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

Atomic Spectroscopy
A Guide to Selecting the
Appropriate Technique and System

PerkinElmer®
For the Better

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:

- Environmental
- Food
- Pharmaceutical
- Petrochemical
- Chemical/Industrial
- Geochemical/Mining

- Biomonitoring
- Agriculture
- Semiconductor
- Nuclear Energy
- Renewable Energy
- Nanomaterials

For more details, see Page 13.

COMMONLY USED
ATOMIC
SPECTROSCOPY
TECHNIQUES

There are three widely accepted analytical methods – atomic absorption, 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

• Graphite Furnace Atomic Absorption Spectroscopy

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

• Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

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 deter-mination of mercury. These instruments use a high-performance single-beam optical system with a low-pressure mercury lamp and 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 intro-duced 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.

The major limitation of Flame AA 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.


HCL or EDL Lamp   Flame   Monochromator   Detector
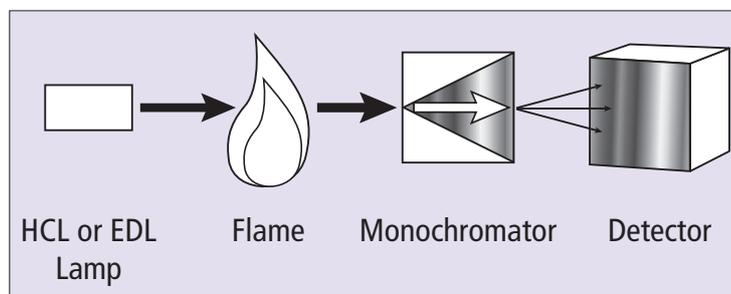
Figure 1. Simplified drawing of a Flame AA system.

Graphite Furnace Atomic Absorption Spectroscopy

With Graphite Furnace Atomic Absorption (GFAA), 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 Flame AA.

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

GFAA allows the determination of over 40 elements in microliter sample volumes with detection limits typically 100 to 1000 times better than those of Flame AA systems.
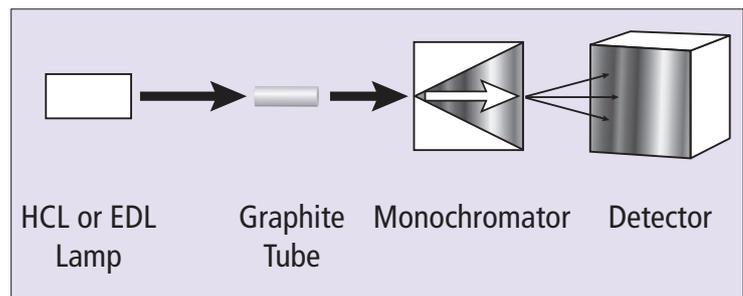
Figure 2. Simplified drawing of a Graphite Furnace AA system.

HCL or EDL Lamp   Graphite Tube   Monochromator   Detector

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 **Ds** Darmstadtium (269)	111 **Rg** Roentgenium (272)							

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

(Key: Atomic number, Element Symbol, Element Name, Atomic Mass — shown for 1 **H** Hydrogen 1.00794)

The Periodic Table of Elements – See page 14 for a listing of detection limits for all elements using the different atomic spectroscopy methods.

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.

