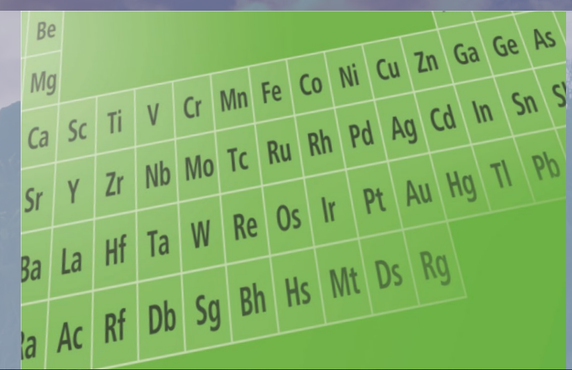
WORLD LEADER IN AA, ICP-OES AND ICP-MS



Atomic Spectroscopy - A Guide to Selecting the Appropriate Technique and System

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WHAT IS ATOMIC SPECTROSCOPY?

Atomic spectroscopy is the technique for determining the elemental composition of an analyte by its electromagnetic or mass spectrum. Several analytical techniques are available, and selecting the most appropriate one is the key to achieving accurate, reliable, real-world results. Proper selection requires a basic understanding of each technique since each has its individual strengths and limitations. It also requires a clear understanding of your laboratory's analytical requirements. The following pages will give you a basic overview of the most commonly used techniques and provide the information necessary to help you select the one that best suits your specific needs and applications.

Primary Industries

Many industries require a variety of elemental determinations on a diverse array of samples. Key markets include:

- Agriculture
- Biomonitoring
- Chemical/Industrial
- Environmental
- Food
- Geochemical/Mining
- Nanomaterials
- Nuclear Energy
- Petrochemical
- Pharmaceutical
- Renewable Energy
- Semiconductor
- Single Cell Analysis

For more details, see pages 16-17.

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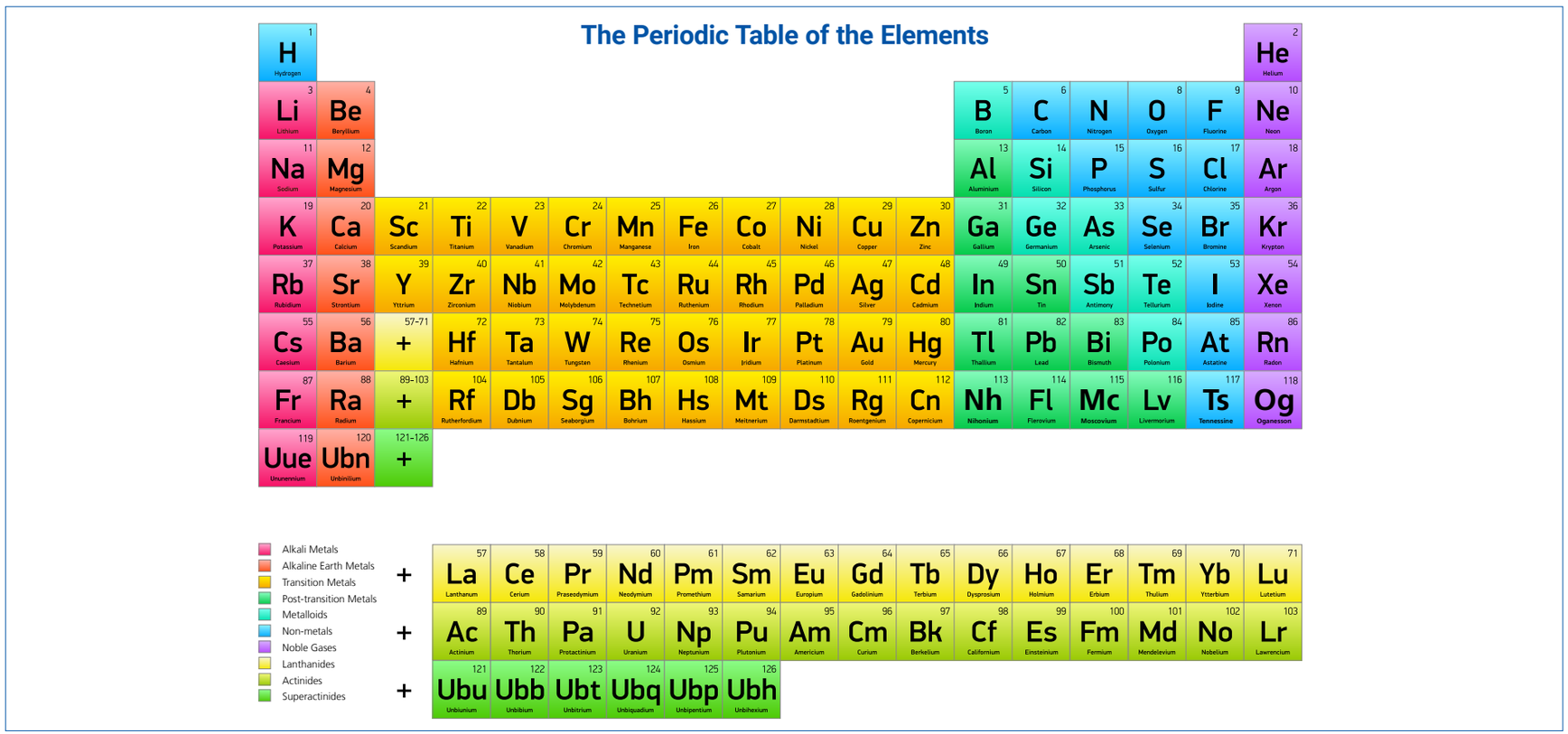
COMMONLY USED ATOMIC SPECTROSCOPY TECHNIQUES

There are three widely accepted analytical methods – atomicabsorption, atomic emission and mass spectrometry – which will form the focus of our discussion, allowing us to go into greater depth on the most common techniques in use today:

- Flame atomic absorption spectroscopy (FAAS)
- Graphite furnace atomic absorption spectroscopy (GFAAS)
- Inductively coupled plasma optical emission spectroscopy (ICP-OES)
- Inductively coupled plasma mass spectrometry (ICP-MS)



The periodic table of elements – see pages 14 -15 for a listing of detection limits for all elements using the different atomic spectroscopy methods.

