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A Comprehensive Review on Atomic Absorption Spectroscopy: Principles, Techniques, and Applications

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Abstract

Atomic Absorption Spectroscopy (AAS) is a chemical analysis equipment that works on the premise of atoms absorbing energy. Atomic spectrometry is a method of measuring spectrum that is related to absorption and atomic emission. Atomic absorption spectrometry (AAS) is a technology that uses free gaseous atoms to absorb electromagnetic radiation at a given wavelength and generate a quantifiable signal. Atomic absorption spectrophotometry is a technique of quantitative elemental evaluation whose size is primarily based totally at the absorption of mild at positive wavelengths via way of means of metallic atoms in a loose state. Atomic absorption spectrophotometry has an instrument that is arguably similar to other types of spectrophotometry but atomic absorption spectrophotometry has a distinctive feature in instrumentation, namely the atomizer. This atomizer will absorb the wavelength directly proportional to Lambert's law. Atomization in atomic absorption spectrophotometry is divided into 3: Atomization with Flame, Vapor Generation Method, Furnace atomization. Interferences in AAS can be categorized into two general groups: spectral and non-spectral. Atomic Absorption Spectroscopy (AAS) stands as a pivotal analytical technique employed across diverse industries, playing a crucial role in the identification and quantification of metallic elements present in a given sample. In the future, AAS could be further developed and improved for applications in various fields.

Keywords: *atomic absorption spectroscopy, atomization, instrumentation, principle, interferences*

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INTRODUCTION

Atomic Absorption Spectroscopy (AAS) is a chemical analysis equipment that works on the premise of atoms absorbing energy. Atomic spectrometry is a method of measuring spectrum that is related to absorption and atomic emission[1]. Atomic absorption spectroscopy (AAS) is a Spectro analytical process that uses the absorption of optical radiation (light) by free atoms in a gaseous state to determine the quantitative elements. The absorption of light by free metallic ions is the basis for atomic absorption spectroscopy. The technique is used in analytical chemistry to determine the concentration of a certain element (the analyte) in a sample to be researched. AAS is utilized in pharmacology, biophysics, archeology, and toxicology research to determine over 70 different elements in solution or directly in solid samples via electrothermal vaporization[2].

Atomic absorption spectrometry (AAS) is a technology that uses free gaseous atoms to absorb electromagnetic radiation at a given wavelength and generate a quantifiable signal. The absorption signal varies with the concentration of free absorbing atoms in the optical channel. As a result, for AAS tests, the analyte must first be transformed into gaseous atoms, which is commonly accomplished by applying heat to a cell known as an atomizer. The two primary AAS-based analytical procedures are defined by the kind of atomizer: flame AAS (FAAS), which offers analytical signals in a continuous fashion, and electrothermal AAS (ETAAS), which delivers analytical signals in a discontinuous mode (2-4 min per sample). Liquid (or dissolved) samples are easily delivered into the analyzer in both situations, as an aerosol in the case of FAAS or as well-defined low microliter quantities in the case of ETAAS. Furthermore, the combination of hydride production and cold vapor techniques allows for the delivery of analytes as a gas phase into the atomizer[3]. Direct elemental analysis of solids without prior dissolving is also possible, particularly in ETAAS[4].

