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GAS CHROMATOGRAPHY -ARTICLE REVIEW

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Abstract:
Gas chromatography (GC) is an important technique used for the analysis of mixture.In these instruments (GC Digital Gas Flow Meter) (GC-2010 Pro) the method allows mixtures to separate into each component and determine the amounts of components present in sample. By using Gas chromatography, we can analyze a very small amount (microliters) of sample. The sample to be analyzed by GC must be volatile and thermally stable. Helium gas is used to carry the vaporized sample, where the components of sample flow with different rates. The vaporized sample is allowed to flow in along tube having a porous material called column. As column temperature raised, vapour pressure analyte increases eluted faster. The flame ionization detector is used to analyses the parameters like retention time, retention volume, separation factor, Area under the curve (AUC). The analytical process is relatively fast, accurate and precise.

Keywords: *Gas chromatography, Method development, Columns, Volatile, thermostable, Flame ionization detector, Accuracy, Retention time, Retention volume, separation factor, Area under the curve, Derivatization.*

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GAS CHROMATOGRAPHY:

Gas chromatography is a term used to describe the group of analytical separation techniques used to analyze volatile substances in the gas phase. In gas chromatography, the components of a sample are dissolved in a solvent and vaporized in order to separate the analytes by distributing the sample between two phases: a stationary phase and a mobile phase. Themobile phase is a chemically inert gas that serves to carry the molecules of the analyte through the heated column. Gas chromatography is one of the sole forms of chromatography that does not utilize the mobile phase for interacting with the analyte. The stationary phase is either a solid adsorbent, termed gas-solid chromatography (GSC), or a liquid on an inert support, termed gas-liquid chromatography (GLC).

INTRODUCTION:

In early 1900s, Gas chromatography (GC) was discovered by Mikhail Semenovich Tsvett as a separation technique to separate compounds. In organic chemistry, liquid-solid column chromatography is often used to separate organic compounds in solution. Among the various types of gas chromatography, gas-liquid chromatography is the method most commonly usedto separate organic compounds. The combination of gas chromatography and mass spectrometry is an invaluable tool in the identification of molecules. A typical gas chromatograph consists of an injection port, a column, carrier gas flow control equipment, ovens and heaters for maintaining temperatures of the injection port and the column, an integrator chart recorder and a detector.

Principle:

- The basic principle of Gas chromatography is partition. In GC, the separation of mixture of compounds occurs between a gaseous mobile phase and a liquid stationary phase. The mixture of compounds to be separated is converted to vapour and mixed with gaseous mobile phase.
- The compound which is more soluble in stationary phase travels slower and eluted later.
- The compound which is less soluble in stationary phase travels faster and eluted out first.
- No two compounds have same partition coefficient for fixed combination of stationary phase, mobile phase and other conditions. So, the compounds are separated according to their partition coefficient. {partition coefficient is the ratio of solubility of a substance distributed between two immiscible liquids at a constant temperature.

Criteria;

Two important main criteria's are as follows;

Volatility;

compound has to be volatile it cannot be mixed with mobile phase. Hence volatility is important.

Thermostability;

All the compounds will not be in the form of vapour. There will be solid as well as liquid samples. Hence to convert them to a vapour form, they have to be heated to a higher temperature. At that temperature, the compounds have to be thermostable, if they are not thermostable, the compounds cannot be analysed by Gas chromatography, since they will be decomposed.

Instrumentation:

Carrier Gas:

The carrier gas plays an important role, and varies in the GC used. Carrier gas must be dry, freeof oxygen and chemically inert mobile-phase employed in gas chromatography. Helium is most commonly used because it is safer than, but comparable to hydrogen in efficiency, has a larger range of flow rates and is compatible with many detectors. Nitrogen, argon, and hydrogen arealso used depending upon the desired performance and the detector being used. Both hydrogen and helium, which are commonly used. Nitrogen or argon which has a much better advantage than hydrogen or helium due to their higher molecular weights, in which improve vacuum pump efficiency. =All carrier gasses are available in pressurized tanks and pressure regulators; gages and flow meters are used to meticulously control the flow rate of the gas. Most gas supplies used should fall between 99.995% - 99.9995% purity range and contain a low level (< 0.5 ppm) of oxygen and total hydrocarbons in the tank. The carrier gas system contains a molecular sieve to remove water and other impurities.

Figure no: 1 Gas recommendation for capillary columns

Gas Recommendations for Capillary Columns

Detector	Carrier gas	Preferred makeup gas	Second choice	Detector, anode purge, or reference gas
Electron Capture	Hydrogen	Argon/Methane	Nitrogen	Anode purge must be same as makeup
	Helium	Argon/Methane	Nitrogen	
	Nitrogen	Nitrogen	Argon/Methane	
	Argon/Methane	Argon/Methane	Nitrogen	
Flame Ionization	Hydrogen	Nitrogen	Helium	Hydrogen and air for detector
	Helium	Nitrogen	Helium	
	Nitrogen	Nitrogen	Helium	
Flame Photometric	Hydrogen	Nitrogen		Hydrogen and air for detector
	Helium	Nitrogen		
	Nitrogen	Nitrogen		
	Argon	Nitrogen		
Nitrogen-Phosphorus	Helium	Nitrogen	Helium**	Hydrogen and air for detector
	Nitrogen	Nitrogen	Helium**	
Thermal Conductivity	Hydrogen*	Must be same as carrier and reference gas	Must be same as carrier and reference gas	Reference must be same as carrier and makeup
	Helium			
	Nitrogen			

* When using hydrogen with a thermal conductivity detector, vent the detector exhaust to a fume hood or a dedicated exhaust to avoid buildup of hydrogen gas.