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Flame Atomic Absorption Spectroscopy

Atomic absorption (AA) occurs when a ground state atom absorbs energy in the form of light of a specific wavelength and is elevated to an excited state. The amount of light energy absorbed at this wavelength will increase as the number of atoms of the selected element in the light path increases. The relationship between the amount of light absorbed and the concentration of analytes present in known standards can be used to determine unknown sample concentrations by measuring the amount of light they absorb.

Performing atomic absorption spectroscopy requires a primary light source, an atom source, a monochromator to isolate the specific wavelength of light to be measured, a detector to measure the light accurately, electronics to process the data signal and a data display or reporting system to show the results. (See Figure 1.) The light source normally used is a hollow cathode lamp (HCL) or an electrodeless discharge lamp (EDL). In general, a different lamp is used for each element to be determined, although in some cases, a few elements may be combined in a multi-element lamp. In the past, photomultiplier tubes have been used as the detector. However, in most modern instruments, solid-state detectors are now used. Flow injection mercury systems (FIMS) are specialized, easy-to-operate atomic absorption spectrometers for the determination of mercury. These instruments integrate flow injection mercury cold vapor generation with the use of an intense low-pressure mercury lamp, a long path measurement cell and a sensitive solar-blind detector for maximum performance.

Whatever the system, the atom source used must produce free analyte atoms from the sample. The source of energy for free-atom production is heat, most commonly in the form of an air/acetylene or nitrous-oxide/acetylene flame. The sample is introduced as an aerosol into the flame by the sample-introduction system consisting of a nebulizer and spray chamber. The burner head is aligned so that the light beam passes through the flame, where the light is absorbed.

A limitation of FAAS is that the burner-nebulizer system is a relatively inefficient sampling device. Only a small fraction of the sample reaches the flame, and the atomized sample passes quickly through the light path. An improved sampling device would atomize the entire sample and retain the atomized sample in the light path for an extended period of time, enhancing the sensitivity of the technique, which leads us to the next option – electrothermal vaporization using a graphite furnace.

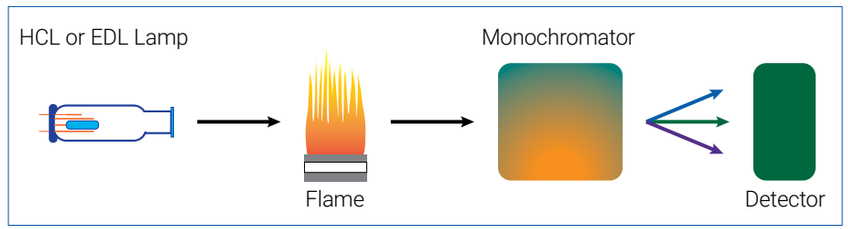

Figure 1. Simplified drawing of a FAAS system.

Graphite Furnace Atomic Absorption Spectroscopy

With graphite furnace atomic absorption spectroscopy (GFAAS), the sample is introduced directly into a graphite tube, which is then heated in a programmed series of steps to remove the solvent and major matrix components and to atomize the remaining sample. All of the analyte is atomized, and the atoms are retained within the tube (and the light path, which passes through the tube) for an extended period of time. As a result, sensitivity and detection limits are significantly improved over FAAS.

Graphite furnace analysis times are longer than those for FAAS sampling, and fewer elements can be determined using GFAAS. However, the enhanced sensitivity of GFAAS, and its ability to analyze very small samples, significantly expands the capabilities of atomic absorption.

GFAAS allows the determination of over 40 elements in microliter sample volumes with detection limits typically 100 to 1000 times better than those of FAAS systems.

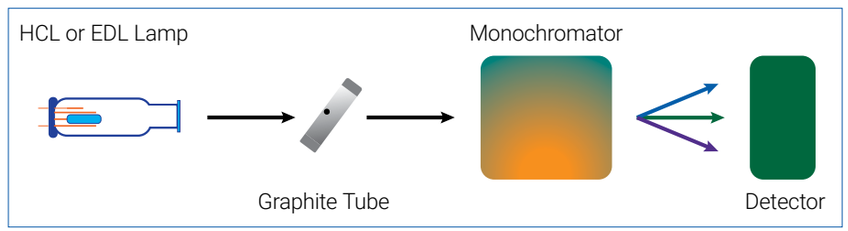

Figure 2. Simplified drawing of a GFAAS system.

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Inductively Coupled Plasma Optical Emission Spectroscopy

ICP is an argon plasma maintained by the interaction of an RF field and ionized argon gas. The plasma can reach temperatures as high as 10,000 ˚K, allowing the complete atomization of the elements in a sample and minimizing potential chemical interferences.

Inductively coupled plasma optical emission spectroscopy (ICP-OES) is the measurement of the light emitted by the elements in a sample introduced into an ICP source. The measured emission intensities are then compared to the intensities of standards of known concentration to obtain the elemental concentrations in the unknown sample.

There are two ways of viewing the light emitted from an ICP. In the classical ICP-OES configuration, the light across the plasma is viewed radially (Figure 3a), resulting in the highest upper linear ranges. By viewing the light emitted by the sample looking down the center of the torch (Figure 3b) or axially, the continuum background from the ICP itself is reduced and the sample path is maximized. Axial viewing provides better detection limits than those obtained via radial viewing by as much as a factor of 10. The most effective systems allow the plasma to be viewed in either orientation in a single analysis, providing the best detection capabilities and widest working ranges.

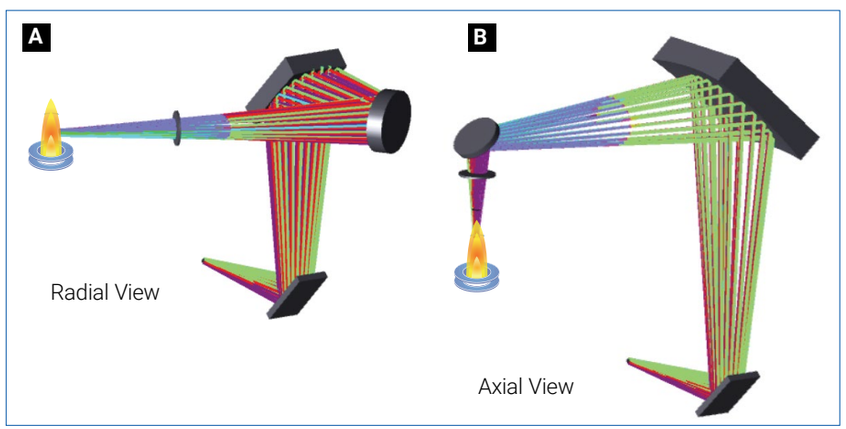

Figure 3. (A) Radially viewed plasma with a vertical slit image in the plasma. (B) Axially viewed plasma with a circular slit image in the plasma.

