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GAS CHROMATOGRAPHY-MASS SPECTROSCOPY: AN OVERVIEW

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ABSTRACT
GC-MS is highly effective and versatile analytical technique with numerous scientific applications. The review elaborates modern methods of instrumentation and significant uses of this technique. It is very useful for quality control, analytical research, maintenance for human welfare and development. Analysis begins with the gas chromatography where the sample is effectively vapourised into the gas phase and separated into its various components using a capillary column coated with a stationary phase.

KEYWORDS: Gas chromatography, Mass spectroscopy, Single quadrupole GC-MS, GC-MS 2400 System, Mass analyser.

INTRODUCTION

Only analytes that can tolerate the demanding partitioning conditions of the gas chromatograph that are both volatile and thermally labile are suitable for GC/MS. Many analytes can only be detected and separated from complicated mixtures by GC/MS, despite this restriction. Other than GC/MS, there is no method that can be used to separate and ionise compounds that exclusively exist in the gas phase at temperatures below 100 °C. The range of potential analytes can be greatly widened due to the capacity to synthesise stable, volatile derivatives of numerous substances that aren't suitable for GC/MS in their original forms. The most used GC/MS ionisation technique is electron ionisation (EI) because of the massive fragmentation it causes; many chemicals generate distinctive patterns that can be used in conjunction with gas chromatographic retention-time data for an unambiguous identification.[1]

Gas chromatography–mass spectrometry (GC-MS)

In order to identify various chemicals inside a test sample, analysts use a technique called gas chromatography-mass spectrometry (GC-MS), which combines the advantages of mass spectrometry and gas chromatography.[2]

Uses of GC-MS include the detection of drugs, investigation of fires, environmental analysis, research of explosives, and identification of unidentified materials, including those of material samples taken from the planet Mars during probe expeditions as early as the 1970s. To find chemicals in luggage or on people, GC-MS can also be utilised in airport security. In samples that were previously believed to have decomposed beyond identification, it can also find trace components. It enables examination and detection of substances in even minute concentrations, similar to liquid chromatography-mass spectrometry.[3]

Because it is utilised to conduct a 100% specific test that positively detects the presence of a particular chemical, GC-MS has been recognised as the "gold standard" for forensic substance identification. Every one of the several chemicals in a category may be detected by a nonspecific test. The identity of the chemical may statistically be suggested by a non-specific test, but this may result in false positive identification. Unfortunately, the 300°C temperature utilised in the GC-MS injection port (and oven) can cause thermal degradation of injected molecules, resulting in the measurement of degradation products rather than the actual molecule(s) of interest.[4]

The purity and stability of organic compounds, as well as the individual components of a mixture, are frequently assessed subjectively and quantitatively using GC-MS. Environmental chemistry for studies on the atmosphere, soil, and water, forensic science for the detection of drugs of abuse (or their metabolites), food science for determining the quality and authenticity of food and drink, and renewable fuel development are just a few of the diverse fields that frequently use GC-MS. The concepts of mass spectrometry will be described in this article in terms of the most fundamental equipment needed and how a measurement is made, and then the mass spectrum the data obtained from an MS

measurement will be explained. It can be challenging to interpret the wealth of information seen in mass spectra. The numerous kinds of mass spectrometers are then briefly covered, and the article concludes with a section on recent developments in MS technology.[5]

GC-MS Principle

The first steps in a GC-MS experiment include sample preparation, injection, and separation on a GC column. An interface is required to transfer the molecules from the GC to the mass spectrometer since the operation of a mass spectrometer necessitates a high vacuum system. The molecules that exit the column enter the most popular form of instrument, the ionisation chamber, where they are subjected to a stream of powerful electrons that ionise and fragment some of the molecules. In addition to molecular ions that have not been fragmented, processes that result in their fragmentation or rearrangement can also produce ions. In a mass analyser, the ions are accelerated and swiftly sorted in accordance with the mass to charge ratio (m/z, where m is the mass and z is the charge). The mass analyser can quickly sort thousands of distinct ion masses (m/z). The number of electrons produced when the ions impact the detector for each m/z is then measured by a detector to determine the abundance of the ions. A chromatogram that shows the amount of each compound as a function of retention time is produced by GC using MS as the detector. A mass spectrum, which is a histogram of each ion's abundance as a function of m/z and acts as the fingerprint to identify the substance represented by a peak on the chromatogram, is the fundamental MS-specific dimension of data.[6, 7]

INSTRUMENTATION

Fig. No. 1: GC-MS INSTRUMENT.

