A Practical Guide To Elemental Analysis of Lithium Ion Battery Materials Using ICP-OES

Agilent

Trusted Answers

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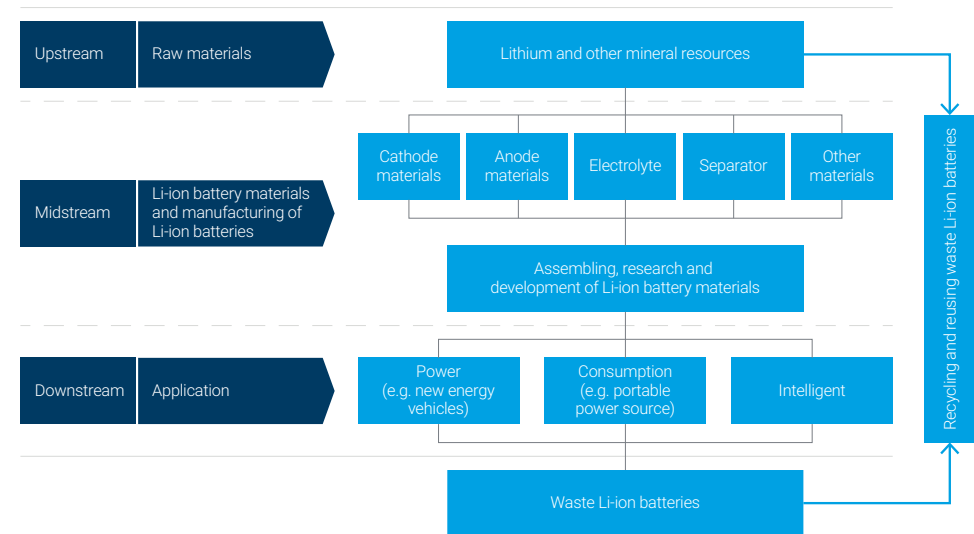# The Lifecycle of Lithium Ion Battery Materials

Elemental analysis measurements at each stage

The lithium battery industry requires the analysis of the elemental composition of materials along the value chain:

- Lithium and other minerals extraction: identification and quantification of elements in ores and brines, and of metal and magnetic impurities in the refining process

- Lithium battery research and development: studying the interactions between components, studying the impact of different elements used in batteries to improve battery safety, performance, cycle life, power density, and energy density, measuring elements in decomposition products

- Lithium battery manufacturing quality control: Measuring impurities in anode, cathode and electrolyte materials, controlling any restricted elements such as lead, mercury, and chromium

- Manufacturing environmental monitoring: Ensuring factory discharges comply with regulated limits

- Lithium battery recycling and resource recovery of valuable metal elements (Ni, Co, Mn, Li, etc.)

Lithium-Ion Battery Industry

Upstream	Raw materials

Lithium and other mineral resources

Cathode materials	Anode materials	Electrolyte	Separator	Other materials

Midstream	Li-ion battery materials and manufacturing of Li-ion batteries

Assembling, research and development of Li-ion battery materials

Downstream	Application

Power (e.g. new energy vehicles)	Consumption (e.g. portable power source)	Intelligent

Waste Li-ion batteries

Recycling and reusing waste Li-ion batteries

Elemental analysis during resource extraction

Battery manufacturers are demanding higher purity raw materials. Suppliers of Li and Li-compounds must determine the content of some key elements in ores or brines before extraction to manage the extraction process and the quality of the final product.

Elemental analysis of these types of samples is challenging for ICP-based analytical techniques. The samples typically have high total dissolved solids (TDS) content, high density of the solutions, and likely presence of algae and undissolved particles in brine samples. Matrix in these samples may deposit on the sample introduction system or quench the plasma, impacting the long-term stability of measurements. Ore or brine samples are likely to contain unknown quantities of a wide range of elements. This unknown composition can cause spectral and physical interferences, which can impact the accuracy of measurements.