The optical system used for ICP-OES consists of a spectrometer that is used to separate the individual wavelengths of light and focus the desired wavelengths onto the detector (Figure 4). Older, "direct reader" types of ICP-OES systems used a series of photomultiplier tubes to determine pre-selected wavelengths. This limited the number of elements that could be determined as the wavelengths were generally fixed once the instrument was manufactured. Sequential-type systems can select any wavelength and focus it on a single detector. However, this is done one element at a time, which can lead to longer analysis times.

In today's modern ICP-OES systems, solid-state detectors based on charge-coupled devices (CCDs) are used, providing very flexible systems and eliminating the need for large numbers of single photomultiplier detectors.

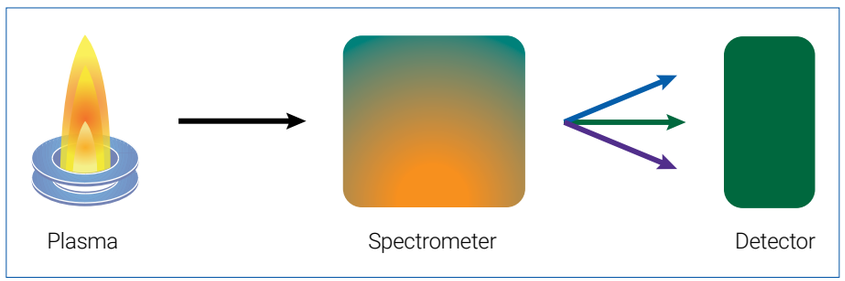

Figure 4. Simplified drawing of a basic ICP system.

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Inductively Coupled Plasma Mass Spectrometry

With inductively coupled plasma mass spectrometry (ICP-MS), the argon ICP generates singly charged ions from the elemental species within a sample that are guided into a mass spectrometer and separated according to their mass-to-charge ratio. Ions of the selected mass-to-charge ratio are then directed to a detector that determines the number of ions present (Figure 5). Due to their speed of analysis, ease of use and maintenance, quadrupole ICP-MS systems are used in labs globally. However, for labs performing research or aiming to increase analytical performance, mass spectrometers with more than one transmission analyzer quadrupole, such as multi-quad systems, are often preferred.

The strength of ICP-MS is that it can perform multi-element analyses, similar to ICP-OES, while delivering detection limits often significantly lower than GFAAS. It is also one of the few analytical techniques that allows the quantification of elemental isotopic concentrations and ratios, as well as precise speciation capabilities when used in conjunction with HPLC or GC interfaces, enabling users to determine the exact form of a species present – not just the total concentration.

However, since the sample is introduced into the instrument, there are limitations as to the overall volume which can be introduced. Moreover, the maintenance needs of ICP-MS systems are sometimes higher than ICP-OES due to the presence of cones, despite having similarities in sample introduction. There are several items, such as the interface cones and ion lenses (if present), located between the ICP torch and the mass spectrometer, that need to be cleaned on a periodic basis to maintain acceptable instrument performance. Generally, ICP-MS systems require that the total dissolved solids content of a sample be below 0.2% for routine operation and maximum stability, where this can be achieved using either offline or online dilution methods.

ICP-MS technology has seen significant improvements over the last decades, increasing robustness, accuracy and stability. For example, the use of three wide-aperture cones has delivered reduced cone clogging and ion beam spread; a quadrupole ion deflector has eliminated the traditional ion lenses and the need for routine maintenance beyond the cones; and interference control has been made even easier with a true quadrupole cell that allows three modes of operation (Reaction, Collision, Standard), which can now be further enhanced by a full-length transmission analyzer quadrupole before the cell, allowing only the mass of interest to enter cell.

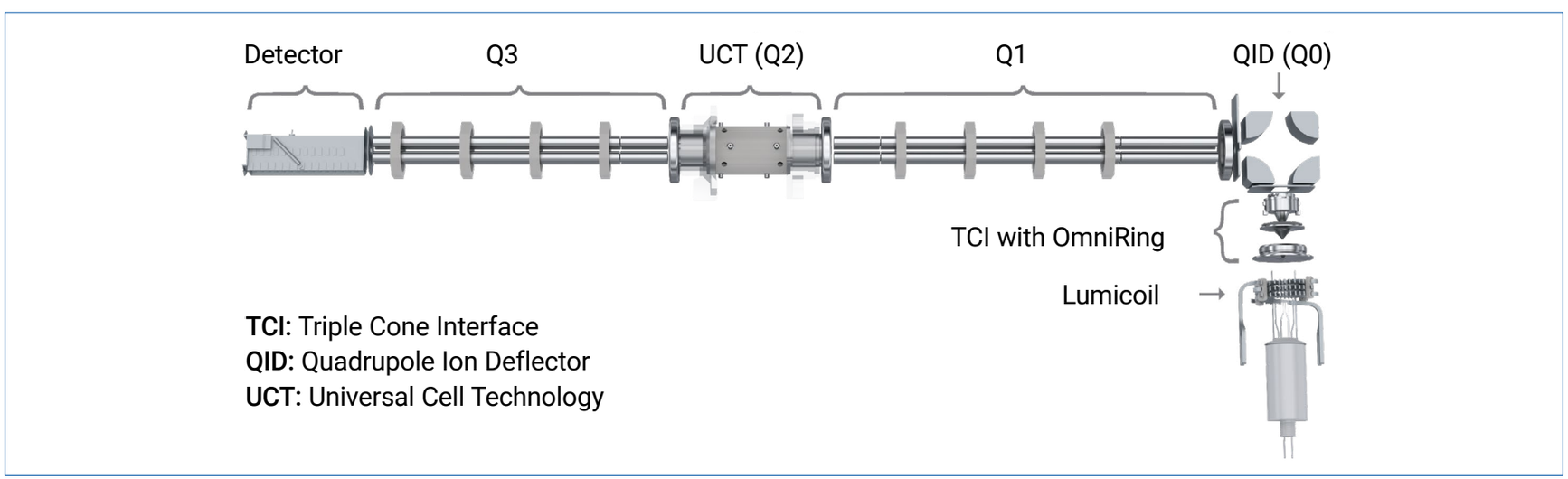

Figure 5. Illustration of multi-quad ICP-MS ion optics, featuring four quadrupoles.