** Helium is not recommended as a makeup gas at flow rates > 5 mL/min. Flow rates above 5 mL/min shorten detector life.

Flow regulators and flow meters;

Flow regulators are used to measure the flow rate of carrier gas. They are rotameter and soap bubble flow meter.

Rotameter;

It is placed conveniently before the column inlet. It has an ordinary glass tube (like burette) with a float held on to a spring. The level of the float is determined by the flow rate of carrier gas and a pre calibrated.

Soap bubble meter;

It is similar to rotameter and instead of a float, soap bubble formed indicates the flow rate. It has a glass tube with a inlet tube at the bottom through which gas comes in. A rubber bulb is used to store soap solution. When the bulb is gently pressed, a drop of soap solution is converted into a bubble by the pressure of carrier gas and travels upwards is a measure of flowrate of carrier gas. The graduations are also recalibrated.

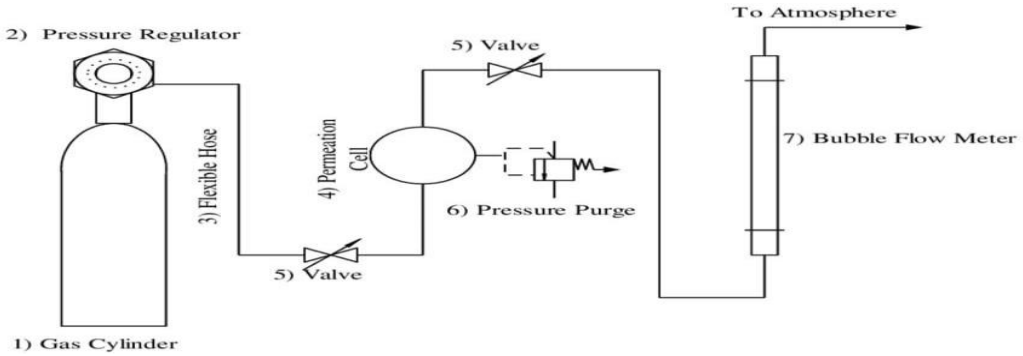


Figure no: 2 schematic diagram of gas chromatography

Sample Injection:

A sample port is necessary for introducing the sample at the head of the column. Modern injection techniques often employ the use of heated sample ports through which the sample can be injected and vaporized in a near simultaneous fashion. A calibrated microsyringe is used to deliver a sample volume in the range of a few microliters through a rubber septum and into the vaporization chamber.

Column Oven:

The thermostatic oven serves to control the temperature of the column within a few tenths of a degree to conduct precise work. The oven can be operated in two manners: isothermal programming or temperature programming. In isothermal programming, the temperature of the column is held constant throughout the entire separation. The optimum column temperature forisothermal operation is about the middle point of the boiling range of the sample. However, isothermal programming works best only if the boiling point range of the sample is narrow. Temperature
Programming.