Elemental analysis during battery manufacture

A lithium ion battery consists of four basic components:

– Cathode materials: These include a variety of cathode materials including lithium iron phosphates, lithium nickel manganese cobalt etc. The performance of cathode materials impact the energy density, safety, and cycle life of the battery.

– Anode materials: These include metals, metal oxides, inorganic nonmetals (e.g. carbon and silicon). The performance of anode materials is a major contributor the energy density of a battery.

– Separator materials: They are typically membranes made from organic materials such as polypropylene and polyethylene. Separator materials can affect the capacity, cycle performance, current density, and other electrical properties.

– Electrolyte: These contain high purity organic solvents, electrolyte lithium salts and additives. The performance of electrolyte materials can affect the safety of a battery.
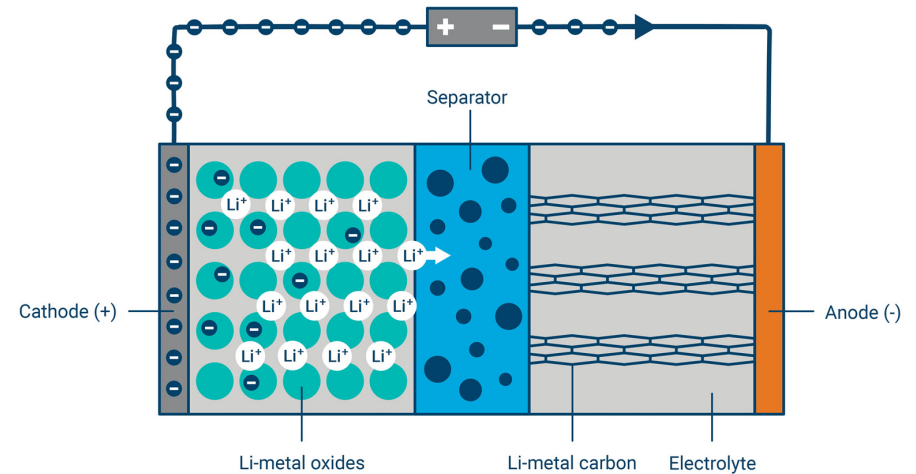
A lithium ion battery consists of a cathode, anode, electrolyte, and separator. When the battery is charging the electrons flow from the cathode to the anode. The flow is reversed when the battery is discharging.

Battery manufacturers typically measure the impurities and elemental composition of the:

– Electrolyte

– Graphite anode materials

– Cathode materials

Manufacturers will also be required to measure the elemental composition of any discharges from their factory, to comply with regulations.

Elemental analysis during recycling

Approximately 95 per cent of lithium-ion battery components can be turned into new batteries or used in other industries, if recycled. The materials recovered account for more than half of a battery's cost- so there are strong incentives to recycle. The prices of common cathode materials, such as cobalt and nickel, fluctuate considerably. Many of these elements are sourced from countries which are politically unstable, e.g 50% of global cobalt reserves are in the Congo. In many types of Li-ion batteries, the concentrations of these metals, along with those of lithium and manganese, exceed the concentrations in natural ores, making spent batteries akin to highly enriched ore. If those metals can be recovered from used batteries at a large scale and more economically than from natural ore, the price of batteries should drop. Recycling also means less mining and less associated social and environmental harm.

Batteries recycling typically involves high-temperature melting-and-extraction, or smelting, a process like ones used in the mining industry. But there is a large amount of research taking place to find better ways to recycle lithium-ion batteries, with elemental analysis being a key analytical technique for the process. As battery chemistry changes continually, the recycling process becomes more complicated and the need to identify which elements are present and at what concentrations becomes more important.

Analysis Challenges

Elemental analysis of samples across the battery material supply chain is challenging for ICP-based analytical techniques. Such samples typically have high total dissolved solids (TDS) content and contain easily ionized elements. For example, when analyzing $LiCO_3$ – the presence of many lithium ions in the plasma can affect the measurement of easily ionizable elements such as sodium and potassium, giving erroneous results. Battery material samples also exhibit high background signals and interferences are common. Lithium is also notorious for degrading sample introduction system components, including the plasma torch.

