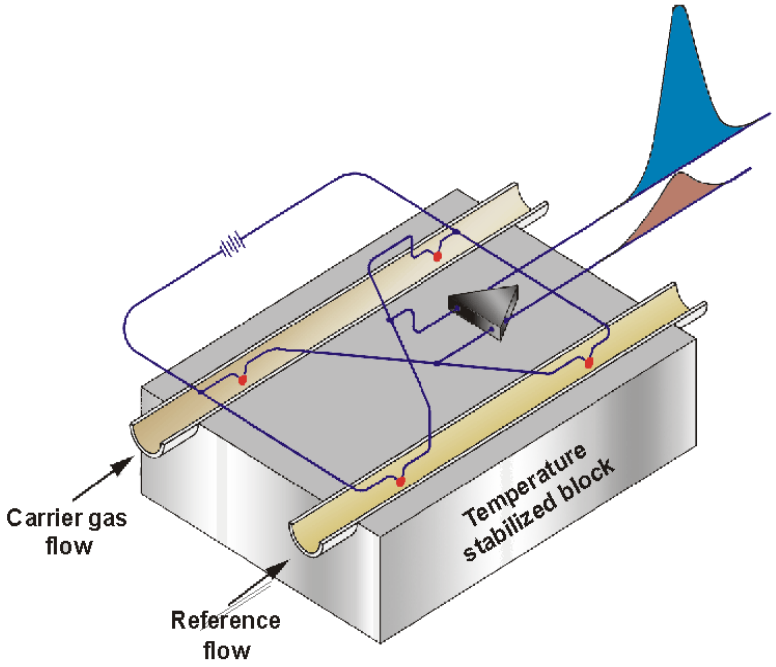
Mode of detection

Change in resistance of a wire based on variations in the thermal conductivity of the gas evolving from a column.



Thermal Conductivity Detector

- Exploits the changes in the thermal conductivity of a gas stream brought about by the presence of analyte molecules.
- The resistance of either a heated platinum wire or a heated semiconductor thermistor gives a measure of the thermal conductivity of the gas.
- Twin detector pairs are typically incorporated into two arms of a Wheatstone bridge.
- In the presence of a relatively small concentration of analyte a large decrease in thermal conductivity of carrier gas occurs resulting in a temperature rise in detector.
- Thermal conductivities of He and H_2 are ~ 6 – 10 times higher than most organic compounds. Necessitates the use of these gases as carrier gas.
- Linear range of 10^5 is suitable for organic and inorganic samples.
- Non-destructive and allows collection of sample after detection but low sensitivity ~ 10^{-8} g/s analyte/gas



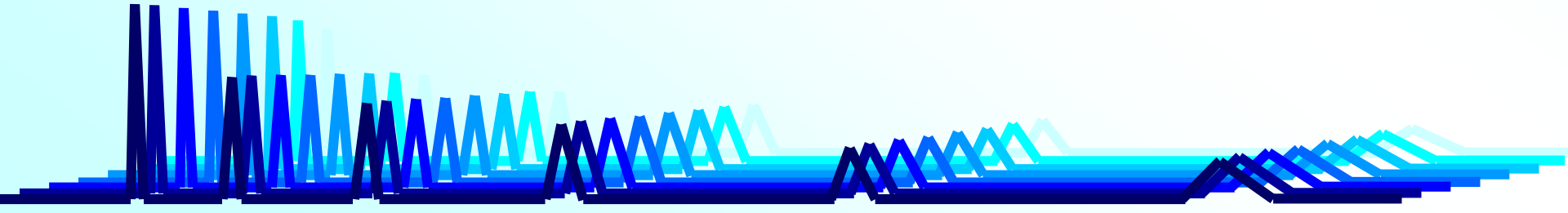
Flame ionization detector

- Specific - sample must be combustible
- Destructive
- Limit of detection ~ 5 pg carbon / second
- Linear range ~ 10^7