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SELECTING A TECHNIQUE FOR YOUR ANALYSIS

With the availability of a variety of atomic spectroscopy techniques, laboratory managers must decide which of these is best suited to their particular analytical requirements. Unfortunately, because the techniques complement each other so well, it may not always be clear which is the optimum solution for a particular application.

Selecting a technique requires the consideration of a variety of important criteria, including:

- Detection limits
- Analytical working range
- Sample throughput
- Data quality
- Cost
- Interferences
- Ease-of-use
- Availability of proven methodology

In order to help you narrow your selection, many of these criteria are discussed below for FAAS, GFAAS, ICP-OES and ICP-MS. In simple terms, your choice can be guided by answering the four questions in Table 1.

Table 1. Technique decision matrix.

	FAAS	GFAAS	ICP-OES	Multi-Quad/ ICP-MS
How Many Elements?				
Single	■			
Few (< 5)		■		
Many (> 5)			■	■
What Levels?				
PPM	■		■	■
PPB		■	■	■
PPT		■		■
PPQ				■
How Many Samples?				
Very few	■	■		
Few	■	■	■	■
Many			■	■
Typical Sample Consumption				
mL	■	■	■	■
µL		■		■

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Detection Limits

The detection limits achievable for individual elements are important in determining the usefulness of an analytical technique for a given analytical problem. Without adequate detection-limit capabilities, lengthy analyte pre-concentration procedures may be required prior to analysis.

Typical detection-limit ranges for the major atomic spectroscopy techniques are shown in Figure 6. For a complete listing of detection limits by element for FAAS, GFAAS, ICP-OES (with radial and axial torch configurations) and ICP-MS, see pages 14-15.

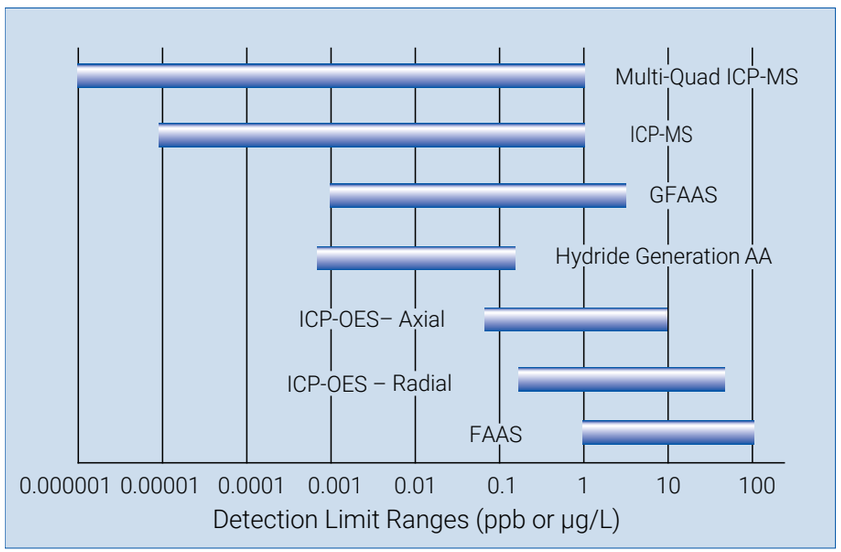

Figure 6. Typical detection limit ranges for the major atomic spectroscopy techniques.

Analytical Working Range

The analytical working range can be viewed as the concentration range over which quantitative results can be obtained without having to recalibrate the system. Selecting a technique with an analytical working range (and detection limits) based on the expected analyte concentrations minimizes analysis times by allowing samples with varying analyte concentrations to be analyzed together. A wide analytical working range can also reduce sample-handling requirements, minimizing potential errors.

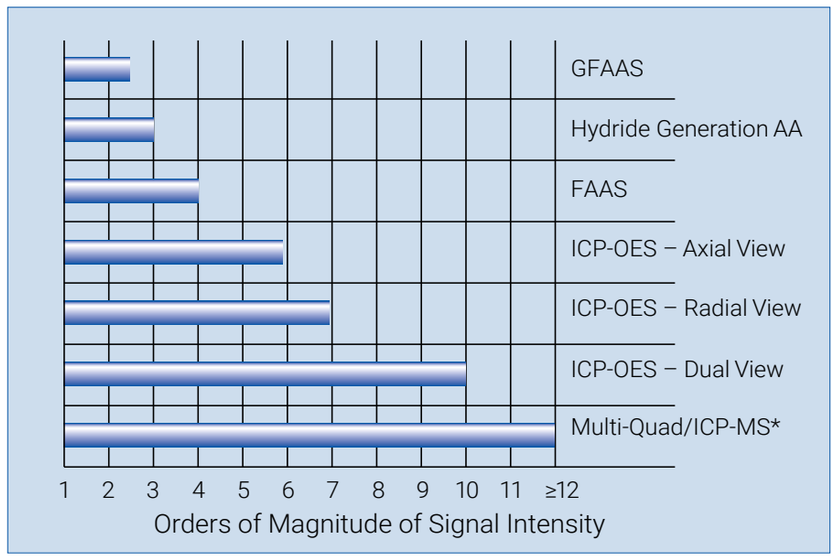

*Figure 7. Typical analytical working ranges for the major atomic spectroscopy techniques *with Extended Dynamic Range (EDR).*

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Sample Throughput

Sample throughput is the number of samples that can be analyzed or elements that can be determined per unit of time. For most techniques, analyses performed at the limits of detection or where the best precision is required will be more time-consuming than less demanding analyses. Where these factors are not limiting, the number of elements to be determined per sample and the analytical technique will determine the sample throughput.