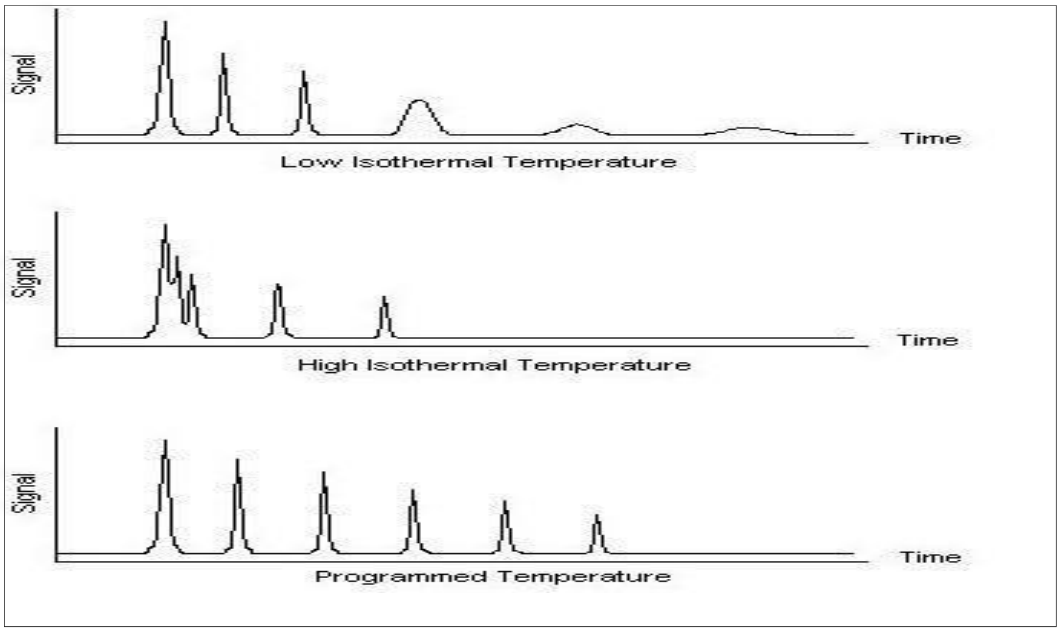


Figure no: 3 Column temperature programmes

Open Tubular Columns and Packed Columns:

Open tubular columns, which are also known as capillary columns, come in two basic forms. The first is a wall-coated open tubular (WCOT) column and the second type is a support-coated open tubular (SCOT) column. WCOT columns are capillary tubes that have a thin layer of the stationary phase coated along the column walls. In SCOT columns, the column walls are first coated with a thin layer (about 30 micrometers thick) of adsorbent solid, such as diatomaceous earth, a material which consists of single-celled, sea-plant skeletons. The adsorbent solid is then treated with the liquid stationary phase. While SCOT columns are capable of holding a greater volume of stationary phase than a WCOT column due to its greater sample capacity, WCOT columns still have greater column efficiencies.

	Type of Column			
	FSWC	WCOT	SCOT	Packed
Length	10 to 1000 m	10 to 1000 m	10 to 100 m	1 to 6 m
Inner Diameter	0.1 to 0.3 mm	0.25 to 0.75 mm	0.5 mm	2 to 4 mm
Efficiency (plates/m)	2000 to 4000	1000 to 4000	600 to 1200	500 to 1000
Sample Size	10 to 75 ng	10 to 1000 ng	10 to 1000 ng	10 to 10^6 ng
Pressure	Low	Low	Low	High
Speed	Fast	Fast	Fast	Slow
Inertness	Best	Good	Fair	Poor

Figure no :4 Types of columns

Detection Systems:
The detector is the device located at the end of the column which provides a quantitative measurement of the components of the mixture as they elute in combination with the carrier gas.In theory, any property of the gaseous mixture that is different from the carrier gas can be used asa detection method.

Each detector has two main parts that when used together they serve as transducers to convert the detected property changes into an electrical signal that is recorded as a chromatogram. The first part of the detector is the sensor which is placed as close to the column exit as possible in order to optimize detection. The second is the electronic equipment used to digitize the analog signal so that a computer may analyze the acquired chromatogram. The sooner the analog signal is converted into a digital signal, the greater the signal-to-noise ratio becomes, as analog signal are easily susceptible to many types of interferences.

Table 1: Typical gas chromatography detectors and their detectionlimits.

Type of Detector	Applicable Samples	Detection Limit
Mass Spectrometer (MS)	Tunable for any sample	0.25 to 100 pg
Flame Ionization (FID)	Hydrocarbons	1 pg/s
Thermal Conductivity(TCD)	Universal	500 pg/ml
Electron-Capture (ECD)	Halogenated hydrocarbons	5 fg/s
Atomic Emission (AED)	Element-selective	1 pg
Chemiluminescence (CS)	Oxidizing reagent	Dark current ofPMT
Photoionization (PID)	Vapor and gaseous Compounds	0.002 to 0.02 µg/L

Figure no :5 Typical gas chromatography detectors

Flame Ionization Detectors:
Flame ionization detectors (FID) are the most generally applicable and most widely used detectors. In a FID, the sample is directed at an air-hydrogen flame after exiting the column. Atthe high temperature of the air-hydrogen flame, the sample undergoes pyrolysis, or chemical decomposition through intense heating.

It is advantageous to use FID because the detector is unaffected by flow rate, noncombustible gases and water. These properties allow FID high sensitivity and low noise. The unit is both reliable and relatively easy to use. However, this technique does require flammable gas and also destroys the sample.

Thermal Conductivity Detectors:
Thermal conductivity detectors (TCD) were one the earliest detectors developed for use with gas chromatography. The TCD works by measuring the change in carrier gas thermal conductivity caused by the presence of the sample, which has a different thermal conductivity from that of the carrier gas. Their design is relatively simple, and consists of an electrically heated source that is maintained at constant power. The source is usually a thin wire made of platinum, gold. The resistance within the wire depends upon temperature, which is dependent upon the thermal conductivity of the gas.

The advantages of TCDs are the ease and simplicity of use, the devices' broad application to inorganic, organic compounds, and the ability of the analyze to be collected after separation and detection. The greatest drawback of the TCD is the low sensitivity of the instrument in relation to other detection methods, in addition to flow rate and concentration dependency.