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 (CCD) are used, providing very flexible systems and eliminating the need for large numbers of single photomultiplier detectors.
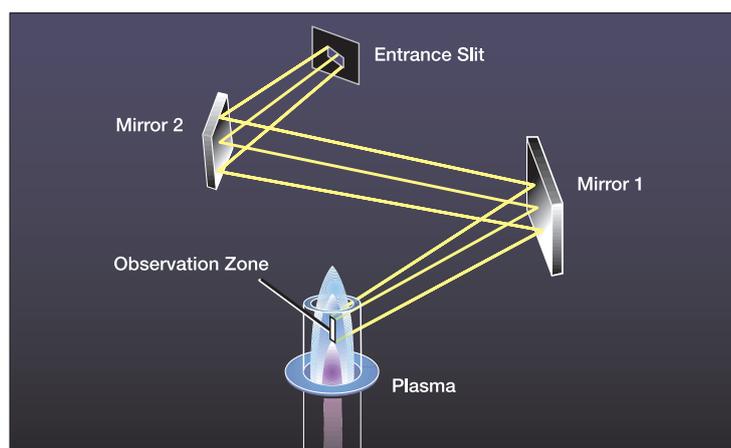
Figure 3a. Radially viewed plasma with a vertical slit image in the plasma.
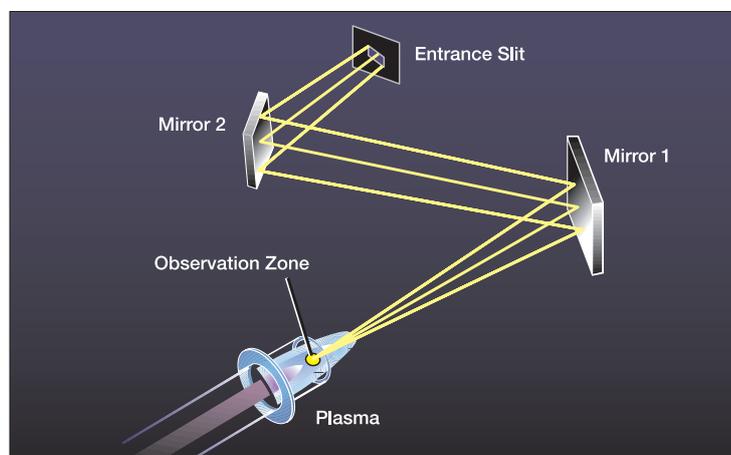
Figure 3b. Axially viewed plasma with an axial slit image in the plasma.
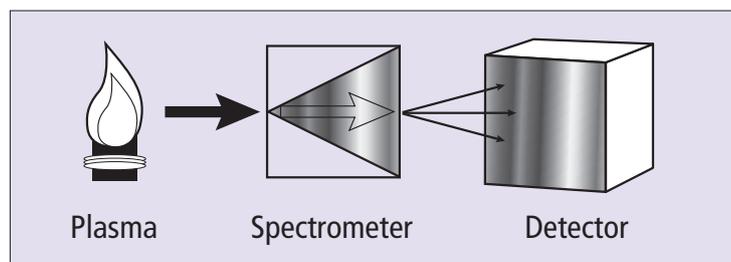
Figure 4. Simplified drawing of a basic ICP system.

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 directed 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). Typically, a quadrupole mass spectrometer is used for its ease-of-use, robustness and speed. Due to the similarity of the sample-introduction and data-handling techniques, using an ICP-MS is very much like using an ICP-OES system.

ICP-MS combines the multi-element capabilities of ICP tech-niques with exceptional detection limits equivalent to or below those of GFAA. It is also one of the few analytical techniques that allows the quantification of elemental isotopic concentra-tions and ratios, as well as precise speciation capabilities when used in conjunction with HPLC or GC interfaces. This feature enables the analytical chemist to determine the exact form of a species present – not just the total concentration.

However, due to the fact that the sample components are actually introduced into the instrument, there are some limitations as to how much sample matrix can be introduced into the ICP-MS. In addition, there are also increased maintenance requirements as compared to ICP-OES systems. Generally, ICP-MS systems require that the total dissolved solids content of a sample be below 0.2% for routine operation and maximum stability. There are several items, such as the interface cones and ion lens, located between the ICP torch and the mass spectrometer, that need to be cleaned on a periodic basis to maintain acceptable instrument performance.