PRINCIPLE

Atomic Absorption Spectroscopy (AAS) is a tool in analytical chemistry that makes use of the precept of power absorbed via way of means of atoms[5]. Atomic absorption spectrophotometry is a technique of quantitative elemental evaluation whose size is primarily based totally at the absorption of mild at positive wavelengths via way of means of metallic atoms in a loose state. Atomic absorption spectroscopy is primarily based totally at the absorption of mild power via way of means of impartial atoms and the absorbed mild is normally seen and ultraviolet mild. In general, the precept of atomic absorption spectroscopy is similar to seen and ultraviolet spectrophotometry. The distinction lies withinside the form of the spectrum, the manner the pattern is processed, and the equipment. This approach has the precept of soaking up mild via way of means of atoms, the atoms soak up mild at positive wavelengths, relying on the character of the element. Light at this wavelength has sufficient power to alternate the digital power stage of an atom. Atomic Absorption Spectrometry (SSA/AAS) consists of the absorption of mild via way of means of impartial atoms of metallic factors which can be nevertheless of their floor state. The precept of AAS is essentially similar to the absorption of mild via way of means of molecules or compound ions in solution[6]. The regulation of mild absorption or Lambert - Beer which applies to spectrophotometers soaking up ultraviolet mild, seen mild and purple mild, additionally applies to AAS. Lambert's regulation states that if a supply of monochromatic mild passes via a obvious medium, the depth of the transmitted mild decreases because the thickness of the soaking up medium increases. Beer's regulation states that the depth of transmitted mild will lower exponentially with growing attention of the species that absorbs the mild[7].

The simple mechanism of power choice via way of means of atoms makes use of the atomic absorption spectrum of a pattern to evaluate the attention of a specific analyte inside it. This calls for requirements with recognised analyte content material to set up the connection among measured absorbance and analyte attention and consequently is based at the Beer–Lambert regulation. The regulation of absorption is a simple precept of UV-seen spectrophotometry. This regulation discusses the connection among the thickness of the absorbent cloth and the attention of the pattern solution, that's called the Beer-Lambert regulation or honestly Beer's regulation. This regulation states that the quantity of mild absorbed is proportional to the attention of the soaking up substance and the thickness of the soaking up cloth.

The atomic absorption spectrometry approach become selected as it has excessive sensitivity, is easy, cheap, simple, fast, and calls for little pattern[8]. Analysis the use of AAS is likewise greater sensitive, particular for the desired element, and may be used to decide ranges of factors whose concentrations are very small while not having to be separated first. Atomic absorption spectrophotometry is a completely suitable approach for reading materials at low concentrations. This approach is a method that maximum usually used for elemental evaluation primarily based totally at the emission and absorbance of atomic vapors.

INSTRUMENTS AND TECHNIQUES

Instrumentation

Atomic absorption spectrophotometry has an instrument that is arguably similar to other types of spectrophotometry. However, atomic absorption spectrophotometry has a distinctive feature in instrumentation, namely the atomizer. This atomizer will absorb the wavelength directly proportional to Lambert's law.

1. Light Source

The sources of radiation or light most often used in atomic absorption spectrophotometry are Hollow Cathode Lamps (HCL) and Electrodeless Discharge Lamps (EDL). Hollow Cathode Lamp (HCL) is a lamp consisting of a hollow cathode coated by elements, both pure and mixed elements and wolfram. Generally, HCL uses Ne, Ar, and He as filler gas [9].

Electrodeless Discharge Lamps (EDL) have higher emissions and narrower channel widths when compared to HCL. EDL requires more time and a separate power to become a stable unit. A small number of analytes in EDLs stabilize under low pressure, these analytes act as metals or salts that move with the inert gas in the quartz sphere, such as argon gas. The release of the low pressure in the EDL will occur when the bulb is inserted in the coil which causes an electromagnetic radio frequency field to appear[2].

2. Atomizer

Atomizer plays a role in atomization or atomic formation. Atomizers in Atomic Absorption Spectrophotometry are divided into burners or burners and nebulizers or foggers.

a. Burner, the role of the burner is to convert the salt vapor from the compound components that are then analysed into normal atoms in the flame.
b. Nebulizer, in the nebulizer there is a withdrawal of the solution from the capillary through the suction of oxidant gas and fuel which will then be sprayed into the fogging chamber. This causes the solution to turn into fog grains which will enter the flame[5].

3. Monochromator

Monochromator is in charge of separating the radiated radiation into elements that are more specific than other radiation which will then be measured by the detector

(Epra Journal). This radiation is released by a Hollow Cathode Lamp (HCL) which is then monochromatically dipatau so that the radiation bandwidth can be reduced. Radiation interference that appears will also be reduced, ranging from flames to other components [10].