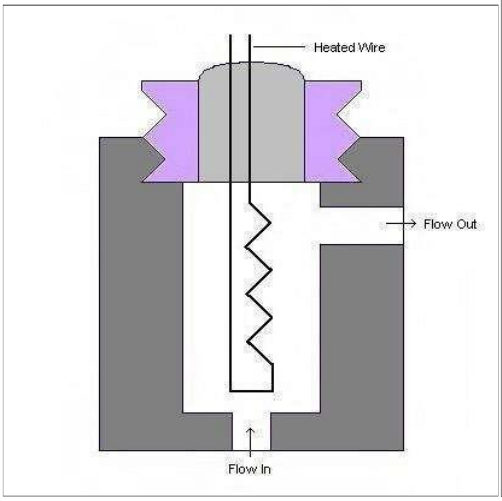


Figure no: 6 Thermal conductivity detector

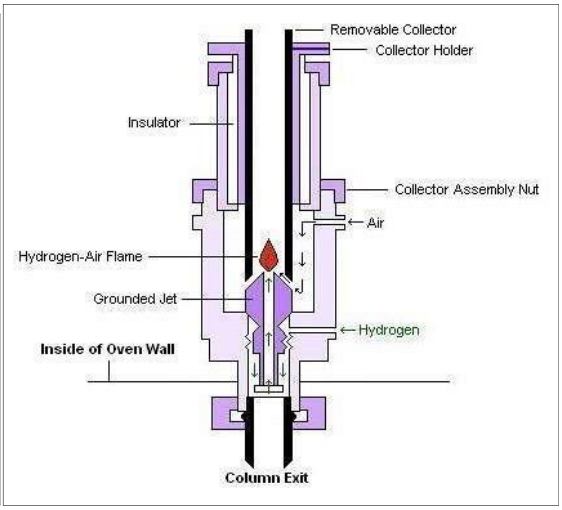


Figure no: 7 Flame ionization detector

Electron-capture Detectors:

Electron-capture detectors (ECD) are highly selective detectors commonly used for detecting environmental samples as the device selectively detects organic compounds with moieties suchas halogens, peroxides, quinones and nitro groups and gives little to no response for all other compounds. Therefore, this method is best suited in applications where traces quantities of chemicals such as pesticides are to be detected and other chromatographic methods are unfeasible.

The simplest form of ECD involves gaseous electrons from a radioactive emitter in an electric field. As the analyte leaves the GC column, it is passed over this emitter, which typicallyconsists of nickle-63 or tritium. The electrons from the emitter ionize the nitrogen carrier gas and cause it to release a burst of electrons. In the absence of organic compounds, a constant standing current is maintained between two electrodes. With the addition of organic compounds with electronegative functional groups, the current decreases significantly as thefunctional groups capture the electrons.

The advantages of ECDs are the high selectivity and sensitivity towards certain organic species with electronegative functional groups. However, the detector has a limited signal range and is potentially dangerous owing to its radioactivity. In addition, the signal-to-noise ratio is limited by radioactive decay and the presence of O2 within the detector.

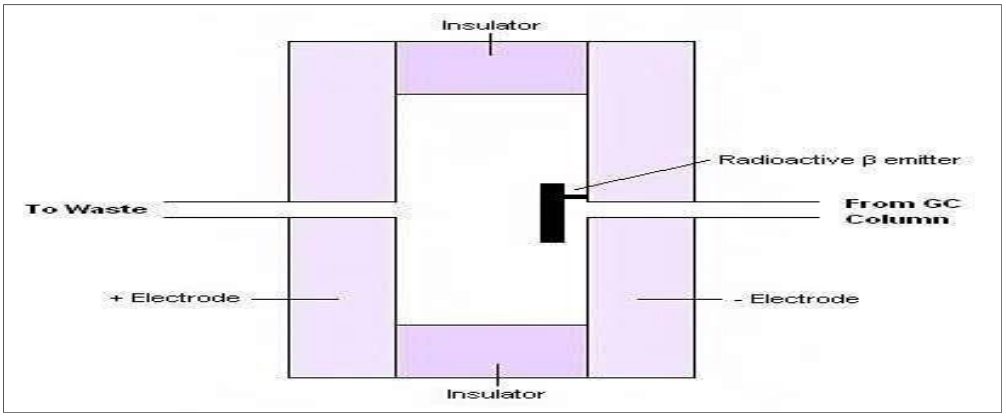


Figure no: 8 schematic Electron-capture detectors

Atomic Emission Detectors:

Atomic emission detectors (AED), one of the newest additions to the gas chromatographer's arsenal, are element-selective detectors that utilize plasma, which is a partially ionized gas, to atomize all of the elements of a sample and excite their characteristic atomic emission spectra. AED is an extremely powerful alternative that has a wider applicability due to its based on the detection of atomic emissions. There are three ways of generating plasma: microwave-induced plasma (MIP), inductively coupled plasma (ICP) or direct current plasma (DCP).

Instrumentation:

The components of the Atomic emission detectors include 1) an interface for the incoming capillary GC column to induce plasma chamber,2) a microwave chamber, 3) a cooling system, 4)a diffraction grating that associated optics, and 5) a position adjustable photodiode array interfaced to a computer.