GC-MS Ionization Techniques

The gas that leaves the GC enters an ionisation chamber, where the carrier gas and analytes are irradiated with incredibly energetic electrons. The most used technique is hard ionization's electron impact (EI), often known as electron ionisation .By adding a voltage to a heated filament, this approach produces a high-energy electron beam. When neutral molecules enter the ionisation chamber, a high-energy electron beam bombards them, removing electrons from their valence shells and causing some of the molecules to become molecular ions. Here, radical cations M+ (hereafter referred to as M+) are created, where M is the analyte molecule, the + symbol denotes the ions' positive charge, and the dot represents an unpaired electron. The molecular ion may be one of the ionised molecules, but it may also possess enough energy to fragment into mass fragment ions, suffer bond cleavage, or undergo rearrangement (product ions). The vacuum system removes the majority of both the sample and the various by-products created during electron ionisation.[8]

One popular method of soft ionisation is chemical ionisation (CI). By adding a proton (H+) to the molecule, this method creates an adduct ion (MH+). The amount of energy delivered to the molecule and the kinds of ions produced by various ionisation methods varies most significantly from one another. Most of the time, there isn't enough energy to break up the molecule ions, which makes their signal more potent. CI and EI are frequently complementing methods. Since EI is the most often used ionisation method for GC-MS, only EI MS will be covered in the following sections.[9]

Mass Analysers

The accelerator plates and Repeller used to send positively charged ions out of the ionisation chamber control the ions' direction and speed. The trajectory of ions with the same m/z value is focused on the analyser exit slit by single-focusing, magnetic sector mass spectrometers.[10]

By continuously changing the accelerating voltage and magnetic field, the ions' velocity and trajectory are managed. For further information on magnetic sector mass analysers. Vacuum pumps remove unionised molecules, and molecules with negative charges are attracted to the Repeller plate.[11]

The quadrupole mass filter is the most often used mass analyser. The quadrupole is made up of four solid rods with circular or hyperbolic cross sections that are evenly spaced apart and parallel to the ion route. The magnetic fields employed in the magnetic-sector mass spectrometer are not used in the quadrupole to separate the ions by their m/z. Instead, electric fields are used. Direct-current (DC) and radio frequency (RF) voltages applied to each rod with the opposite polarity on the pairs of opposing rods separate them.[12]

By adjusting the field strengths, it is possible to separate ions with stable oscillations from those with unstable oscillations, causing the former to strike a rod, become neutral, and then be pumped out of the analyser by the vacuum system. In addition, mass analysers have been developed those separate ions according to their time-of-flight (ToF) or flight time. Ions with comparable starting kinetic energy move through this region over a lengthy field-free flight tube. Smaller ions move more quickly and get to the detector before bigger, slower ions.[13]

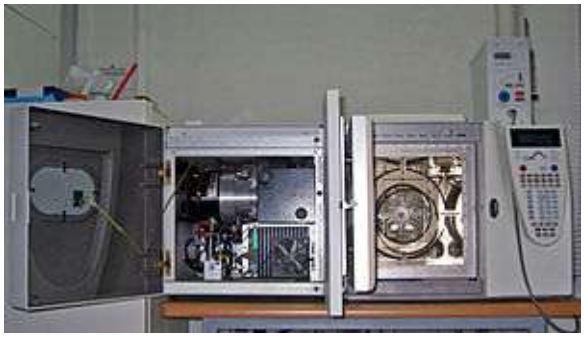

Fig. No. 2: GC-MS COLUMN.

The insides of the GC-MS, with the column of the gas chromatograph in the oven on the right

The gas chromatograph and the mass spectrometer are the GC-two MS's main constituent parts. The capillary column used in the gas chromatograph is dependent on the phase (5% phenyl polysiloxane, for example) and column dimensions (length, diameter, film thickness) for molecular separation. As the sample moves down the length of the column, the separation of the molecules will be aided by the differences in chemical characteristics between the various molecules in the mixture and their varying affinities for the stationary phase. It is possible for the mass spectrometer downstream to collect, ionise, accelerate, deflect, and detect the ionised molecules individually because the molecules are kept by the column and elute (come off) from the column at distinct times (referred to as the retention time). The mass spectrometer does this by isolating each molecule into ionised fragments, which are then detected using the mass-to-charge ratio of the fragments.[14]

