

Thermo Scientific iCAP 7000 Plus Series ICP-OES: Innovative ICP-OES Optical Design

Key Words

Optical Design, Polychromator, Spectrometer

Key Benefits

The Thermo Scientific™ iCAP™ 7000 Plus Series ICP-OES provides the lowest cost of analysis through productivity, sensitivity and ease of use.

- The Echelle polychromator enables rapid, simultaneous, multi-element analysis
- The compact spectrometer allows for an efficient optical gas purge, enabling low running costs
- A low number of optical surfaces provides powerful light transmission for high sensitivity and optimized signal to noise ratios enabling low detection limits
- Outstanding optical resolution combined with easy method development reduces spectral overlap and the need for mathematical interference corrections
- Wavelength coverage of 166 to 847 nm enables access to the most comprehensive range of useful analytical lines
- Innovative thermostatic control ensures that the instrument remains extremely stable, providing long term precision

Introduction

Inductively Coupled Plasma Optical-Emission Spectrometry (ICP-OES) is an elemental analysis technique that derives its analytical data from the emission spectra of elements excited within a high-temperature plasma. The purpose of the ICP-OES optical system is to separate element-specific wavelengths of light, emitted from the excited sample and to focus the resolved light onto the detector as efficiently as possible. The spectrometer is comprised of two sections, the fore-optics and the polychromator. When the light exits the polychromator it is focused on to the detector.



Plasma Viewing Configurations

ICP-OES instruments can be configured as radial, axial or dual view. In the radial configuration, the plasma is viewed from the side, while in the axial configuration; the plasma is viewed end-on (along the length of the plasma) and in the dual view configuration, the plasma can be viewed in either the radial or axial orientation (see Figure 1).

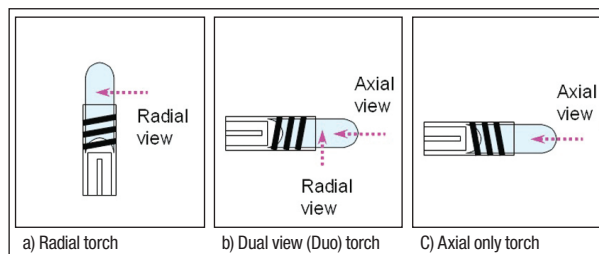


Figure 1. Plasma viewing options in ICP-OES instruments.

The dedicated radial plasma view is accepted as the configuration with the highest tolerance for high dissolved solids and other complex matrices. This is due to lower levels of matrix interferences in the region of the plasma that is viewed and that the plasma does not deposit material on an interface. The radial plasma view offers less sensitivity than the axial view, however, it is preferable for analyzing difficult samples such as organics or very high dissolved solid matrices, as the plasma viewing position can be optimized to reduce background emissions. The axially viewed plasma configuration offers greater sensitivity, than radial configuration, but has higher susceptibility to matrix interferences, as the entire plasma is viewed, increasing the quantity of light observed from both analyte and background emissions. However, combining an axial plasma view with an automatically switchable radial plasma view in the dual plasma view configuration produces a sensitive, versatile instrument with the ability to handle a wide range of samples with complex matrices. The switching between the two plasma views is carried out by the fore-optics (Figure 2).

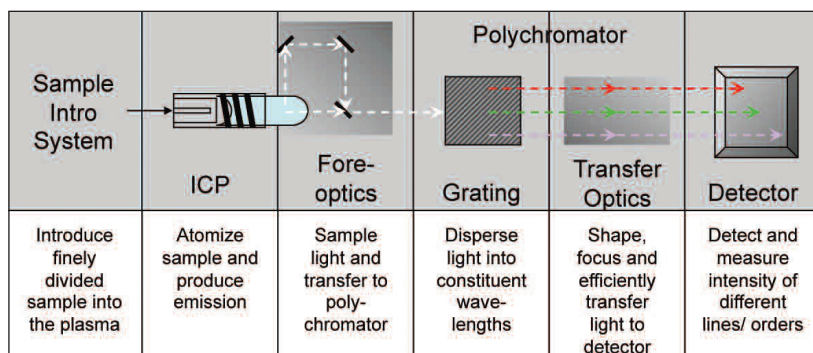


Figure 2. A simplified linear schematic of an ICP-OES instrument showing the purpose of each major component.