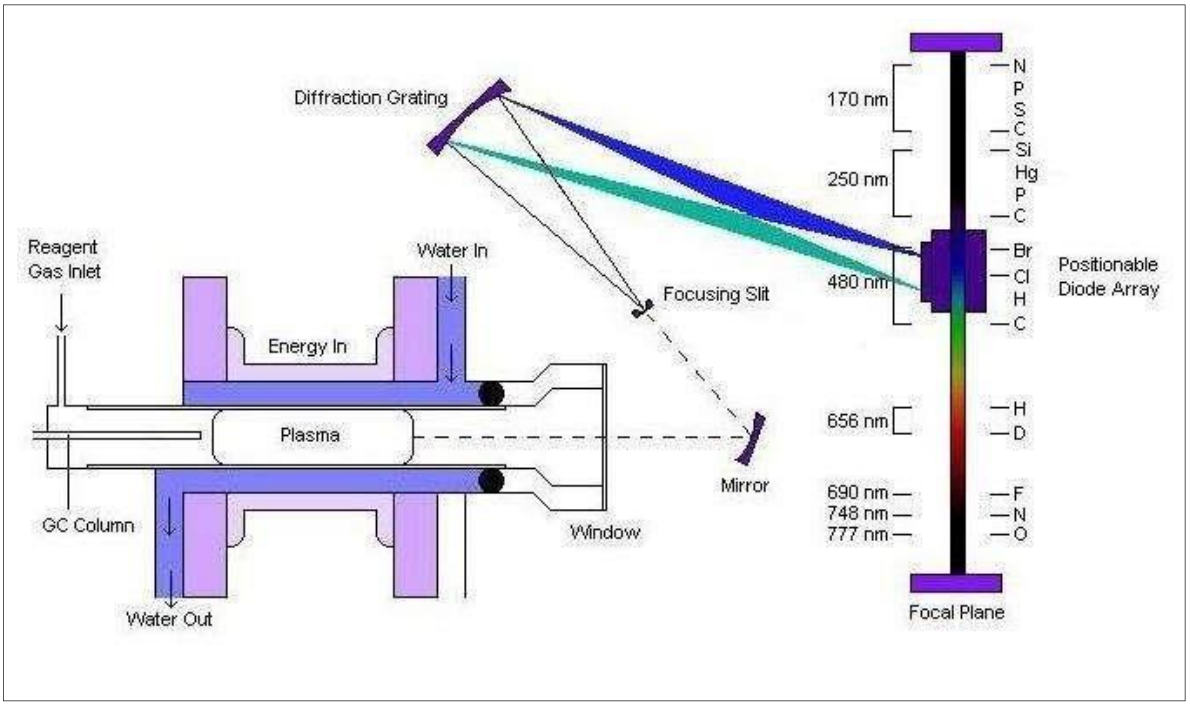


Figure no 9: schematic diagram of atomic emission detector

GC Chemiluminescence Detectors:

Chemiluminescence spectroscopy (CS) is a process in which both qualitative and quantitative properties can be be determined using the optical emission from excited chemical species.It is very similar to AES, but the difference is that it utilizes the light emitted from the energized molecules rather than just excited molecules. Moreover, chemiluminescence can occur in either the solution or gas phase whereas AES is designed for gaseous phases. The light source for chemiluminescence comes from the reactions of the chemicals such that it produces light energyas a product. This light band is used instead of a separate source of light such as a light beam.

Photoionization Detectors:

Another different kind of detector for GC is the photoionization detector which utilizestheproperties of chemiluminescence spectroscopy

Instrumentation

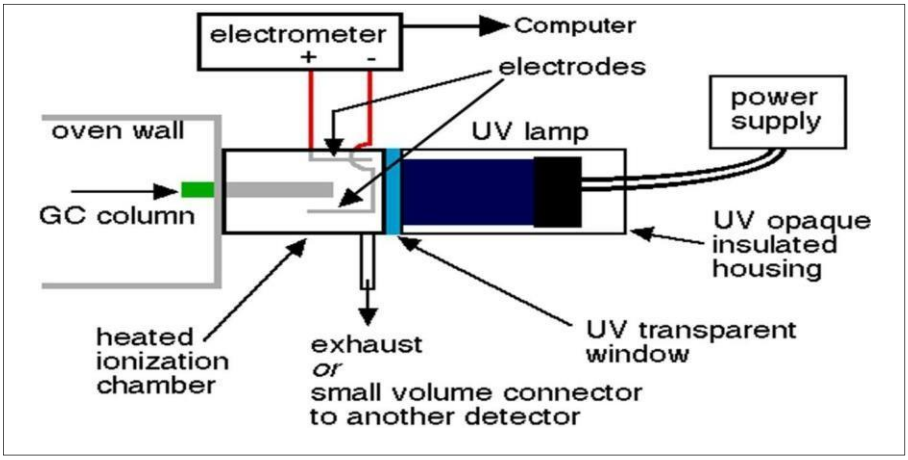


Figure no 10: Schematic of a photoionization detector

Derivatization:

Derivatization is the process by which a compound is chemically changed, producing a new compound that has properties more amenable to a particular analytical method. Some samples analyzed by GC require derivatization to make them suitable for analysis. Compounds that have poor volatility, poor thermal stability, or that can be adsorbed in the injector will exhibit no reproducible peak areas, heights, and shapes.