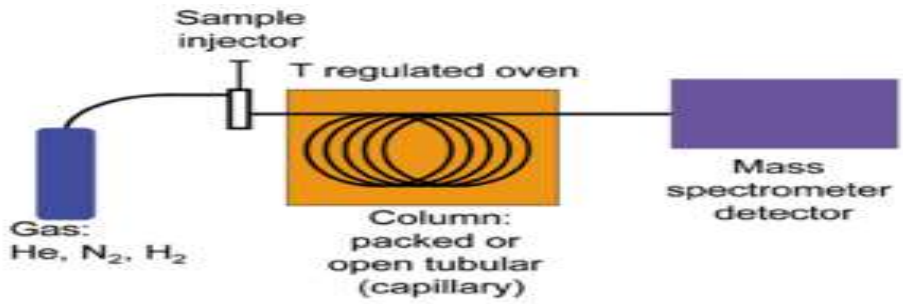

Fig. No. 3: GC-MS SCHEMATIC

When these two parts are utilised together, a far finer level of substance identification is possible than when each part is employed independently. Gas chromatography or mass spectrometry by themselves is insufficient to reliably identify a specific chemical. The mass spectrometry process typically calls for a very pure sample, whereas gas chromatography using a conventional detector (such as a flame ionisation detector) is unable to distinguish between multiple molecules that just so happen to have the same retention time that is, take the same amount of time to travel through the column resulting in two or more molecules that co-elute. In a mass spectrometer, two distinct molecules can occasionally have ionised fragments with similar patterns (mass spectrum). The likelihood of error is decreased by combining the two procedures because it is highly unlikely that two different molecules will react similarly in a gas chromatograph and a mass spectrometer. As a result, the likelihood that the target analyte is present in the sample usually increases when an identifying mass spectrum appears at a typical retention time in a GC-MS study.

SINGLE QUADRUPOLE GC-MS

ISQ™ 7610 Single Quadrupole GC-MS CatLog number: ISQ7610-AEI

Fig. No. 4: SINGLE QUADRUPOLE GC-MS

GC-MS is a common abbreviation for the combination of gas chromatography with a single-quadrupole mass spectrometer. Although these systems can be operated utilising either targeted selected ion monitoring (SIM) or untargeted full scan acquisition, GC-MS is well suited for the routine analysis of samples when either targeted or untargeted analysis is required. Common uses include the examination of pesticides in food and environmental samples, the examination of biological samples for the presence of drugs of abuse, and the examination of

volatile organic compounds in water samples. Analytical testing facilities require the utmost confidence in a GC-MS system to consistently generate reliable results with ease and reliability. You can rely on the Thermos ScientificTM ISQTM 7610 Single Quadrupole GC-MS System for this. Consistent findings from system to system in every laboratory are delivered via simplified operation, automated workflows, and wider dynamic range. With the help of Thermos Scientific's Never VentTM technology, long-life detector, and clever software, downtime is minimised, allowing for the highest possible sample throughput. The system can be upgraded from basic to advanced setups so that you are equipped to handle any analytical task. With quick return on investment (ROI) for your authorised GC-MS analyses, you can now take the lead.[15]

MODERN METHOD OF INSTRUMENTATION GCMS 2400 SYSTEM

Fig. No. 5: GC-MS 2400 SYSTEM.

Via mobile information access provided by the GC 2400 Platform, labs are able to take quicker, more informed decisions. Now, lab analysts may track the status and development of their sample runs from anywhere, within or outside of the lab, using a detachable touch screen.

The problem of balancing high productivity with effective operations faces analytical laboratories every day. Also, gas chromatography operators demand remote access to their GCs as the popularity of hybrid work models increases, whether they are based in a different area of the lab or somewhere else entirely. Learn about the GC 2400TM Platform, which offers cutting-edge technology that makes it possible to access real-time information while on the go. With a detachable, elegantly designed touch screen, you can quickly assess the progress of your sample runs from any location, inside or outside of the lab, and use that information to make decisions. With the simple-to-use SimplicityChromTM Chromatography Data System (CDS) Software, you may boost GC productivity and lab operations' automation. It allows for the integration of all GC workflow steps, from instrument control to data processing.[16]

APPLICATIONS

1. Environmental monitoring

For monitoring and tracing organic contaminants in the environment, GC-MS is now a highly recommended technology. Although GCMS technology is now less expensive, its reliability has significantly improved. The screening of chloro-phenols in water and soil, polycyclic aromatic hydrocarbons (PAH), unleaded gasoline, dioxins, dibenzofurans organo-chlorine pesticides, herbicides, phenols, halogenated pesticides, and sulphur in the air is very convenient when using this method. In biomass research, it can be used to screen for pesticides in spinach and lignin degradation products. Without the need for derivatization, it is possible to analyse decacyclene, ovalene, and even C60 degradation of carbamazepine and its metabolites in treated sewage water and steroids.[17, 18]