- Flame AA – Provides relatively high sample throughput when analyzing a large number of samples for a limited number of elements. A typical determination of a single element requires only 3-10 seconds. Even though it is generally considered to be a single-element technique, FAAS is frequently used for multi-element analysis.
- Graphite furnace AA – A highly sensitive technique which provides low detection limits for many elements. As with FAAS, GFAAS is basically a single-element technique. Because of the need to thermally program the system to remove solvent and matrix components prior to atomization, GFAAS has a relatively low sample throughput. A typical graphite-furnace determination normally requires 2-3 minutes per element for each sample. With multiple methods in the queue, GFAAS can be left unattended for multi-element analysis.
- ICP-OES – A true multi-element technique with exceptional sample throughput. ICP-OES systems typically can determine more than 73 elements per minute in individual samples. Where only a few elements are to be determined, however, ICP is limited by the time required for equilibration of the plasma with each new sample, typically about 15-30 seconds.
- ICP-MS – A true multi-element technique capable of analyzing a wide range of masses, from 3-285 amu. With the ability to analyze up to 73 elements per minute in a single sample, ICP-MS has the added advantage of offering ≥ 12 orders of magnitude linear dynamic range at concentrations as low as single-unit ppq to double-digit ppm without dilution, whereas high ppm-percent level concentrations can be easily analyzed via online dilution and/or signal attenuation methods.

Costs

As they are less complex systems, instrumentation for single-element atomic spectroscopy (FAAS and GFAAS) is generally less costly than that for the multi-element techniques (ICP-OES and ICP-MS). There can also be a considerable variation in cost among instrumentation for the same technique. Instruments offering only basic features are generally less expensive than more versatile systems, which frequently also offer a greater degree of automation. Figure 8 provides a comparison of typical instrument price ranges for the major atomic spectroscopy techniques.

Table 2. Typical Relative Purchase Prices for Atomic Spectroscopy Systems.

Technique	Relative Price
FAAS	$
GFAAS	$$
ICP-OES	$$$
ICP-MS	$$$$
Multi-Quad ICP-MS	$$$$$

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SELECTING A SYSTEM FOR YOUR ANALYSIS

Technique	Strengths	Limitations	Applications	Systems
FAAS – Flame Atomic Absorption Spectroscopy	• Very easy-to-use • Widely accepted • Extensive application information available • Relatively inexpensive	• Low sensitivity • Single-element analytical capability • Cannot be left unattended (flammable gas)	Ideal for laboratories analyzing large numbers of samples for a limited number of elements and for the determination of major constituents and higher concentration analytes.	PinAAcle 500/900F AA Spectrometers 
GFAAS – Graphite Furnace Atomic Absorption Spectroscopy	• Exceptional detection limits • Well-documented applications • May be left unattended	• Limited analytical working range • Sample throughput somewhat less than other techniques	Ideal for laboratories analyzing a limited number of elements and requiring excellent detection limits.	PinAAcle 900 AA Spectrometers 
ICP-OES – Inductively Coupled Plasma Optical Emission Spectroscopy	• Best overall multi-element atomic spectroscopy technique • Excellent sample throughput • Very wide analytical range • Good documentation available for applications • May be left unatteneded • Easy-to-use	• Higher initial investment	Ideal for laboratories analyzing multiple elements in a moderate or large number of samples.	Avio 220/550/560 Max ICP-OES Spectrometers 
ICP-MS – Inductively Coupled Plasma Mass Spectrometry	• Exceptional multi-element capabilities • Ability to perform isotopic analyses • Well-documented interferences and compensation methods • Rapidly growing application information • Detection limits equal to or better than GFAA with much higher productivity • May be left unattended	• Highest initial investment • Method development more difficult than other techniques • Limited solids in sample without dilution and/or pre-concentration methods	Ideal for laboratories analyzing multiple elements in a large number of samples and requiring a system capable of determining trace and ultratrace analyte concentrations.	NexION 1100/2200/5000 ICP-MS Spectrometers 

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Atomic Absorption Spectroscopy (AAS) Systems

PinAAcle 500 Flame AA

The PinAAcle™ 500 offers superior durability, longer life, lower maintenance costs, and the fastest return on investment of any flame atomic absorption (AA) spectrometer. Plus, it's the world's first completely corrosion-resistant flame AA, designed to withstand the harshest environments and most corrosive samples.

PinAAcle 900 Series AA

The PinAAcle™ 900 series of atomic absorption (AA) spectrometers brings AA performance to new heights. Available in flame, furnace or combination models, PinAAcle instruments offer exactly the level of performance you need with the smallest footprint of any combined flame/graphite furnace AA system on the market.

FIMS 100/400

FIMS are compact, easy-to-operate mercury analyzers with integrated flow injection systems for cold vapor mercury AA. FIMS 100 incorporates a single peristaltic pump while FIMS 400 incorporates two peristaltic pumps. They both include high-performance optics with low-pressure Hg lamp and solar-blind detector for maximum sensitivity.

Syngistix for AA Software

As the world leader in atomic absorption, PerkinElmer understands the flexibility and functionality you need in a software. Building on our years of experience, Syngistix™ for AA software delivers new levels of simplicity and productivity across all AA techniques, including flow injection. And for regulated labs, an Enhanced Security™ option is available which provides the functionality to fully meet the technical requirements for 21 CFR Part 11 compliance.

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Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) Systems

Avio 220 Max ICP-OES

The Avio® 220 Max, the industry's only hybrid simultaneous ICP-OES, is a robust, matrix-tolerant, dual-view system with plug-and-play performance, taking you from cold start to analysis in just 10 minutes, allowing you to shut down the instrument between runs. It delivers productivity, performance and faster return on investment, ideal for labs with low-to-medium throughput requirements.

Avio 550/560 Max ICP-OES

With a fully simultaneous dual-view system, high sensitivity and superior resolution, the Avio® 550/560 Max ICP-OES help your lab accomplish more – even with the most difficult samples – while making the most of your resources. They deliver the productivity you need with the high-quality performance and faster return on investment your work demands. Plus, the Avio 560 Max steps up performance with a built-in High Throughput System (HTS), taking 1.5 minute runs down to 30 seconds.

LPC 500 Particle Counter

The LPC 500™ is a single particle optical sizing system designed to count and size particles individually with high resolution. It integrates seamlessly with the Avio 550 Max ICP-OES for elemental analysis, provides sample-to-sample analysis time of ~45 seconds, uses less than 1 mL of lubricant sample per analysis, and boasts the smallest footprint of any standalone automated particle counter.