Mode of detection

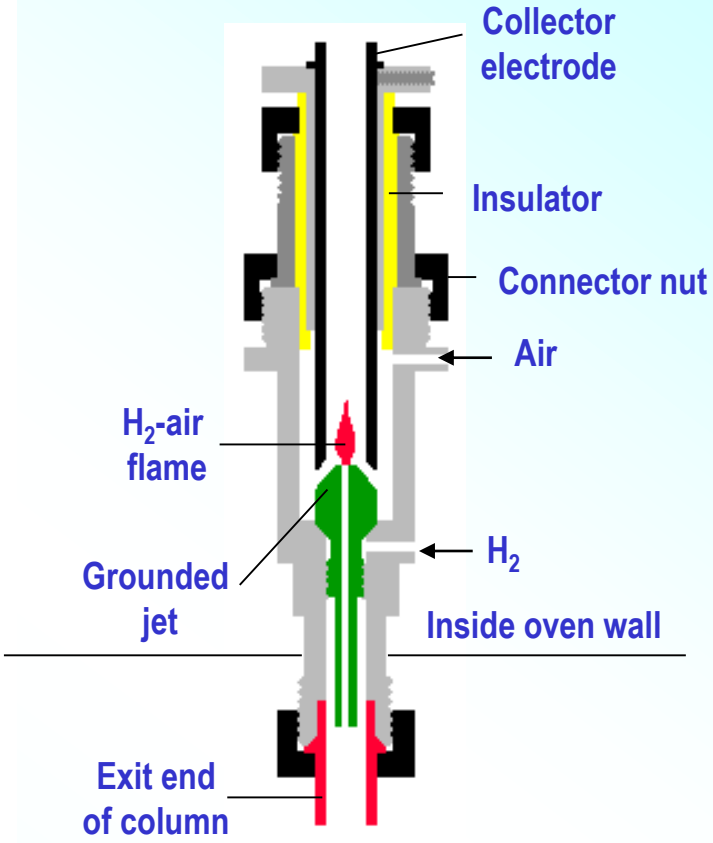
Production of ions in a flame result in a current that can be measured.

A make-up gas may be required to maintain an optimum flow - capillary columns



Flame Ionisation Detector

- Most organic compounds pyrolyse in H_2-air flame and produce ions and electrons.
- A potential of a few hundred volts is applied across the burner tip and a collector electrode located above the flame.
- The resulting current is amplified and proportional to the number of carbon atoms in the flame.
- General detector for GC. However, carbonyl, alcohol, halogen and amine groups yield few electrons. Also insensitive to H_2O CO_2 SO_2 NOx.
- Large linear response range (~ 10^7) and low noise (once detector has settled). Needs to be burning 24 hours before analysis.
- Exhibits very high sensitivity ~ 10^{-13} g/s of analyte/second