Recent developments have led to new technologies to increase the robustness and stability of ICP-MS. Orthogonal ion lens systems increase the ability of the ICP-MS to handle higher total dissolved solids content and dramatically improve long-term stability for high matrix solutions. Interference control has been made even easier by using universal cell technologies that include both collision (using Kinetic Energy Discrimination KED) and Dynamic Reaction Cell (DRC) in a single instrument allowing the analyst to choose the best technique for their samples.
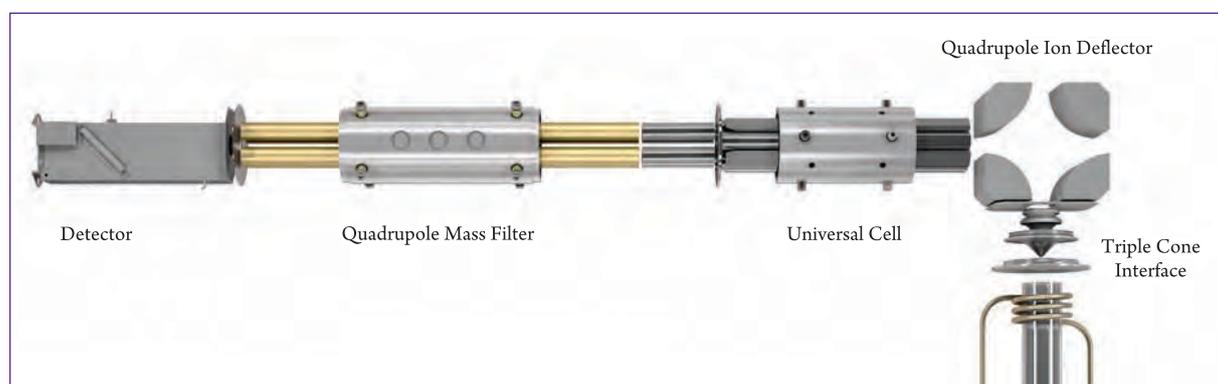
Figure 5. Simplified drawing of ICP-MS system with Universal Cell Technology (UCT).

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 Flame AA, Graphite Furnace AA, ICP-OES and ICP-MS. In simple terms, your choice can be guided by answering the four questions in Table 1.

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 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 Flame AA, GFAA, ICP-OES (with radial and axial torch configurations) and ICP-MS, see the table on page 14.

Table 1. **Technique decision matrix.**

	Flame AA	GFAA	ICP-OES	ICP-MS
How Many Elements?				
Single	■			
Few		■		
Many			■	■
What Levels?				
High ppb	■		■	
Sub ppb		■	■	■
Sub ppb-ppm				■
Sub ppt				■
How Many Samples?				
Very few	■	■		
Few	■	■	■	■
Many			■	■
How Much Sample?				
> 5 mL	■	■	■	■
< 1-2 mL		■		
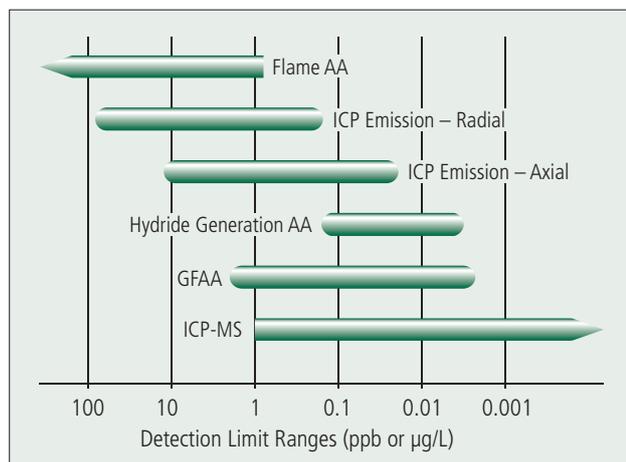
Figure 6. Typical detection limit ranges for the major atomic spectroscopy techniques.

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.

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. However, Flame AA requires specific light sources and optical parameters for each element to be determined and may require different flame gases for different elements. As a result, even though it is frequently used for multi-element analysis, Flame AA is generally considered to be a single-element technique.

- Graphite Furnace AA – As with Flame AA, GFAA is basically a single-element technique. Because of the need to thermally program the system to remove solvent and matrix components prior to atomization, GFAA has a relatively low sample throughput. A typical graphite-furnace determination normally requires 2-3 minutes per element for each sample.

- 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 – Also a true multi-element technique with the same advantages and limitations of ICP-OES. ICP-MS can typically determine more than 73 elements per minute in an individual sample, depending on such factors as the concentration levels and required precision. Although ICP-MS has a wide working range, the upper linear concentration range is generally less than that of ICP-OES systems and may require that some samples be diluted.