4. Detector

Radiation transmitted by the sample will be measured by the detector in the form of electrical energy. Radiation received by the detector can come from the results of resonance line selection and flame emission. The emission in question is an emission derived from atomic emissions that have been analyzed [7].

Atomization

In atomic absorption spectrophotometry there is a special process called atomization. Atomization is the process of converting free gas atoms derived from analytes. Aqueous analytes to be converted to free atoms must be removed solvent and then evaporated. Atomization in atomic absorption spectrophotometry is divided into 3:

1. Atomization with Flame

In this atomization, the snippet will be included in the combustion gas flame. The flame temperature will affect the atomic gas population formed. Behind that, the flame temperature itself is influenced by what percentage of oxygen and fuel gas ratio.

2. Vapor Generation Method

This atomization method has specifications for nine elements. These elements are As, Bi, Sn, Se, Te, Ge, and Hg. In this atomization method, the metal will be analysed in a solution that is in a simple molecular form. However, the Hg compound has the privilege of being in the form of free atoms.

3. Furnace atomization

This atomization has a working principle by increasing the optimum temperature through a graphite tube. The sample solution will be placed on a graphite tube which is then electrified and heated until the sample begins to atomize. The required heating temperature is the highest temperature at which atoms can react[7].

INTERFERENCES AND ANALYTICAL PERFORMANCE CHARACTERISTICS

Interferences

Interferences in AAS can be categorized into two general groups: spectral and non-spectral[11,12].

Spectral Interferences

Spectral interferences in Atomic Absorption Spectroscopy (AAS) mainly arise from the absorption and scattering of light caused by solvent droplets that haven't vaporized, matrix components that remain undissociated, and molecular species formed from the sample[13]. While the use of chemical modifiers can mitigate these interferences to some extent, it is often necessary in routine applications to employ instrumental background correctors [12].

Non-spectral interferences

Non-spectral interferences refer to those that impact the generation or availability of atoms that absorb the analyte. In Flame Atomic Absorption Spectroscopy (FAAS), physical interferences arise from variations in physical properties (such as viscosity and density) between the dissolved sample and calibration standards, and these can be mitigated by employing the same solvent for both sample and standards. Chemical interferences occur due to the formation of low-volatility compounds containing the analyte. To minimize chemical interferences in FAAS, approaches such as selecting optimal flame conditions (e.g., using a nitrous oxide-acetylene flame with higher temperatures and a reducing atmosphere), aligning standard solutions with the sample, or introducing specific substances to reduce interferences are commonly employed strategies[13]. Additionally, a significant portion of alkali and alkaline earth elements may undergo ionization in the flame, leading to a reduction in the concentration of analyte atoms[3].

In Electrothermal Atomic Absorption Spectroscopy (ETAAS), non-spectral interferences play a crucial role and can result from various processes. These processes include the analyte diffusing out of the optical path before reaching the atomization temperature, such as through the formation of gaseous compounds with the analyte, co-volatilization, or the thermal expulsion of the analyte along with rapidly expanding matrix gases. Additionally, occlusion of the analyte contributes to these interferences. These phenomena collectively impede the formation of free analyte atoms during the atomization step[14]. To mitigate these interferences, techniques such as employing L’Vov platforms, utilizing suitable chemical modifiers10, and adopting the standard addition method can be employed[3].

Analytical Figures of Merit

Quantitative analytical methods in Atomic Absorption Spectroscopy (AAS) rely on calibration curves, which are fundamentally linear. However, deviations from the Lambert-Beer law can occur at high concentrations, and the analytical linear ranges in AAS are relatively limited, typically extending to about three orders of magnitude above the corresponding limits of quantification[12]. The limited linear range in AAS arises from variations in the absorption of radiation by analyte atoms, especially pronounced at higher concentrations. Ionization interferences in flames contribute to an upward curvature at elevated concentrations, as a greater proportion of analyte atoms undergo ionization at lower concentrations. To counteract this interference, an "ionization suppressor," such as an easily ionizable element, can be introduced. This suppressor supplies a substantial number of electrons to the flame, effectively inhibiting the ionization of the analyte4. Conversely, incomplete dissociation of analyte molecules results in a curvature towards the concentration axis[3].