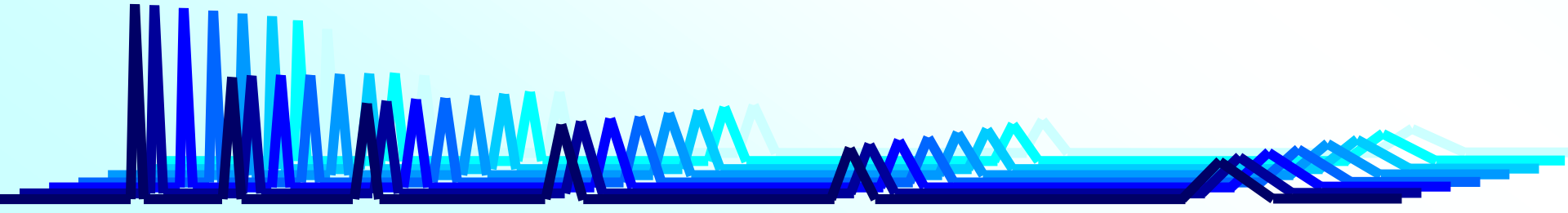


Flame ionization detector

Compounds with little or no FID response

noble gases	NH_3	CS_2
NO_x	CO	O_2
H_2O	CO_2	N_2

perhalogenated compounds
formic acid
formaldehyde

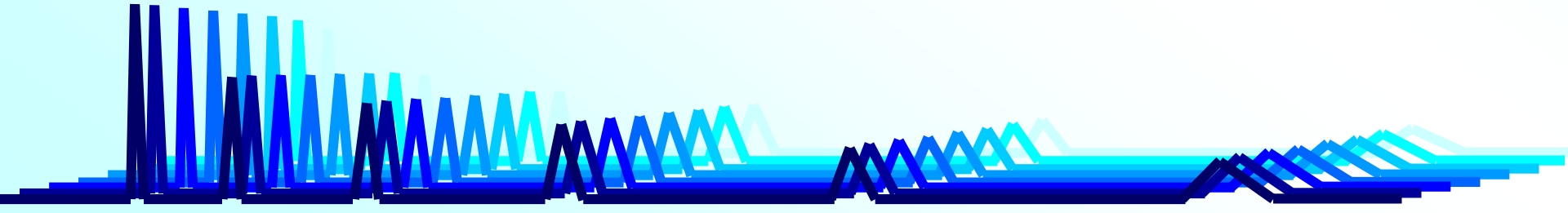


Electron capture

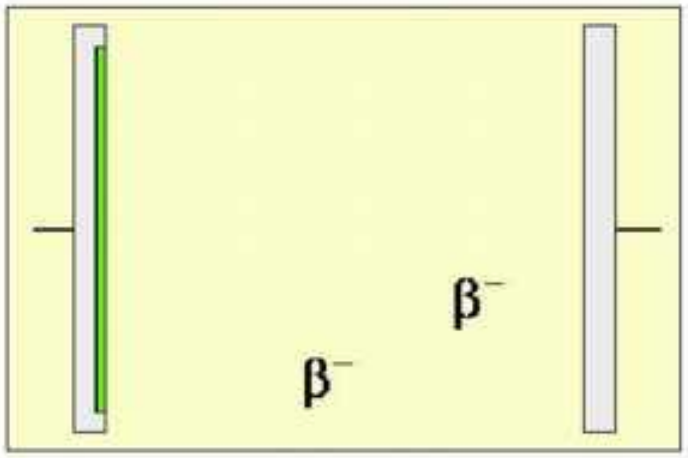
- Specific - sample must contain a gas phase electrophore
- Non-destructive
- Limit of detection ~ 0.1 pg Cl / second
- Linear range ~ 10^4

Mode of detection

Absorption of β particles by species containing halogens, nitriles, nitrates, conjugated double bonds, organometallics.



Electron capture

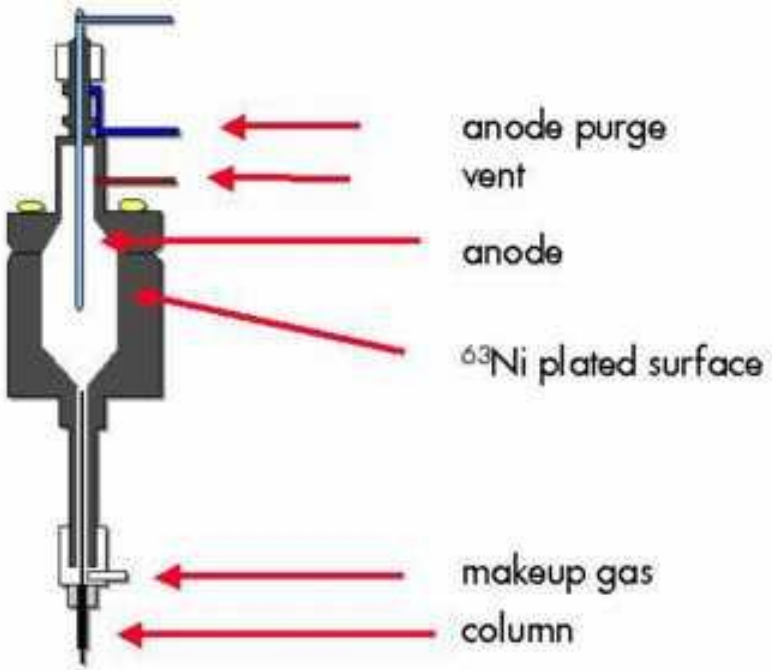


β^- are emitted by an ^{63}Ni source.

Electrophores will absorb β^-, reducing the current.

This is the basis for the response

Electron capture

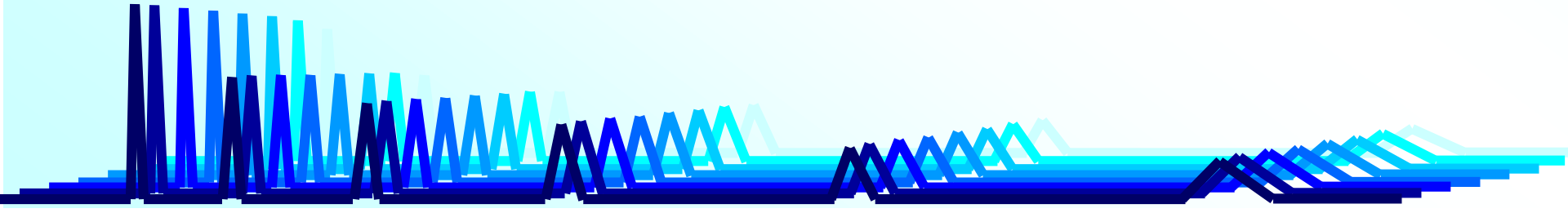


Electron capture detector

Provides excellent trace analysis of
- halogenated compounds
- nitro group compounds
- eluents with conjugated double bonds