Syngistix for ICP Software

Designed to optimize your workflows and the performance of the Avio Max ICP-OES instruments, Syngistix™ for ICP software boasts a number of smart features that improve laboratory efficiencies with workflows that walk you through every step of your analysis – from initial instrument setup to final results – for consistent, efficient, reliable operation. Plus, an Enhanced Security™ option is available for regulated labs, providing the functionality to fully meet the technical requirements for 21 CFR Part 11 compliance.

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Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Systems

NexION 1100 ICP-MS

The NexION® 1100, a single-analyzer with three-quad design ICP-MS, builds on a strong tradition of reliable, easy-to-use, low-maintenance instrumentation, now reinventing the user experience for routine trace-elemental analyses, ideal for high-throughput testing labs running everyday applications.

NexION 2200 ICP-MS

The award-winning NexION® 2200 is a single-analyzer with three-quad design ICP-MS system that offers outstanding sensitivity, superior interference removal, excellent stability, unmatched matrix tolerance, and much more — ideal for laboratories running more challenging trace-elemental applications.

NexION 5000 ICP-MS

The multi-award-winning NexION® 5000 multi-quadrupole ICP-MS, the first in its category to boast four quads, is engineered to meet and exceed the demanding trace-elemental testing requirements of semiconductor, biomonitoring and other applications. Thanks to its tandem four-quad design and other proprietary technologies, it delivers exceptionally low background equivalent concentrations (<1 ppt, even in hot plasma) and outstanding detection limits as well as superior interference removal, phenomenal stability and unmatched matrix tolerance.

Syngistix for ICP-MS Software

Syngistix™ for ICP-MS is a workflow-based software for the NexION ICP-MS instruments, designed to improve efficiencies in the laboratory. It features an intuitive interface, along with automated method setup tools. Plus, its user-defined and customizable reporting capabilities facilitate support for a variety of peripherals, including online auto-dilution and laser ablation systems. Other benefits include built-in methods, Enhanced Security™ option for 21 CFR Part 11 compliance, and application-specific modules for Single Particle and Single Cell ICP-MS, as well as Automated Method Validation for USP <233>.

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ATOMIC SPECTROSCOPY DETECTION LIMITS - PART 1

Element	FAAS	Hg/Hydride	GFAAS	ICP-OES	ICP-MS
Ag	1.5		0.005	0.17	0.00003
Al	45		0.1	0.5	0.00001*
As	150	0.03	0.05	1.0	0.00005#
Au	9		0.15	0.4	0.00005
B	1000		20	0.4	0.0002
Ba	15		0.35	0.006	0.00001#
Be	1.5		0.008	0.02	0.00009
Bi	30	0.03	0.05	1.1	0.000004
Br					0.04
Ca	1.5		0.01	0.03	0.00002#
Cd	0.8		0.002	0.1	0.00006
Ce				0.4	0.00005
Cl					2.0
Co	9		0.15	0.14	0.000006*
Cr	3		0.004	0.17	0.00002#
Cs	15				0.00005
Cu	1.5		0.014	0.26	0.00001#
Dy	50			0.08	0.0002
Er	60			0.11	0.0001

Element	FAAS	Hg/Hydride	GFAAS	ICP-OES	ICP-MS
Eu	30			0.03	0.00007
Fe	5		0.06	0.08	0.00001#
Ga	75			1.1	0.000001#
Gd	1800			0.2	0.0003
Ge	300			1.1	0.00003#
Hf	300			0.4	0.00002#
Hg	300	0.006	0.6	1.0	0.001
Ho	60			0.08	0.00004
I					0.003
In	30			1.0	0.000003
Ir	900		3.0	0.9	0.00005#
K	3		0.005	0.3	0.00002#
La	3000			0.06	0.00004
Li	0.8		0.06	0.01	0.0000004
Lu	1000			0.03	0.00004
Mg	0.15		0.004	0.008	0.00001
Mn	1.5		0.005	0.026	0.00002#
Mo	45		0.03	0.3	0.00001#
Na	0.3		0.005	0.2	0.00001

All detection limits (DLs) are given in µg/L and were determined using elemental standards in dilute aqueous solution. All DLs are based on a 98% confidence level (3 standard deviations). Actual DLs may vary depending on system configuration, matrices, and laboratory conditions.

All AAS DLs were determined using instrumental parameters optimized for the individual element, including the use of System 2 electrodeless discharge lamps where available. Data shown were determined on a PerkinElmer AA.

Cold-vapor mercury DLs were determined with dedicated FIMS 100 and FIMS 400 mercury analyzer. The DLs of FIAS 100 and FIAS 400 is 0.2 µg/L with a hollow cathode lamp, 0.05 µg/L with a System 2 electrodeless discharge lamp.

Hydride DLs shown were determined using an MHS-15 mercury/hydride system.

GFAAS DLs were determined on a PerkinElmer AA using 50 µL sample volumes, an integrated platform and full STPF conditions. GFAAS DLs can be further enhanced by the use of replicate injections.

All ICP-OES DLs were obtained on an Avio 550 Max ICP-OES under simultaneous multi-element conditions with the axial view of a dual-view plasma using a cyclonic spray chamber and a concentric nebulizer.

All ICP-MS measurements were performed on a NexION ICP-MS (either quadrupole or multi-quadrupole) in a class 10,000 cleanroom using a 1-second integration time and 10 replicates in ultrapure water, where measurements on the NexION 5000 are denoted by #. DLs were measured under multi-element conditions in Standard mode, except where denoted by *. DLs denoted by * were performed using Reaction mode with the most appropriate cell gas and conditions for that element.