Thermo Scientific iCAP 7000 Plus Series ICP-OES Optical System

The Thermo Scientific iCAP 7000 Plus Series ICP-OES incorporates an optical design which combines high performance simultaneous analytical performance with cost-efficiency. The primary requirements for the optical design are listed below:

Performance:

- Optimized light transfer in both the UV and visible ranges to enable high sensitivity and excellent analytical detection capability for all commonly used wavelengths.
- High resolution to reduce spectral interferences and improve analysis in spectrally rich solutions.

Productivity:

- Rapid, accurate analysis with simultaneous measurement of analyte, background and internal standard wavelengths.
- Thermal and mechanical stabilization of all optical components to achieve exceptional long-term stability, reducing the need for frequent recalibrations.
- Distributed optical gas purge for rapid installation, start-up and low gas consumption costs.

Versatility:

- Broad wavelength coverage and the ability to simultaneously capture the entire analytical spectrum.
- Fore-optic design to enable model configurations with either a dedicated radial plasma view or a dual plasma view configuration.
- Compact optical design to enable a small instrument footprint.

The focus on the three principles highlighted above enables the iCAP 7000 Plus Series ICP-OES to deliver exceptional cost efficiency through increased sample throughput and reduced gas consumption.

iCAP 7000 Plus Series ICP-OES Fore-Optics

iCAP 7000 Plus Series ICP-OES Duo

The fore-optics of the Duo viewing configuration consists of tandem view mirrors and a plasma focusing mirror – the absolute minimum number of surfaces for the required design, as shown in Figure 3. The mirror arrangement optimizes the view into the axial sample channel and radial view of the plasma in two-dimensions using software control. The tandem viewing mirror in the Duo configuration has been designed to enable rapid switching between radial and axial plasma views during sample analysis for enhanced productivity and flexibility.

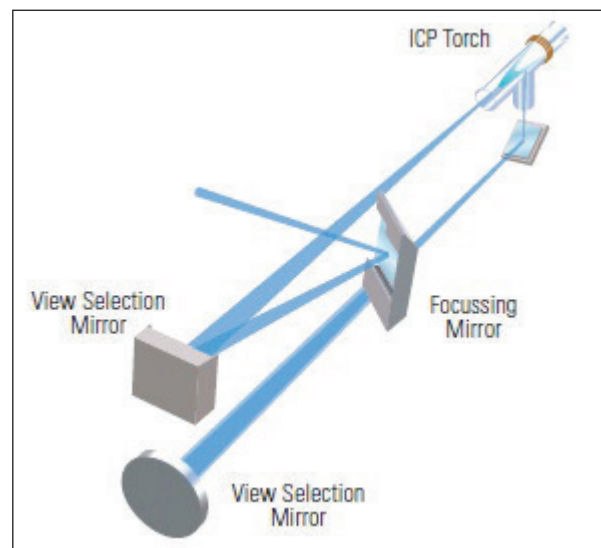


Figure 3. Schematic of the iCAP 7000 Plus Series ICP-OES Duo fore-optics.

The iCAP 7000 Plus Series ICP-OES Duo design uses the minimum number of fore-optics surfaces and movable parts and is a stable and versatile platform with high efficiency light transfer for the transmission of the maximum amount of elemental emission in the minimum time. Unlike a dual view design, axial only instruments do not have the versatility of the added radial view mode for improved interference and matrix-handling and may not be able to analyze some types of samples effectively.

iCAP 7000 Plus Series ICP-OES Radial

The fore-optics in the dedicated radial instrument consists of a view mirror and a focusing mirror, as shown in Figure 4. The mirror arrangement used enables the optimization of the plasma viewing height, enabling viewing of the region of maximum analyte intensity in the plasma.

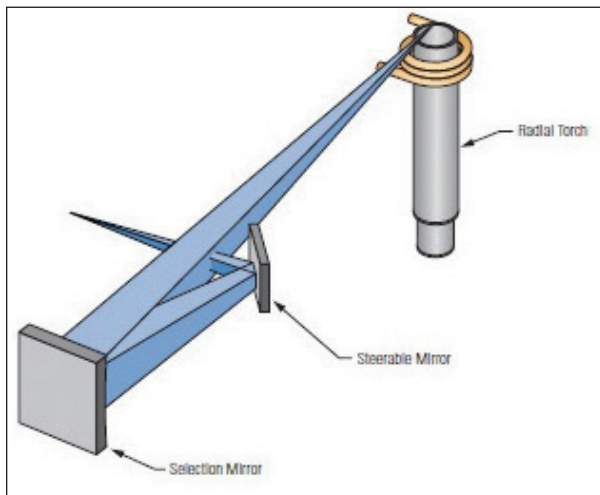


Figure 4. Schematic of the iCAP 7000 Plus Series ICP-OES Radial fore-optics.