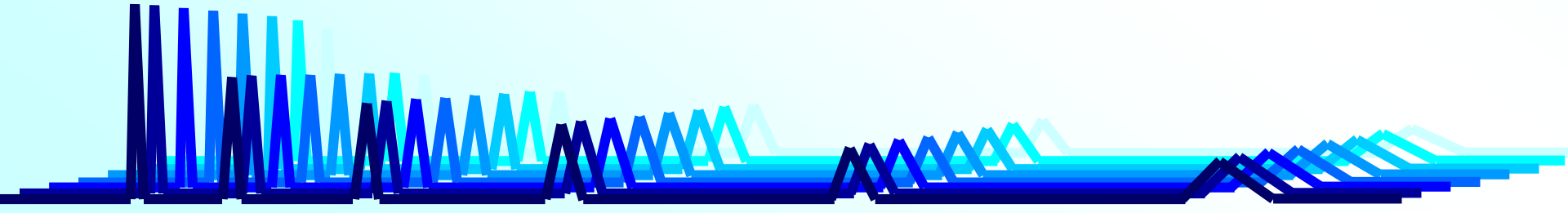
Most common use is environmental analysis of organochlorine pesticides

Major problem - detector is radioactive. Requires regular area testing and must be licensed.



Packed vs. capillary columns

	Packed	Capillary
length, M	0.5 - 5	5 - 100
ID, mm	2 - 4	0.1 - 0.7
flow, ml/min	10 - 60	0.5 - 15
head pressure, psig	10 - 40	3 - 40
total plates	4000	250,000
capacity	10μg/peak	100ng/peak
film thickness, μm	1 - 10	0.1 - 8



Capillary columns

Major differences

Smaller ID

Longer

No packing

Smaller sample capacity

This all adds up to allow components to remain on the column longer while still retaining good peak shape.

Improved sensitivity

Because peaks remain narrower, the sensitivity is improved.

Packed

Capillary

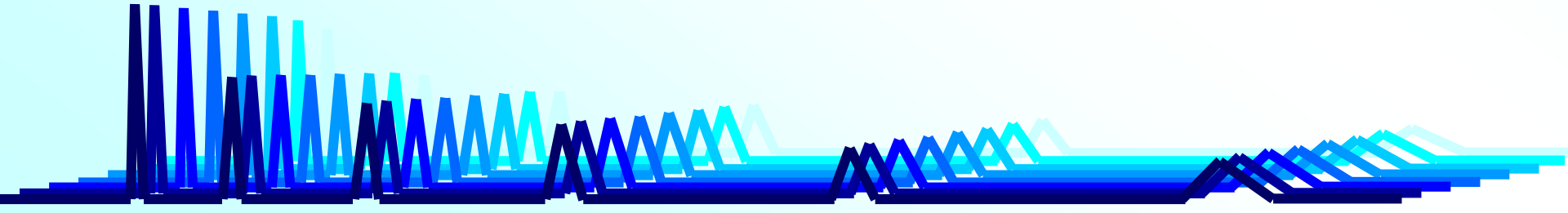
Both peaks have an area of 5000 units.

Because the capillary peak is higher, you get a better S/N.

Retention index

Retention Index is a measure of the retention of a solute relative to the retention of normal alkanes (straight chain hydrocarbons) at a given temperature. The retention index for a normal alkane is its number of carbons multiplied by 100. For example, n-dodecane (n-$C_{12}H_{26}$) has I = 1200. If a solute has I = 1478 it elutes after n-C_{14} and before n-C_{15}, and it is closer to n-C_{15}. Retention indices normalize instrument variables so that retention data can be compared on different GC systems. Retention indices are also good for comparing retention characteristics for different columns.

In gas chromatography, **Kovats retention index** (shorter **Kovats index**, **retention index**; plural **retention indices**) is used to convert retention times into system-independent constants. The index is named after the Hungarian-born Swiss chemist Ervin Kováts, who outlined this concept during the 1950s while performing research into the composition of the essential oils.