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ATOMIC SPECTROSCOPY DETECTION LIMITS - PART 2

Element	FAAS	Hg/Hydride	GFAAS	ICP-OES	ICP-MS
Nb	1500			0.3	0.000009
Nd	1500			0.2	0.0003
Ni	6		0.07	0.4	0.00006*
Os				0.6	0.00006
P	75000		130	2.0	0.003#
Pb	15		0.05	1.3	0.00001*
Pd	30		0.09	0.5	0.00002#
Pr	7500			0.3	0.00003
Pt	60		2.0	1.0	0.00007
Rb	3		0.03	1.3	0.0002
Re	750			0.4	0.00005#
Rh	6			0.7	0.00002#
Ru	100		1.0	0.5	0.00002
S				3.9	0.009#
Sb	45	0.15	0.05	1.7	0.00001#
Sc	30			0.013	0.00002#
Se	100	0.03	0.05	1.8	0.0003*
Si	90		1.0	0.5	0.007#

Element	FAAS	Hg/Hydride	GFAAS	ICP-OES	ICP-MS
Sm	3000			0.3	0.0002
Sn	150		0.1	0.7	0.00003
Sr	3		0.025	0.003	0.000002#
Ta	1500			1.0	0.000006
Tb	900			0.3	0.00003
Te	30	0.03	0.1	2.1	0.00006#
Th				0.6	0.00003#
Ti	75		0.35	0.04	0.00003*
Tl	15		0.1	1.4	0.000004
Tm	15			0.1	0.00003
U	15000			1.2	0.000005
V	60		0.1	0.3	0.00001*
W	1500			0.8	0.00002
Y	75			0.03	0.00002
Yb	8			0.02	0.0001
Zn	1.5		0.02	0.07	0.0001*
Zr	450			0.09	0.00001#

All detection limits (DLs) are given in µg/L and were determined using elemental standards in dilute aqueous solution. All DLs are based on a 98% confidence level (3 standard deviations). Actual DLs may vary depending on system configuration, matrices, and laboratory conditions.

All AAS DLs were determined using instrumental parameters optimized for the individual element, including the use of System 2 electrodeless discharge lamps where available. Data shown were determined on a PerkinElmer AA.

Cold-vapor mercury DLs were determined with dedicated FIMS 100 and FIMS 400 mercury analyzer. The DLs of FIAS 100 and FIAS 400 is 0.2 µg/L with a hollow cathode lamp, 0.05 µg/L with a System 2 electrodeless discharge lamp.

Hydride DLs shown were determined using an MHS-15 mercury/hydride system.

GFAAS DLs were determined on a PerkinElmer AA using 50 µL sample volumes, an integrated platform and full STPF conditions. GFAAS DLs can be further enhanced by the use of replicate injections.

All ICP-OES DLs were obtained on an Avio 550 Max ICP-OES under simultaneous multi-element conditions with the axial view of a dual-view plasma using a cyclonic spray chamber and a concentric nebulizer.

All ICP-MS measurements were performed on a NexION ICP-MS (either quadrupole or multi-quadrupole) in a class 10,000 cleanroom using a 1-second integration time and 10 replicates in ultrapure water, where measurements on the NexION 5000 are denoted by #. DLs were measured under multi-element conditions in Standard mode, except where denoted by *. DLs denoted by * were performed using Reaction mode with the most appropriate cell gas and conditions for that element.

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ATOMIC SPECTROSCOPY APPLICATIONS BY MARKET

MARKET	TYPICAL APPLICATIONS	COMMONLY USED TECHNIQUES		
		AA	ICP-OES	ICP-MS
Agriculture	Soils	▫	■	■
Biomonitoring	Biological fluids	▫	▫	■
Chemical/Industrial	Quality control/Product testing	■	■	■
Environmental	Water	■	■	■
	Soil	▫	■	■
	Air	▫	▫	■
Food	Food safety	▫	▫	■
	Nutritional labeling	■	■	■
Geochemical/Mining	Exploration	▫	■	■
	Research	■	■	■
Nanomaterials	Research	□	□	■
Nuclear Energy	Low-level waste	▫	■	■
	Process water	□	■	■
Petrochemical	Petroleum refining	■	■	■
	Lubricants and oils	□	■	▫
Pharmaceutical	Drug development	□	□	■
	Quality control	■	■	■
Renewable Energy	Biofuels	□	■	■
	Solar panels	□	■	■
Semiconductor	Wafers	□	□	■
	High-purity chemicals	■	▫	■
Single Cell Analysis	Research	□	□	■

Frequency of Technique Used →

□ ▫ ■ ■

IMPORTANCE OF ATOMIC SPECTROSCOPY TO SPECIFIC MARKETS

Agriculture

Trace metals are essential for plant growth. Atomic spectroscopy also facilitates precise soil analysis to ensure that metals are not at levels that could unduly affect the food source (livestock and/or crops).

Biomonitoring

Instrumentation for accurate measurements of metals in biological matrices is vital when assessing human exposures to natural and synthetic chemicals. Speciation is also becoming increasingly important due to its ability to provide additional information on element valence state or molecular form.

Chemical/Industrial

From the analysis of raw materials and components to finished product testing and quality control, industrial and chemical manufacturers require accurate analytical techniques to ensure the safety and performance of their products.

Environmental

In the environment we live in, understanding heavy-metal contamination is critical. The accurate measurement of concentrations of these metals is imperative to maintain clean air, water and soil for a safer world.

Food

Accurate analysis of food for nutritional content, contamination or authenticity – the exact geographic source of the product – is critical for regulatory and quality assurance.

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Geochemical/Mining

With myriad applications from date stamping to precious metals testing, atomic spectroscopy offers a fast, accurate solution for broad geological surveys as well as an invaluable means of testing potential mining areas before incurring the high costs associated with digging.

Nanomaterials

As research science defines more novel applications for nano- materials, the need to eliminate material uncertainty on a particle-by-particle basis continues to grow. Whether there is a need to solve an environmental issue or apply a manufacturing QA/QC solution to a synthesis or formulation process, there is a growing requirement for sensitivity to conduct accurate, precise work.

Nuclear Energy

Operating under constant scrutiny, the nuclear field is required to monitor and measure the levels of a variety of elements to an exacting degree. Atomic spectroscopy is commonly used to determine trace elements in everything from process water to low-level waste.

Petrochemical

From petroleum refining to a broad spectrum of applications using lubricants and oils, many industries require the determination of metals – particularly analytes that can lead to degradation and contamination – to ensure conformity as well as monitor and control processes.

Pharmaceutical

Drug research, development and production is dependent on elemental analysis, starting with the testing of individual ingredients and continuing through production to final quality control, as impurities can affect drug efficacy and metabolism.

Renewable Energy

As the world continues to move toward ecofriendly technologies and energy sources, there's an ever-increasing need for accurate elemental analysis. Applications include testing biofuels for batch consistency and quality control, as well as trace elemental analysis on solar panels to ensure optimum performance.