Selection of Derivatization reagent:

Derivatization reagent is the substance that is used to chemically modify a compound to produce a new compound which has properties that are suitable for analysis in GC or LC. The following criteria must be used as guidelines in choosing a suitable derivatization reagent for GC analysis.

i. The reagent should produce more than 95 % complete derivatives.
ii. It should not cause any rearrangements or structural alterations ofcompoundsduring formation of the derivative.
iii. It should not contribute to loss of the sample during the reaction.
iv. It should produce a derivative that will not interact with the GC column.
v. It should produce a derivative that is stable with respect to time.

Objectives for derivatization:

i. Improvement of resolution and reduce tailing of polar compounds whichmaycontain – OH, –COOH, =NH, –NH_2, –SH, and other functional groups.
ii. Analysis of relatively nonvolatile compounds.
iii. Reduction of volatility of compounds prior to GC analysis.
iv. Improvement of analytical efficiency and hence increase detectability.
v. Stabilization of compounds for GC analysis.

Types of derivatization reactions:

Derivatization reactions used for gas chromatography (GC) fall into three general reaction types namely; Alkylation of which the general process is esterification, Acylation and Silylation. Through these three processes, highly polar materials such as organic acids, amides, poly- hydroxy compounds, amino acids are rendered suitable for GC analysis by making them sufficiently volatile. These general processes are discussed below.

Alkylation

Alkylation is mostly used as the first step for further derivatizations or as a method of protection of certain active hydrogens in a sample molecule. It represents the replacement of active hydrogen by an aliphatic or aliphatic-aromatic (e.g., benzyl) group in process referred to as esterification. Equation 1 below shows the general reaction equation representing the esterification process.

$$RCOOH + PhCH_2X \rightarrow RCOOCH_2Ph + HX$$

Equation 1: General reaction for esterification process

Derivatization reagents used in alkylation

Alkylation reagents can be used alone to form esters, ethers and amides or they can be used in conjunction with acylation or silylation reagents. The reaction conditions can vary from strongly acidic to strongly basic with both generating stable derivatives.

Examples

- **Dialkylacetals**

Dimethylformamide (DMF) is an example of dialkylacetals with a general formula $CH_3CH_3NCHOROR$ are used to esterify acids to their methyl esters. Dialkylacetals have a wider applicability for the derivatization of a number of functional groups containing reactive hydrogens.

$$CH_3CH_3NCHOROR + R`COOH \rightarrow R`COOR + ROH + CH_3CH_3NCHO$$

Equation 2: The reaction between N, N-dimethylformamide dimethylacetaland Carboxylic acid.

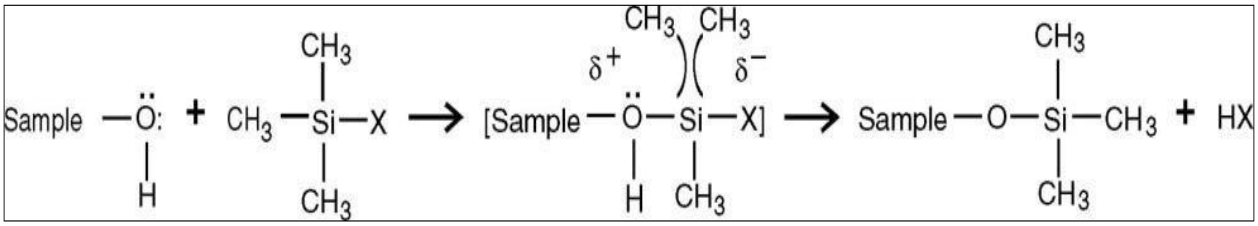
Silylation

Silylation is the most prevalent derivatization method as it readily volatizes the sample and therefore very suitable for non-volatile samples for GC analysis. Silylation is the introduction of a silyl group into a molecule, usually in substitution for active hydrogen such as di methyl silyl [$SiH(CH_3)2$], t-butyl di methyl silyl [$Si\ (CH_3)_2C(CH_3)_3$] and chloromethyldimethylsilyl[$SiCH_2Cl(CH_3)_2$].

Silylation reaction and mechanism:

The silylation reaction is driven by a good leaving group, which means a leaving group with a low basicity, ability to stabilize a negative charge in the transitional state, and little or no back bonding between the leaving group and silicon atom (Knapp, 1979). The mechanism involves the replacement of the active hydrogens (in -OH, -COOH, -NH, - NH_2, and -SH groups) with a trimethylsilyl group.