Costs

As they are less complex systems, instrumentation for single-element atomic spectroscopy (Flame AA and GFAA) 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.
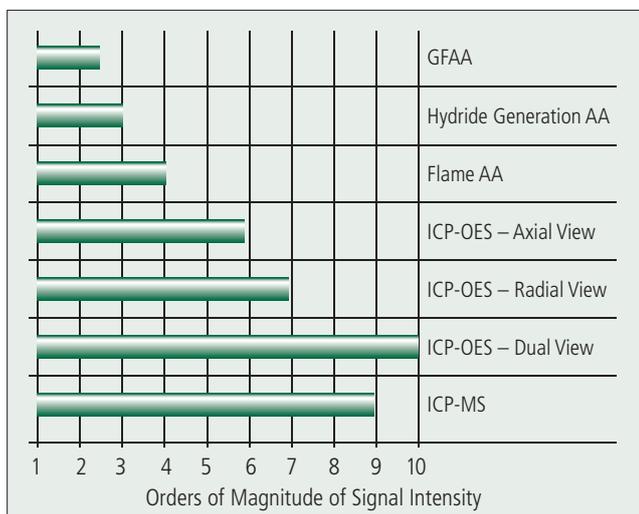
Figure 7. Typical analytical working ranges for the major atomic spectroscopy techniques.
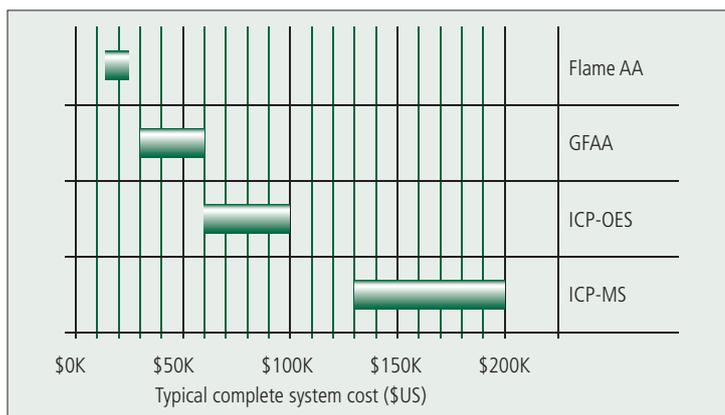
Figure 8. Typical relative purchase prices for atomic spectroscopy systems.

SELECTING A SYSTEM FOR YOUR ANALYSIS

TECHNIQUE	STRENGTHS	LIMITATIONS	APPLICATIONS	SYSTEM
Flame AA – 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.	**AAnalyst 200/400 AA Spectrometers**
GFAA – Graphite Furnace Atomic Absorption Spectroscopy	• Exceptional detection limits • Well-documented applications • May be left unatteneded	• 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 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.	**Optima 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	Ideal for laboratories analyzing multiple elements in a large number of samples and requiring a system capable of determining trace and ultra-trace analyte concentrations.	**NexION ICP-MS Spectrometers**

Once you have identified the best solution for your particular application, read on for more in-depth product details.

AAnalyst 200/400 Atomic Absorption Spectrometers

Whether you choose the AAnalyst™ 200 or AAnalyst 400, you'll discover an easy, affordable and reliable flame atomic absorption (AA) solution. We've simplified the process of AA analysis, from sample introduction to results. We've made it easy for anyone with a basic understanding of AA to get fast, reliable results every time, and we've made the quality and reliability of PerkinElmer available to everyone with these affordable systems.

Easy to use, easy to own, and featuring many of the advances that have made PerkinElmer the market leader, the AAnalyst 200 and 400 are the perfect choice for any laboratory needing a reliable, trouble-free solution for flame AA analysis.

PinAAcle 900 Atomic Absorption Spectrometers

The PinAAcle™ series of atomic absorption (AA) spectrometers brings AA performance to new heights. Engineered with an array of exciting technological advances, it offers a variety of configurations and capabilities to deliver exactly the level of performance you need:

- Flame only, furnace only, or space-saving stacked designs featuring both
- Flame, furnace, flow injection, FIAS-furnace and mercury/hydride capabilities on a single instrument
- Choice of Deuterium or longitudinal Zeeman background correction
- TubeView™ color furnace camera simplifies autosampler tip alignment and sample dispensing
- Proven WinLab32™ software offering both ease-of-use and exceptional flexibility

And no matter which model you select (900F, 900Z, 900H, 900T), you'll discover an intuitive, highly efficient system capable of simplifying your journey from sample to results – even with the most difficult matrices.