2. Food, beverage, flavour and fragrance analysis

Many aromatic compounds are present in foods and beverages either naturally in their unprocessed state or created during processing. Esters, fatty acids, alcohols, aldehydes, terpenes, and other substances are all solely analysed by GC-MS. GC-MS is also used to measure and detect pollutants, food deterioration, and adulteration of oil, butter, and ghee that should be examined and controlled as prescribed by governmental organisations. It is used to analyse piperine, lavender oil, spearmint oil, essential oils, fragrance reference standards, perfumes, chiral compounds in essential oils, fragrances, menthol, allergens, olive oil, lemon oil, peppermint oil, yiang oil, straw berry syrup, butter triglycerides, and residual pesticides in food and wine.[19, 20]

3. Forensic and criminal cases

To determine the suspect's involvement in the case, GC-MS can analyse the suspect's particles. The American Society for Testing Materials (ASTM) standard for the analysis of fire debris can be used to establish the GC-MS analysis of fire debris. It is the primary instrument employed in anti-doping laboratories in sports to check athlete urine samples for the presence of illegal performance-enhancing substances like anabolic steroids. Detecting poisons and steroids in biological samples from suspects, victims, or the deceased is a routine practise in forensic toxicology.[21, 22]

4. Biological and pesticides detections

GC-MS is only employed in bio-analysis of blood and urine for the presence of barbiturates, narcotics, alcohols, residual solvents, medications such anaesthetics, anticonvulsants, antihistamines, anti-epileptic drugs, sedative hypnotics, narcotics, and dietary items. This method might be utilised to identify adulterations, fatty acid profiling in microorganisms, the presence of free steroids, blood pollutants, metabolites in serum, organochlorine pesticides in drinking water, soft drinks by headspace, pesticides in sunflower oil, etc.[23]

5. Security and chemical warfare agent detection

All airports in the United States now have explosive detection systems, and the chemical analysis unit's GC-MS technology is a crucial component. Traditional GC-MS units with transmission quadrupole mass spectrometers, along with those with cylindrical ion trap (CIT-MS) and toroidal ion trap (T-ITMS) mass spectrometers, have been modified for field portability and close to real-time detection of chemical warfare agents (CWAs) like sarin, soman, and VX.[24, 25]

6. Astro chemistry and Geo chemical Research

Several GC-MS have already departed the planet for the astrochemistry research. The Viking spacecraft transported two people to Mars. With GC-MS, researchers examined Venus' atmosphere. One GC-MS was successfully placed on Titan, Saturn's largest moon, by the Huygens probe of the Cassini-Huygens mission. In 2014, the Rosetta mission will use a chiral GC-MS to analyse the material in the comet 67P/Churyumov-Gerasimenko.

A wide range of low volatility hydrocarbons that are accessible to analysis, significantly improved molecular ions, substantial isomer and structurally relevant mass spectrum peaks, and unique isotope ratio information make GC-MS beneficial for organic geochemical applications.[26, 27]

7. Medicine and Pharmaceutical Applications

Today, new born screening tests utilising gas chromatography-mass spectrometry can identify dozens of congenital metabolic illnesses known as inborn errors of metabolism. Even in urine with low concentrations, GC-MS can identify some chemicals. These substances are not ordinarily present, yet they do when a person has a metabolic abnormality. This is a quick, simple, and successful technique to identify the issue, just like in the case of inherited metabolic problems detected by a urine test at birth. The GCMS is employed for evaluating metabolic activity in conjunction with isotopic tagging of metabolites. The majority of applications rely on the use of 13C labelling and the measurement of 13C–12C ratios with an isotope ratio mass spectrometer (IRMS); an MS with a detector made to analyse only a few specific ions and return values as ratios. It is useful to detect oils in creams, ointments, lotion etc.