Inefficient and poorly designed fore-optics purge systems result in UV absorption between the plasma and the fore-optics and poor UV sensitivity. The iCAP 7000 Plus Series ICP-OES Purged Optical Pathway (POP) tube design and optimized purge gas flow eliminates this problem in both Radial and Duo versions by providing an efficiently purged pathway between the plasma and the fore-optics.

Polychromator Design

The iCAP 7000 Plus Series ICP-OES utilizes an echelle spectrometer with a focal length of 383 mm and a unique configuration of a minimal number of all-spherical mirrors enabling high optical resolution of 7 pm at 200 nm in a compact design. It provides comprehensive, virtually continuous wavelength coverage in the range of 166.4 nm to 847.0 nm, allowing the option of alternate wavelength selection in the presence of spectral interferences, e.g. the interference of iron on boron at 249.777 nm in steel samples. In this case, boron can simply be analyzed at 208.959 nm instead. The innovatively designed polychromator enables exceptionally high light transfer efficiency with minimal light scattering to deliver high analytical performance. As the light from the plasma enters the polychromator, it is selectively focused through two optimized slits. The use of this two slit configuration enables optimal light transmission across the entire UV-Visible wavelength range for optimal analytical performance.

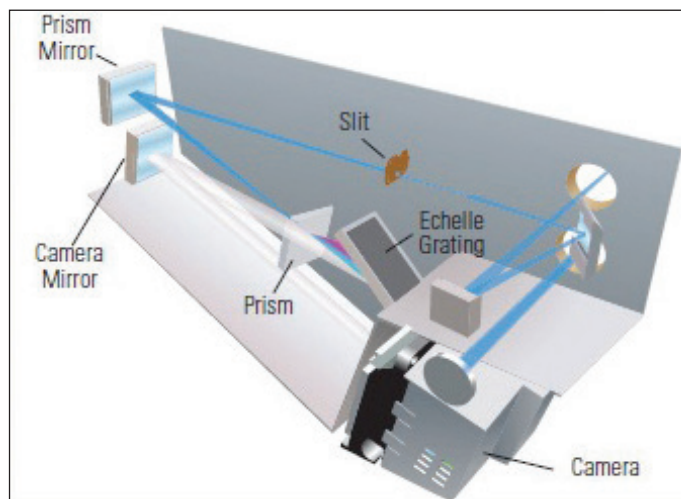


Figure 5. Schematic of iCAP 7000 Plus Series ICP-OES polychromator layout, showing light path.

Once through the entrance slit the light is focused on the prism, by the prism mirror. The prism then separates the light by wavelength in a single dimension, at low resolution. An echelle grating orders the separated light, from the prism, in the other dimension. This creates a high resolution, 2 dimensional spectrum, known as an echelleogram. After passing through the prism for the second time, the camera mirror collects and focuses the now completely dispersed spectrum onto the Charge Injection Device (CID) detector. The uniquely angled and positioned, all-spherical mirror design transfers the slit image to the detector with minimal degradation of resolution, regardless of element wavelength/ order position on the chip. The final two dimensional spectrum is used for the interpretation of the resultant analyte signals. The excellent resolution achieved by the innovative optical design is demonstrated by the spectrometer's ability to resolve the thallium doublet at 190.856 nm and 190.870 nm, shown in Figure 6.

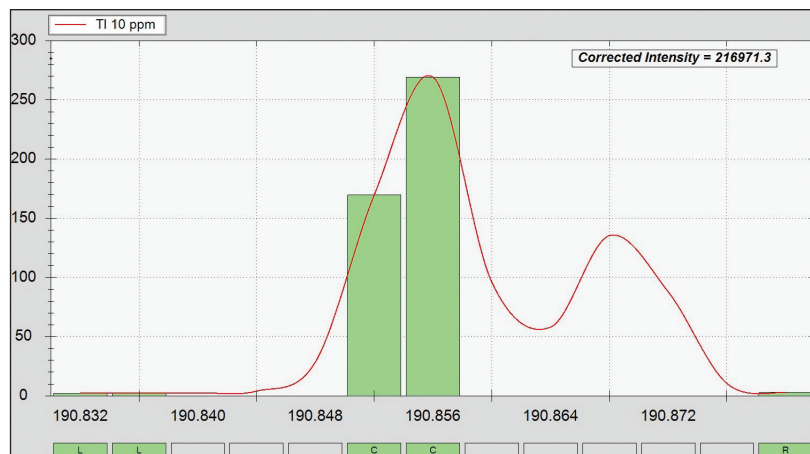


Figure 6. Thallium doublet from the iCAP 7000 Plus Series ICP-OES, shown in raw pixel form. The well separated doublet peaks indicate the high resolution of the spectrometer.