Optima 8x00 ICP-OES Spectrometers

With its groundbreaking features and expanded capabilities, the Optima™ 8x00 series is more than just an evolution of the world's most popular ICP-OES… it's a revolution. Built around the proven design of the Optima platform, the 8x00 series delivers breakthrough performance through a series of cutting-edge technologies that optimize sample introduction, enhance plasma stability, simplify method development and dramatically reduce operating costs:

- eNeb™ Sample Introduction – generates a constant flow of uniform droplets for superior stability and unsurpassed detection limits.
- Flat Plate™ Plasma Technology – with a patented, maintenance-free RF generator uses half the argon of traditional systems dramatically reducing operating costs.
- PlasmaCam™ Viewing Camera – offers continuous viewing of the plasma, simplifying method development and enabling remote diagnostic capabilities for maximum uptime.

NexION ICP-MS Spectrometers

Engineered to deliver a level of stability, flexibility and performance never before seen in an ICP-MS instrument, the NexION® 300 systems represent the first truly significant and revolutionary industry advancement in recent memory.

For the first time ever, a single ICP-MS instrument offers both the simplicity and convenience of a collision cell and the exceptional detection limits of a true reaction cell.

With this patented Universal Cell Technology™ (UCT), analysts can now choose the most appropriate technique for a specific sample or application. No restrictions on which gases you can use. No limits on your mass range. No compromises on how you choose to work. And no hassles switching from one mode to another. Just the promise of superior accuracy and detection limits, faster analysis times, and an easier, more customizable operator experience than with any other instrument on the market.

Signal responses are kept stable hour after hour by a unique Triple Cone Interface and Quadrupole Ion Deflector. Designed to remove an unprecedented level of un-ionized material (and preventing it from entering the Universal Cell), this innovative ion path keeps the instrument clean, minimizing drift and completely eliminating the need for cell cleanings.

Atomic Spectroscopy Applications by Market

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

Frequency of Technique Used
(white → yellow → orange → red)
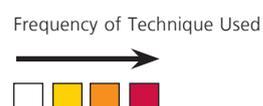
IMPORTANCE OF
ATOMIC SPECTROSCOPY
TO SPECIFIC MARKETS

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.

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.

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.

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.

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.

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.

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).

Semiconductor

Determining lower and lower values in a variety of materials – rapidly and affordably – has become necessary in the increasingly competitive semiconductor industry.

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.

Renewable Energy

As the world continues to move toward eco-friendly 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.

Nanomaterials

As research science defines more novel applications for nanomaterials, 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.