In the pharmaceutical industry, GC-MS is frequently used for analytical research and development, quality assurance, manufacturing, and pilot plant departments for active pharmaceutical ingredients (API), bulk medications, and formulations. It is used to build processes and methods and to find API impurities. It is a crucial component of studies in medicinal chemistry (compound synthesis and characterisation), pharmaceutical analysis (impurity profiling, stability testing), pharmacognosy, pharmaceutical process control, pharmaceutical biotechnology, and other fields.[28, 29]

8. Petrochemical and hydrocarbons analysis

The GC-MS is a very useful technique due to the significantly enhanced molecular ions that are always observed, the isomer and structurally relevant mass spectrum peaks, and the enlarged range of low volatility hydrocarbons that are accessible to study, including waxes up to C74H150. By using GC-MS, a wide variety of petrochemicals, fuels, and hydrocarbon mixes, such as gasoline, kerosene, naphthenic acids, diesel fuel, different types of oil, transformer oil, biodiesel, wax, and a wide variety of geochemical samples, can be analysed.[30]

9. Clinical toxicology

Clinical toxicology's primary selling points include improved molecular ions, a wider choice of substances that may be analysed, higher sensitivity for substances, and quicker analysis. GC-MS is used to identify the poison and venoms. In clinical toxicology, it is widely employed.[31]

10. Academic research

The GC-MS offers a rare chance to analyse novel compounds for characterisation and identification of synthetic or derivatized compounds thanks to its distinctive and potent technology. It is extensively employed in fields of both pure and practical science, including chemistry, polymers, and biotechnology. It produces valuable data that can be applied to research publications across the globe.[32, 33]

11. Industrial applications

Industries employ GC-MS to analyse substances such allergens in cosmetics, inorganic gases, amino alcohol in water, contaminants in styrene, glycol, diols, and xylene. Formic acid in acetic acid is characterised for industrial usage using GC-MS. Acetic acid is a crucial step in the industrial chemical production of coal. In addition to synthetic fibre and fabrics, it is used to make poly ethylene, cellulose acetate, and poly vinyl.[34]

12. Energy and fuel applications

Natural gases, 1,3-butadiene, ethylene, gas oil, unleaded gasoline, polyethene, diesel, aromatic solvents, sulphur, contaminants in polypropylene, sulphur in menthane, and other substances are all analysed using GC-MS. gasoline without lead, polyethylene, diesel, modified biomass, grafted polymers, etc.[35]

By its diverse range of applications, GC-MS has opened up a new field of study and elevated the presentation and characterisation of substances to new heights of impact.[36, 37]

ADVANTAGES

The analyte must have a significant vapour pressure between 30 and 300°C in order to benefit from GC-MSGC. Retention time matching, which might be inaccurate or deceptive, provides the basis for identification.[38]

The primary characteristics of the enhanced molecular ion, improved condense in sample identification, significantly increased range of thermally labile and low volatility samples amenable for analysis, significantly faster analysis, improved sensitivity particularly for compounds that are hard to analyse, and the many other features and options provide compelling reasons to use the GC-MS in a broad range of areas.[38, 39]

2. High sensitivity with superior detection limits Low to high ppb is the norm.

High selectivity—identification is based on two rather than one parameter— (The mass spectrum's retention time must match the required value.) -chooses analyte of interest with a high degree of confidence.

Speed: A normal analysis takes anything between a half-hour and an hour.[40]

3. Useful for identifying volatile chemicals. Both substantial commercial and public libraries. Small metabolites (less than 500 Daltons) were identified and measured.[41]

DISADVANTAGES

1. Expensive: GC-MS systems can be costly to buy and maintain, making them unaffordable for particular labs or applications.
2. Complicated sample preparation: Careful sample preparation, including extraction and clean-up processes, is necessary for GC-MS analysis. These operations can be time-consuming and call for specialised equipment and knowledge.
3. Incompatibility with specific samples: GC-MS is incompatible with some samples, such as those that are very viscous or have a lot of water in them, making them unsuitable for analysis. Other analytical methods might be more applicable in these situations.[42]
4. Increased capital expense.
5. More upkeep (time, expertise and money)
6. For best findings, a mass spectrometric and chromatographic analyst is needed.[43]
7. Only substances with a vapour pressure of at least 10 torr.
8. Positional substituents on aromatic rings are frequently challenging to determine.
9. A weak MS feed causes background noise in the mass spectrum.[44]
10. Derivatization is necessary after the sample pre-processing phase.
11. Several metabolites are incompatible with non-volatile substances or thermally unstable.[45]

CONCLUSION

Although GC-MS is a sophisticated technique that cannot be compared to other contemporary analytical tools, mass spectrophotometer can be used in conjunction with GC-MS to produce GC-MS/MS. It can be used for a wide range of purposes, including industrial, academic, and quality control applications. Its succinct, effective, automated system generates quick, repeatable, and efficient outcomes that play a critical role in the growth of science and technology. For greater future prospects, this adaptable analytical technique could be investigated.

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