Equation 4: Reaction mechanism for the formation of trialkylsilyl derivatives for trimethylchlorosilane, trifluoroacetamide (MSTFA), trimethylsilyldiethylamine (TMS-DEA),N-



X = Cl

Derivatization reagents used in Silylation

Reagents used for the sialylation derivatization process include Hexamethyldisilane Trimethylchlorosilane (TMCS), Trimethylsilyl imidazole (TMSI), Bistrimethylsilylacetamide (BSA), Bistrimethylsilyltrifluoroacetamide (BSTFA), N-methyl- trimethylsilyl

Examples;

Trimethylsilyl imidazole (TMSI)

Trimethylsilyl imidazole (TMSI) is not a weak donor, but it is selective as it reacts with alcohols and phenols but not amines or amides (nitrogen groups An example of reaction equation.

Equation 5: Silylation reaction using Trimethylsilylimidazole (TMSI)

Acylation;

Derivatization by acylation is a type of reaction in which an acyl group is introduced to an organic compound. In the case of a carboxylic acid, the reaction involves the introduction of the acyl group and the loss of the hydroxyl group. Compounds that contain active hydrogens (e.g., -OH, -SH and -NH) can be converted into esters, thioesters and amides, respectively, through acylation.

$$CH_3OCOCOCH_3 + HOR \xrightarrow{H^+} CH_3OCOR' + HOCOCH_3$$

Equation 6: Acylation Reaction

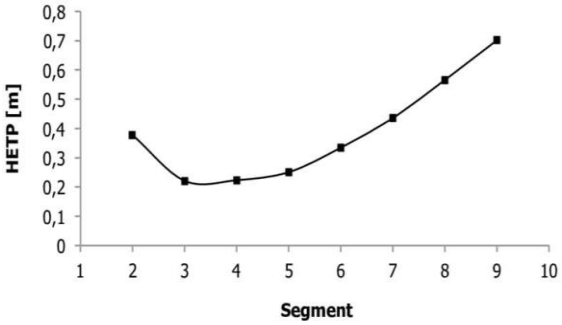
Benefits of acylation in GC analysis:

i. It improves analyte stability by protecting unstable groups.

ii. It can provide volatility on substances such as carbohydrates or amino acids, whichhave many polar groups that they are nonvolatile and normally decompose on heating.

iii. It assists in chromatographic separations which might not be possible withcompounds that are not suitable for GC analysis.

iv. Compounds are detectable at very low levels with an electron capture detector (ECD).



Derivatization reagents used in acylation

Common reagents for the Alkylation process are Fluoracylimidazoles, Fluorinated Anhydrides, N-Methyl-bis(trifluoroacetamide) (MBTFA), Pentafluorobenzyl Chloride (PFBCI) and Pentafluoro propanol (PFPOH). Acylating reagents readily target highly polar, multi-functional compounds, such as carbohydrates and amino acids.

Chiral Derivatization:

Chiral derivatization involves reaction of an enantiomeric molecule with an enantiomerically pure chiral derivatizing agent (CDA) to form two diastereomeric derivatives that can be separated in this case using GC. A solution in which both enantiomers of a compound are present in equal amounts is called a racemic mixture. Diastereomers are stereoisomers (they have two or more stereo centers) that are not related as object and mirror image and are therefore not enantiomers. In other word, unlike enantiomers which are mirror images of each other and non-superimposable, diastereomers are not mirror images of each other and non- superimposable**.**

PARAMETERS USED IN GAS CHROMATOGRAPHY

Retention time (Rt):

Retention time is the difference in time between the point of injection and appearance of peak maxima. Retention time is the time required for 50% of a component to be eluted from a column. Retention time is measured in minutes or seconds. Retention time is also proportional to the distance moved on a chart paper, which can bemeasured in cm or mm.

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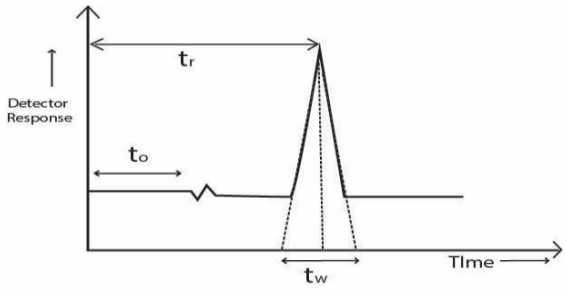

Retention volume (Vr):

Retention volume is the volume of carrier gas required to elute 50% of the componentfrom the

Retention volume = Retention time x flow rate

Separation factor (S):

Separation factor is the ratio of partition co-efficient of the two components to be separated. It can be expressed and determined by using the following equation:

S = Kb / Ka = Ka / Kb =(tb – t0) / (ta – t0)

Where;

t0 = Retention time of unretained substance Kb,

Ka = Partition coefficients of b and a tb,

ta = Retention time of substance b and a

S= depends on liquid phase & column temperature

If there is more difference in partition coefficient between two compounds, the peaks are far apart and the separation factor is more. If the partition coefficients of two compounds are similar, then the peaks are closer and the separation factor is less.