Thermal stabilization

The iCAP 7000 Plus Series ICP-OES polychromator is thermostatically controlled at 38 ± 0.1 °C using a thermally conductive heating blanket, covered by an insulating, thermal foam layer to ensure optimum thermal stability. In addition, a thermal break is incorporated into the design of the interface between the optics and the torch box which enables analytical stability.

Optical purge design

Gases common in air, such as oxygen and carbon dioxide, can absorb much of the intensity of UV radiation (< 190 nm) therefore in order to enable the sensitive analysis of analytes in this wavelength region, the use of a purge system in the polychromator, fore-optics and the plasma interface is critical.

The iCAP 7000 Plus Series ICP-OES uses a unique distributed gas purge system which purges the polychromator uniformly and is integral to the design of the fore-optics and plasma interface. The purge system can be configured to use either argon or nitrogen gas and was developed using Computational Fluid Dynamics (CFD) techniques, in order to examine and optimize the purge gas flow, thermal distribution, gradients and stability. The compact design and low volume optical tank ensures quick and efficient purging using minimum gas flows.

The purge gas exits the optical system through the POP tube, and in doing so removes constituents in the plasma interface that may otherwise absorb the UV light intensity, this is shown in Figure 7. Additionally, the POP tube purge gas flow provides a counter flow of argon to occlude environmental factors, such as dust and soot, removing the interferences they cause. Some other ICP-OES designs are required to use additional gas flows such as a shear gas, to optimize their plasma interface. This can increase instrument running costs, interfere with light transmission or requires expensive accessories such as air compressors to be purchased with the instrument.

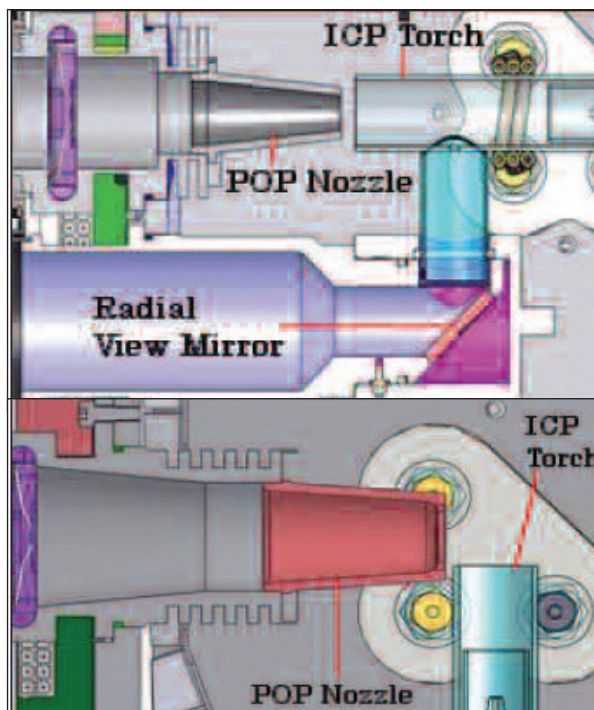


Figure 7. Schematic of the POP tubes for Duo (above) and Radial (below) instruments.

The iCAP 7000 Plus Series ICP-OES has been designed to include the minimum number of components in the polychromator and there are no electronic components present in the optical tank which can compromise the optical performance with out-gassing. When out-gassing occurs in a system without a purge gas i.e. a sealed, recirculating system, the compounds that are given off in the optical chamber may coat the optical components, drastically reducing optical light transfer. The use of a free-flowing purge gas additionally avoids the requirement for the use of expensive gas pumps and scrubbers.

Conclusion

The optical design of the iCAP 7000 Plus Series ICP-OES, echelle polychromator produces high light throughput, providing exceptional sensitivity and outstanding resolution. This high resolution enables the analyst to avoid many spectral interferences which would otherwise cause problems during analysis. Combining these effects with an efficient optical purge and careful thermal stabilization produces a spectrometer system with superlative analytical performance and low gas consumption. This allows the analyst to provide the greatest quality of results while minimizing cost of ownership.