The detection limits (DLs) achieved in Flame Atomic Absorption Spectroscopy (FAAS) are significantly influenced by the analyzed element and the quality of the instrumentation. As a general approximation, DLs in FAAS are typically on the order of mg L1 (ppm). In contrast, DLs in Electrothermal Atomic Absorption Spectroscopy (ETAAS) are notably lower, often below 1 mg L1 (ppb). Precision under optimized conditions for FAAS ranges from 0.5% to 2%, while precision in ETAAS falls within the range of 0.5% to 5%, provided meticulous attention is given to controlling sample contamination risks[3].

APPLICATIONS

Atomic Absorption Spectroscopy (AAS) stands as a pivotal analytical technique employed across diverse industries, playing a crucial role in the identification and quantification of metallic elements present in a given sample. The continued use of flame-based atomic spectrometric instruments can be attributed to the fact that they are very robust and comparatively cheap, offer high sample throughput and the corresponding analytical methods are well established and validated[3]. Its broad spectrum of applications spans industries ranging from mining and pharmaceuticals to environmental monitoring and agriculture. the versatility of Atomic Absorption Spectroscopy renders it an invaluable instrument in diverse industrial domains, where its applications extend beyond mere detection to encompass crucial aspects of quality control and decision-making processes.

Given the inherent toxicity associated with heavy metals, diligent efforts are made to minimize their presence. AAS emerges as an indispensable tool in this regard, ensuring meticulous quality control in various sectors. The pharmaceutical industry uses these machines to determine if a metal catalyst after a drug has been purified. The pharmaceutical industry uses these machines to determine if a metal catalyst after a drug has been purified[15]. For example, where antibiotics are commonplace, AAS is employed to scrutinize the absence of contaminants such as palladium or platinum, which may serve as catalysts during the drug manufacturing process[16]. Similarly, industries involved in the production of consumables such as food, cannabis, and health supplements rely on AAS for quality assurance, ensuring the safety of their products for human consumption[17].

The mining industry would utilize these devices to detect the quantity and presence of precious metals like gold and silver. The extraction of precious metals like gold is of paramount importance, AAS facilitates precise quantification. This analytical technique aids in determining the profitability of extracting gold from existing mine heaps, thereby guiding strategic decision-making in the mining sector[18].

A particularly critical application of AAS lies in the analysis of drinking water, especially in regions where environmental stewardship may be lacking. The ability of AAS to detect and quantify elements in water samples contributes significantly to ensuring the safety and potability of drinking water[19].

VIEWS ON THE POSSIBILITY OF FUTURE DEVELOPMENT AND IMPROVEMENT OF AAS

The possibility of developing AAS (Atomic Absorption Spectrometry) in the cosmetics sector is to detect the presence of Zn and Hg (mercury) in cosmetics which can damage the skin. It is in accordance with the research conducted by Rohman and Wijayanti (2015) proving that atomic absorption spectroscopy using flame atomization and mercury analyzer was successfully used for quantitative analysis of Zn and Hg in cosmetic creams. The developed method meets the validation parameter acceptance criteria according to the Internal Conference on Harmonization (ICH).

Atomic Absorption Spectrometry (AAS) has been proven to be an effective tool for detecting AFB1 in food products. The method exhibits high sensitivity, specificity, accuracy, and precision, and a broad linearity range, making it suitable for analyzing a variety of samples. The detection results from this method were found to be consistent with those obtained using LC-MS/MS when tested on real samples, suggesting its potential for AFB1 detection in food. The method was further enhanced by integrating an automated magnetron pretreatment system based on a quantum dot immunosensor with an atomic absorption spectrometer, enabling signal conversion between AFB1 mycotoxin and Cd2+ metal ions. This approach broadens the application range of AAS and offers a reference for the concurrent determination of multiple toxic substances, such as mycotoxins and heavy metals[21].