Semiconductor & Electronics

The electronics industry is faced with the enormous challenge of "chasing zero", so manufacturers must measure the lowest level of elemental impurities in process chemicals and electronic devices to ensure the highest performance of their products.

Single Cell Analysis

The transfer of analytes in and out of cells is key to many biological processes. Single Cell ICP-MS permits scientists to study the cellular uptake of heteroatom-containing drugs, thereby understanding their efficacy.

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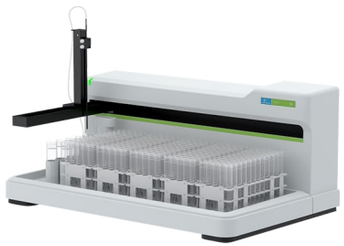
ATOMIC SPECTROSCOPY ACCESSORIES

PerkinElmer makes it easy to get the most out of your AA, ICP-OES and ICP-MS system with a full range of accessories designed to optimize performance, streamline your workflow, and generate faster, more accurate results.

S20 Series Autosamplers

The S20 series autosamplers is the next generation of high-performance, robust, and agile autosamplers designed specifically for PerkinElmer's spectroscopy platforms. It comprises the S23 (3 racks running up to 270 samples) and S25 (5 racks running up to 450 samples), delivering seamless operation to laboratories that require reliable automation and ease of use, improving sample-to-sample run times.



MPS 320 Microwave Digestion System

The MPS 320™ is a reliable and easy-to-operate microwave digestion system for PerkinElmer's AA, ICP-OES, and ICP-MS instruments that accommodates a wide range of sample matrices and applications. It provides the choice of closed-vessel digestion, a requirement for working with volatile elements, or unique, easy-to-use and high-throughput auto-venting vessels, which allow digestion to continue when preset pressure is reached.

SPB Preparation Blocks

When conducting routine sample preparation, PerkinElmer's SPB blocks are ideal for any open-vessel digestion/heating method requiring a temperature below 180 °C.

FIAS 100/400

FIAS are fully integrated and automated flow injection mercury/hydride analysis systems that provide automation and sample handling for AA and ICP, dramatically increasing laboratory productivity and capability. FIAS 100 incorporates a single peristaltic pump for carrier, reagent and sample solutions; while FIAS 400 incorporates two peristaltic pumps for carrier, reagent and sample solutions.

MHS-15 Mercury/Hydride System

The MHS-15 mercury/hydride system is a manual accessory for the high-sensitivity determination of mercury and hydride-forming elements, such as As, Se, Sb, Te, Bi and Sn, by FAAS. The MHS-15 system includes a reaction assembly and a quartz-cell assembly. The analyzer is free-standing and is placed adjacent to the AA spectrometer's sample compartment.

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ATOMIC SPECTROSCOPY CONSUMABLES AND SUPPLIES

Trust the consumables engineered for your instruments.

We offer a wide selection of superior quality consumables and supplies designed to work with your PerkinElmer AA, ICP, and ICP-MS instruments. Our precision-designed products deliver the peace of mind that comes from knowing that you'll get the results you need.

AA Graphite Tubes – Engineered to the highest quality specifications, using a high-density base graphite material, exclusive to PerkinElmer.

AA Lamps – Whether Lumina™ HCL or System 2 EDL, they are designed and tested on our AA spectrometers to assure compatibility and the highest performance.

AA Nebulizers – Stainless steel and high-sensitivity, corrosion-resistant options are available, and all manufactured to exacting tolerances to provide maximum sensitivity.

ICP/ICP-MS Injectors – A complete selection in various sizes and materials (alumina, quartz, sapphire) to meet all of your application needs.

ICP/ICP-MS Nebulizers – Available in a variety of materials (glass, quartz, PFA, and HF-resistant) to accommodate your application requirements.

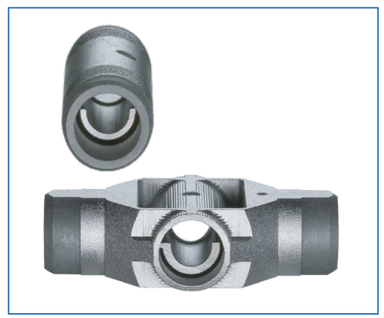
ICP/ICP-MS Spray Chambers – An integral part of the sample introduction system, each type is tested to provide the best performance and analytical results.

ICP/ICP-MS Torches – Manufactured with the best materials for optimal performance and designed specifically for your instrument. Both demountable and fixed torches are available.

ICP-MS Cones – Precision-designed and manufactured for the best analytical results. Large-orifice sampler and skimmer cones provide superior long-term stability.

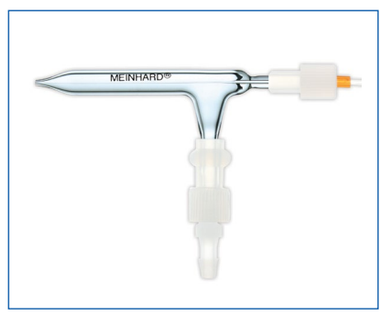
Reference Materials – From inorganic aqueous to metallo-organic reference materials, choose from a wide range of standards all certified and tested to provide the quality and reliability you expect.

Sample Preparation – Whether using our Titan MPS Microwave Digestion System, our SPB Sample Preparation Blocks or both, you can benefit from a complete selection of consumables and supplies that ensure sample preparation success.



Graphite Tubes

Hollow Cathode and
Electron Discharge Lamps



Nebulizers

Spray Chambers

Precision-designed products, along with genuine PerkinElmer consumables and supplies, can be found at www.perkinelmer.com/supplies

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THE MOST TRUSTED NAME IN ELEMENTAL ANALYSIS

PerkinElmer has been at the forefront of atomic spectroscopy technology for over 60 years. With a comprehensive portfolio that includes FAAS systems, high-performance GFAAS systems, flexible ICP-OES systems and the most powerful ICP-MS systems, we can provide the ideal solution no matter what the specifics of your application.

We understand the unique and varied needs of the customers and markets we serve. And we provide integrated solutions that streamline and simplify the entire process from sample handling and analysis to the communication of test results.

With tens of thousands of installations worldwide, PerkinElmer systems are performing inorganic analyses every hour of every day. Behind that extensive network of products stands the industry's largest and most-responsive technical service and support staff. Factory-trained and located in 150 countries, they have earned a reputation for consistently delivering the highest levels of personalized, responsive service in the industry.

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