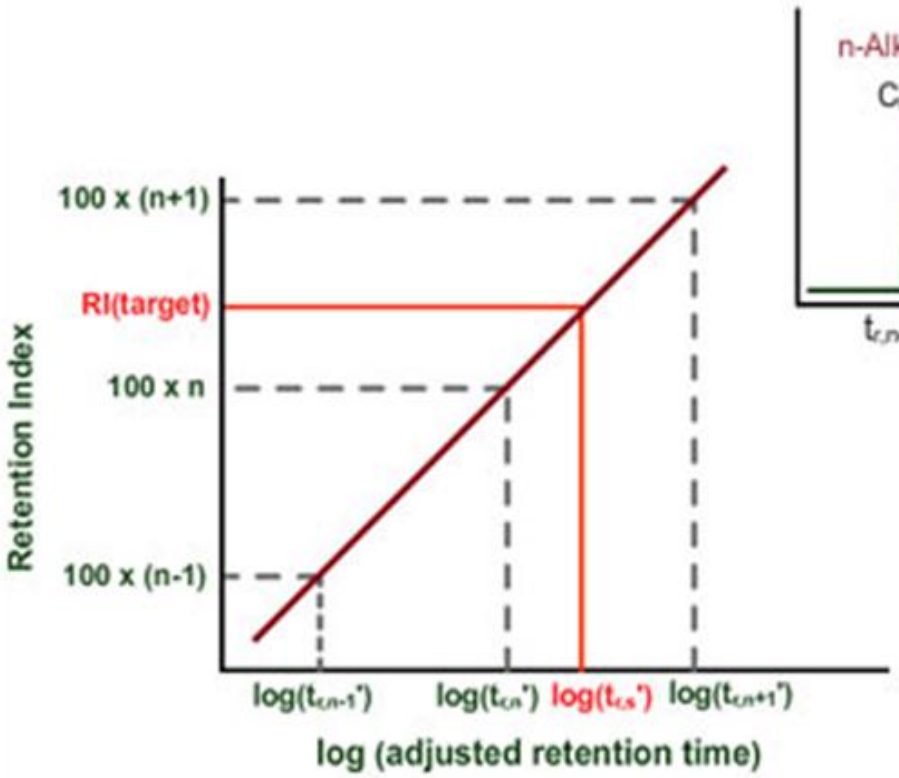


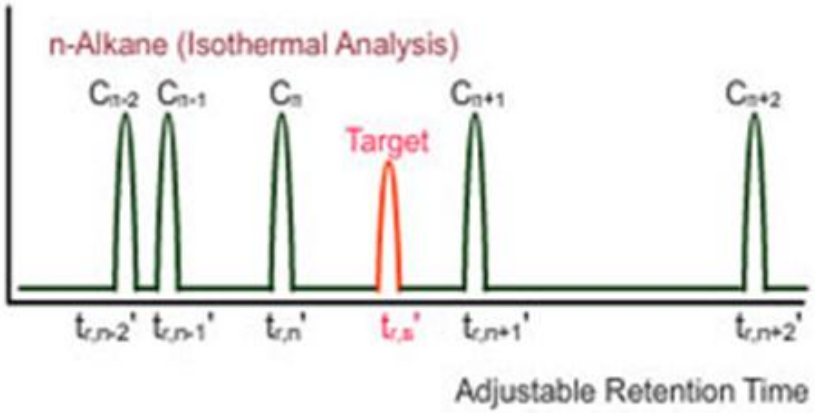
The retention index of a certain chemical compound is its retention time normalised to the retention times of adjacently eluting n-alkanes. While retention times vary with the individual chromatographic system (e.g. with regards to column length, film thickness, diameter, carrier gas velocity and pressure, and void time), the derived retention indices are quite independent of these parameters and allow comparing values measured by different analytical laboratories under varying conditions. Tables of retention indices can help identify components by comparing experimentally found retention indices with known values.

Retention Index (Isothermal)

If a logarithm of adjusted retention times or relative retentions of n-alkanes is plotted with carbon numbers for isothermal analysis, they will show linear relation. Adding a logarithm of adjusted retention time of an unknown to the above～mentioned graph indicates how many carbon numbers this compound corresponds to. In general, 100 times of a carbon number is defined as the retention index.

Retention Index (Isothermal)





$$RI(target) = 100\left(\frac{\log(t_{r,s}')-\log(t_{r,n}')}{\log(t_{r,n+1}')-\log(t_{r,n}')}+n\right)$$

Advantages and disadvantages of GC

- Fast analysis
  - typically minutes (even sec.)
- High resolution
  - Record: N~1.3 x 10^6
- Sensitive detectors (easy ppm, often ppb)
- Highly accurate quantification (1-5 % RSD)
- Automated systems
- Non-destructive
  - allows online coupling to mass spectometry
- Small sample (μL)
- Reliable and relatively simple
- Low cost (~€20,000)

- Limited to volatile samples
  - Temperature limited to ~ 380°C
- Needs P_{vap} ~ 60 Torr at that temperature
- Not suitable for thermally labile samples
- Some samples may require extensive preparation (derivatization)
- Requires spectroscopy (usually MS) to confirm peak identify