Resolution:

Resolution is a measure of the extent of separation of two components and the baseline separation achieved. It can be determined by using the following formula:

Rs = 2 (Rt2-Rt1) / W1 + W2

Theoretical Plate (Plate theory):

A theoretical plate is an imaginary or hypothetical unit of a column where theoretical plate is an imen stationary phase and mobile phase hat attained equilibrium. A theoretical plate can also be called as

a unit of the column. functional

HETP - Height Equivalent to a Theoretical Plate
A theoretical plate can be of any height, which decides the efficiency of separation. If HETP is less, the column is more efficient. If HETP is more, the column is less efficient. HETP can be calculated by using the following formula:

HETP = length of the column / no. of theoretical plates HETP is given by the Van Demeter equation

HETP = A + B / u + Cu

Where;
A = Eddy diffusion term or multiple path diffusion which arises due to packing of the column. This is unaffected by carrier gas velocity or flow rate. This can be minimised by uniformity in packing.

B = Longitudinal diffusion term or molecular diffusion which depends on flow rate.

C = Effect of mass transfer which depends on flow rateu = Flow rate or velocity of the mobile phase.

The following figure is the effect of flow rate on HETP. A column is efficient only when HETP is minimum. Hence an ideal flow rate corresponding to the minimumvalue of HETP is used.

Efficiency (No. of theoretical plates):
Efficiency of a column is expressed by the number of theoretical plates. It can be determined by using the formula:

$$n = 16\ Rt^2 / W^2$$

where;
n = no. of theoretical platesRt = Retention time (Rt) W = peak width at base

Rt and w are measured in common units (mm or cm or minutes or seconds) andare proportional to the distances marked on chart paper.

If the number of theoretical plates is high, the column is said to be highly efficient. If the number of theoretical plates is low, the column is said to be less efficient. For gas chromatographic columns, a value of 600/metre is sufficient. But in HPLC, high values like 40,000 to 70,000/metre are recommended.

Asymmetry factor:
A chromatographic peak should be symmetrical about its centre and said to follow Gaussian distribution. In such cases, the peak will be like an isosceles triangle. But in practice, due to some factors, the peak is not symmetrical and shows tailing or fronting as shown in the following figures.

Fronting is due to saturation of stationary phase and can be avoided by using less quantity of sample. Tailing is due to more active adsorption sites and can be eliminated by support pretreatment, more polar mobile phased increasing the amount of liquid phase.

Asymmetry factor (0.95 to 1.05) can be calculated by using the formula: AF = b/a (b and a calculated at 5% or 10% of the peak height)

Limitations
1.Not suitable for detecting semi-volatile compounds
2.Only indicates if volatile organic compounds are presents.
3.High concentration so methane are required for higher performance.

- Frequent calibration are required.

1. Units of parts per million range
2. Environmental distraction, especially water vapor.
3. Strong electrical fields Rapid variation in temperature at the detector and naturally occurring compounds may affect instrumental signal.

Applications:
- Gas chromatography is a physical separation method in where volatile mixtures are separated.
- GC is used in many different fields such as pharmaceuticals, cosmetics, and even environmental toxins.
- The samples must be volatile, human breathe, blood, saliva and other secretions containing large amounts of organic volatiles can be easily analyzed using GC. Knowing the amount of which compound is in each sample gives a huge advantage in studying the effectsof human health and of the environment as well.
- Air samples can be analyzed using GC. Air quality control units use GCcoupled with FID in order to determine the components of a given air sample.
- GC is useful for method which can determine the components of a given mixture using the retention times and the abundance of the

samples.

- Gas chromatography applied to many pharmaceutical applications such as identifying the amount of chemicals in drugs.
- Cosmetic manufacturers use this gas chromatography to effectively measure how much of each chemical is used for their products.
- The pharmaceutical industry uses gas chromatography to help produce pure products in large quantities. The method is used to ensure the purity of the produced material, eliminated inconsistencies in pharmaceutical products
- Gas chromatography is used in many research areas, in particular, for the analysis of meteorites and natural products.
- Scientists use gas chromatography to analyze the composition of meteorites that fall to the earth.
- Gas chromatography is used in forensic science. Mostly, it is used to determine the circumstances of a person's death, such as whether they ingested poison, or consumed drugs or alcohol in the hours prior.
- Scientists take samples of blood and fibers from the crime scene and analyze them using gas chromatography to help investigators piece together the facts.
- Gas chromatography is being used to combat the problem, by monitoring the levels of harmful pollutants in the air so that scientists can visualize where air pollution is more concentrated, and how these changes throughout the day and the year to develop effective preventative methods.
- Gas chromatography is used to detect blood alcohol levels. It has continued to be used to detect how much alcohol a person has consumed to help gauge how impaired their normal functioning may be. Also, it has been adopted by forensic science to determine blood alcohol levels at the time of death.
- Metabolomics study using GC is possible only if the compound can be volatilized or it can be derivatized to a volatile form using various types of derivatizing agents. Derivatization is the process of modifying the chemical structure of a compound to make it easy for identification by GC.

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