DETECTION LIMITS

Element	Flame AA	Hg/Hydride	GFAA	ICP-OES	ICP-MS	Element	Flame AA	Hg/Hydride	GFAA	ICP-OES	ICP-MS
Ag	1.5		0.005	0.6	0.002	Mo	45		0.03	0.5	0.001
Al	45		0.1	1	0.005[a]	Na	0.3		0.005	0.5	0.0003[c]
As	150	0.03	0.05	1	0.0006[b]	Nb	1500			1	0.0006
Au	9		0.15	1	0.0009	Nd	1500			2	0.0004
B	1000		20	1	0.003[c]	Ni	6		0.07	0.5	0.0004[c]
Ba	15		0.35	0.03	0.00002[d]	Os				6	
Be	1.5		0.008	0.09	0.003	P	75000		130	4	0.1[a]
Bi	30	0.03	0.05	1	0.0006	Pb	15		0.05	1	0.00004[d]
Br					0.2	Pd	30		0.09	2	0.0005
C					0.8[e]	Pr	7500			2	0.00009
Ca	1.5		0.01	0.05	0.0002[d]	Pt	60		2.0	1	0.002
Cd	0.8		0.002	0.1	0.00009[d]	Rb	3		0.03	5	0.0004
Ce				1.5	0.0002	Re	750			0.5	0.0003
Cl					12	Rh	6			5	0.0002
Co	9		0.15	0.2	0.0009	Ru	100		1.0	1	0.0002
Cr	3		0.004	0.2	0.0002[d]	S				10	28[j]
Cs	15				0.0003	Sb	45	0.15	0.05	2	0.0009
Cu	1.5		0.014	0.4	0.0002[c]	Sc	30			0.1	0.004
Dy	50			0.5	0.0001[f]	Se	100	0.03	0.05	2	0.0007[b]
Er	60			0.5	0.0001	Si	90		1.0	10	0.03[a]
Eu	30			0.2	0.00009	Sm	3000			2	0.0002
F					372	Sn	150		0.1	2	0.0005[a]
Fe	5		0.06	0.1	0.0003[d]	Sr	3		0.025	0.05	0.00002[d]
Ga	75			1.5	0.0002	Ta	1500			1	0.0005
Gd	1800			0.9	0.0008[g]	Tb	900			2	0.00004
Ge	300			1	0.001h	Te	30	0.03	0.1	2	0.0008[k]
Hf	300			0.5	0.0008	Th				2	0.0004
Hg	300	0.009	0.6	1	0.016[i]	Ti	75		0.35	0.4	0.003[l]
Ho	60			0.4	0.00006	Tl	15		0.1	2	0.0002
I					0.002	Tm	15			0.6	0.00006
In	30			1	0.0007	U	15000			10	0.0001
Ir	900		3.0	1	0.001	V	60		0.1	0.5	0.0005
K	3		0.005	1	0.0002[d]	W	1500			1	0.005
La	3000			0.4	0.0009	Y	75			0.2	0.0002
Li	0.8		0.06	0.3	0.001[c]	Yb	8			0.1	0.0002[m]
Lu	1000			0.1	0.00005	Zn	1.5		0.02	0.2	0.0003[d]
Mg	0.15		0.004	0.04	0.0003[c]	Zr	450			0.5	0.0003
Mn	1.5		0.005	0.1	0.00007[d]						

All detection limits are given in micrograms per liter and were determined using elemental standards in dilute aqueous solution. All detection limits are based on a 98% confidence level (3 standard deviations).

All atomic absorption detection limits 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.

All Optima ICP-OES detection limits were obtained under simultaneous multi-element conditions with the axial view of a dual-view plasma using a cyclonic spray chamber and a concentric nebulizer.

Cold-vapor mercury detection limits were determined with a FIAS-100 or FIAS-400 flow injection system with amalgamation accessory.

The detection limit without an amalgamation accessory is 0.2 µg/L with a hollow cathode lamp, 0.05 µg/L with a System 2 electrodeless discharge lamp. (The Hg detection limit with the dedicated FIMS-100 or FIMS-400 mercury analyzers is < 0.005 µg/L without an amalgamation accessory and < 0.0002 µg/L with an amalgamation accessory.) Hydride detection limits shown were determined using an MHS-15 Mercury/Hydride system.

GFAA detection limits were determined on a PerkinElmer AA using 50 µL sample volumes, an integrated platform and full STPF conditions. Graphite-furnace detection limits can be further enhanced by the use of replicate injections.

Unless otherwise noted, ICP-MS detection limits were determined using a PerkinElmer ICP-MS equipped with Ryton™ spray chamber, Type II Cross-Flow nebulizer and nickel cones. All detection limits were determined using 3-second integration times and a minimum of 8 measurements.

Letters following an ICP-MS detection limit value refer to the use of specialized conditions or a different model instrument as follows: [a] Run on a PerkinElmer ICP-MS in standard mode using Pt cones and quartz sample-introduction system. [b] Run on a PerkinElmer ICP-MS in DRC mode using Pt cones and quartz sample-introduction system. [c] Run on a PerkinElmer ICP-MS in standard mode in Class-100 Clean Room using Pt cones and quartz sample-introduction system. [d] Run on a PerkinElmer ICP-MS in DRC mode in Class-100 Clean Room using Pt cones and quartz sample-introduction system. [e] Using C-13. [f] Using Dy-163. [g] Using Gd-157. [h] Using Ge-74. [i] Using Hg-202. [j] Using S-34. [k] Using Te-125. [l] Using Ti-49. [m] Using Yb-173.