The efficacy of atomic absorption spectrometry in molecular quantification has been convincingly showcased through the immediate assessment of concentrations of caffeine and propranolol across diverse samples. The emission wavelengths of Fe (271.9 nm) and Mg (285.2 nm) were harnessed for the measurement of the analyte, and the outcomes exhibited commendable precision and detection thresholds, matching those linked with UV-Vis, CE, and HPLC. The potential for future investigations lies in probing the flexibility of atomic absorption spectrometers in formulating methodologies for the immediate quantification of additional organic compounds present in food, pharmaceutical, or other categories of samples[22].

The refined AAS technique underscores its applicability in quantifying and assessing the concentration of platinum in drugs that incorporate platinum, like cisplatin. Utilizing this AAS approach, we discovered superior conditions for integrating cisplatin into ceramic biomaterials intended for replacement. The sustained dispensation of the drug from this treated material can maintain local drug concentrations potent enough to inhibit the proliferation of tumors in the problematic region[23].

In this study, a validated simple, accurate, and precise method was developed to determine the Magnesium content in the bulk drug Esomeprazole-Magnesium. Permissible Magnesium content is between 3.30% to 3.55% on anhydrous basis (USP NF 40). The sample analyzed using the developed method was 3,48 % so the Magnesium content in the given sample was in the unacceptable range[24].

CONCLUSION

Atomic Absorption Spectroscopy (AAS) is a widely used analytical technique in various industries for the quantitative determination of chemical elements. It is based on the absorption of light by free metallic ions and is used to determine the concentration of over 70 different elements in solution or directly in solid samples. AAS has applications in fields such as pharmacology, biophysics, archaeology, toxicology research, mining, pharmaceuticals, environmental monitoring, and agriculture. It is a sensitive, specific, and cost-effective method that provides valuable information for quality control and decision-making processes.

In terms of instrumentation, AAS utilizes a light source, such as Hollow Cathode Lamps (HCL) or Electrodeless Discharge Lamps (EDL), to emit radiation at specific wavelengths. The radiation is then absorbed by the analyte atoms in the sample. The atomizer, which can be a burner or nebulizer, plays a crucial role in atomization or atomic formation. The monochromator separates the radiated radiation into specific elements, and the detector measures the transmitted radiation as electrical energy. Atomization can occur through flame, vapor generation, or furnace methods.

AAS can experience interferences, both spectral and non-spectral, which can affect the accuracy of the analysis. Spectral interferences arise from the absorption and scattering of light caused by solvent droplets, undissociated matrix components, and molecular species formed from the sample. Non-spectral interferences can result from physical variations between the sample and calibration standards or the formation of low-volatility compounds containing the analyte. These interferences can be mitigated through various techniques, such as employing chemical modifiers or selecting optimal flame conditions.

The analytical performance characteristics of AAS include the linear range, detection limits, and precision. The linear range is limited and deviations from the Lambert-Beer law can occur at high concentrations. Detection limits are influenced by the analyzed element and the quality of the instrumentation, with lower limits achieved in Electrothermal Atomic Absorption Spectroscopy (ETAAS) compared to Flame Atomic Absorption Spectroscopy (FAAS). Precision ranges from 0.5% to 2% in FAAS and 0.5% to 5% in ETAAS.

In the future, AAS could be further developed and improved for applications in various fields. Some potential areas of development include the detection of specific elements in cosmetics, the analysis of mycotoxins and heavy metals in food, the direct determination of organic compounds in different samples, and the evaluation of platinum content in drugs. These advancements would enhance the capabilities and versatility of AAS in different industries and contribute to the safety and quality control of various products.

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