ATOMIC SPECTROSCOPY
ACCESSORIES

Multiwave 3000

🟨   🟧   🟥

Microwave sample-preparation system

- Built-in cooling system to reduce total cycle time, improving productivity
- Ideal for drying, evaporation, acid digestion and solvent extraction

FIAS

🟨   🟧   🟥

Fully automated flow-injection system

- Simplifies and speeds up analyses requiring complex sample preparation such as Mercury and other hydride-forming elements

Specialized Software

🟨   🟧   🟥

- QC charting
- Tools for 21 CFR Part 11 compliance
- Speciation software

Autosamplers

🟨   🟧   🟥

- Flexible rack configurations
- Fast, accurate random access
- Corrosion-resistant sampling components
- Flow-through rinse station to minimize sample-to-sample contamination

High-Throughput Sample-Introduction System

🟧   🟥

- Minimizes sample uptake and washout time
- Throughput increased up to 2-3 fold
- Eliminates sample contact with peristaltic pump tubing

AA Consumables

🟨

- HCL and EDL lamps
- Graphite tubes
- Standards

Mercury Hydride System

🟨   🟧

- Highly sensitive determination of Mercury or hydride-forming elements

Graphite Furnace (for AAnalyst 400)

🟨

- Quick, easy interchange between flame and furnace
- Low sample consumption (as low as a few µL)
- Exceptional detection limits, down to the pg range

ICP-OES and ICP-MS Consumables

🟧   🟥

- Cones
- Torches
- Nebulizers
- Standards

For more information on any of the products shown here, or for a complete listing of all atomic spectroscopy accessories available, please visit **www.perkinelmer.com**

For more product information, visit:
www.perkinelmer.com/atomicspectroscopy
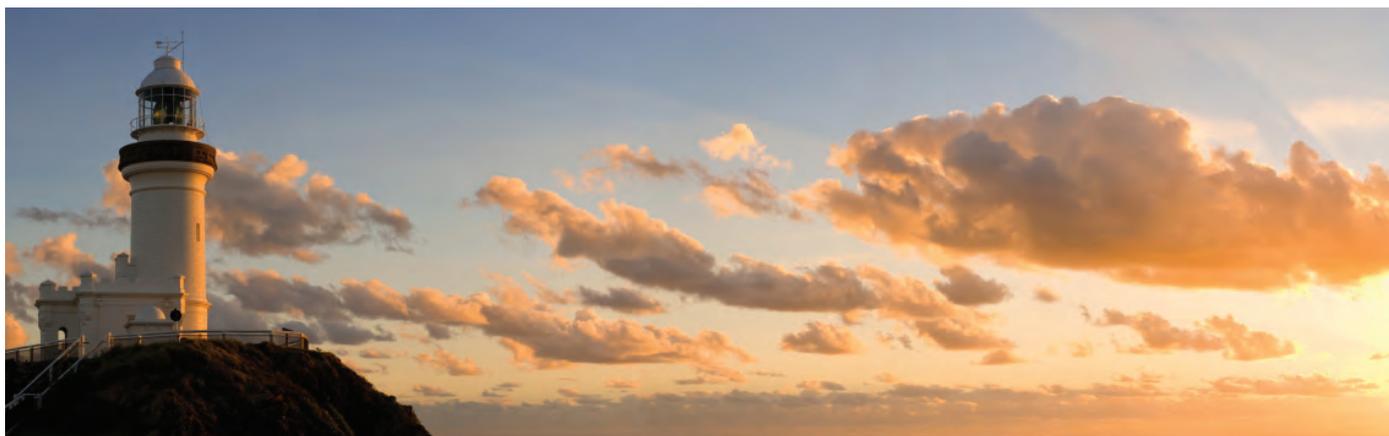
The Most Trusted Name in Elemental Analysis

PerkinElmer has been at the forefront of inorganic analytical technology for over 50 years. With a comprehensive product line that includes Flame AA systems, high-performance Graphite Furnace AA 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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