Typical battery component samples have:

- High amounts of dissolved solids

- High concentrations of some elements and low concentrations of others

- Lithium mining samples may contain many different elements

These types of samples are more difficult to measure than drinking water or other common ICP-OES sample types.

Common Analysis Problems and How to Overcome Them

Nebulizer blockages

Battery material samples can contain fine particles that are virtually invisible to human eye. These particles can partially or fully block the small capillary tube at the tip of a glass concentric nebulizer. These blockages lead to many performance problems, which inevitably lead to having to remeasure samples.

Symptoms

A typical symptom of a partial nebulizer blockage is a low recovery for a continuing calibration verification (CCV) standard. It is good laboratory practice to monitor a Quality Control (QC) solution such as a CCV solution periodically throughout an analysis. Typically, a CCV is measured every 20–30 samples, so if it fails you must remeasure all 20–30 samples that were measured before the failed QC. A complete nebulizer blockage results in no signal at all, so is easy to diagnose as all results, including the internal standard, will show low or no emission signal. You can avoid having to remeasure samples due to a nebulizer blockage by monitoring both the CCV results and internal standard results over the course of an analytical run.

Solutions

If you are frequently suffering from nebulizer blockages, consider taking the following actions:

- Filter or centrifuge the samples
- Set the autosampler probe depth above the base of the tube, to minimize the chance for particles on the bottom of the test tube to be drawn into the probe.
- Change the type of nebulizer you are using to one with a larger internal diameter on the sample line that is more resistant to blockage
- Add a switching valve to reduce the time the sample spends in the sample introduction system and increase the rinse time without increasing sample analysis times. This reduces the chance of blockages, and can also reduce the degradation of the torch, extending lifetimes
- Use an argon humidifier to keep the tip of the nebulizer moist; solids are less likely to be deposited on the tip of the nebulizer, reducing blockages
- Adjust the sample preparation to fully digest the fine particles. This could include using a microwave digestion system.

The Agilent 5800 and 5900 ICP-OES instruments have a "Neb alert" function that alerts the analyst when the nebulizer backpressure changes. An increase in pressure can indicate that a blockage is developing, whereas a decrease in pressure may be caused by a leaking connection. When a predefined backpressure threshold is reached, an onscreen alert notifies the analyst of the problem. The run can be automatically stopped so the user can fix the problem before the quality of sample analysis is impacted.

Each type of nebulizer will run at a slightly different backpressure, so the alert threshold can be adjusted to suit the nebulizer type. To get an idea of what "normal' is for the nebulizer being used, the analyst can review the plot of the nebulizer backpressure on the analysis page or use the separate Nebulizer Test function within the Agilent ICP Expert software.

Poor measurement stability

Poor stability is often experienced when measuring samples with high total dissolved solids (TDS) – like those typical of battery component samples.

Symptoms

Measurement stability is important for the accuracy of your measurements. If your instrument is stable, you will get the same result for the same sample measured at different times i.e the results do not 'drift'. If you have a stability problem, you'll usually see different results for a QC sample such as a continuing calibration verification (CCV) standard measured at different points in your sample batch, e.g., every 50 samples. Sometimes the results will trend in one direction, if there is a stability problem e.g., up or down.

If you are using an internal standard, then look at the %RSD on your IS replicates and internal standard ratio for each solution. If the concentration of the IS is sufficient to give a good signal-to-background ratio, and you select a sensitive wavelength for the IS, then the %RSD should be less than 1% for the IS. With good precision on the replicates, the measured internal standard ratio should be within 10% of 1. This result indicates excellent stability.

Agilent offers a one-stop supply of standard solutions, general consumables, and consumables for the whole battery production process. **More >>**

Solutions

Use sample introduction components best suited to high matrix samples: Reducing the sample volume being pumped into the plasma will help improve stability. We recommend:

- Use an Agilent double pass spray chamber, which is well suited to high matrix samples. Agilent offers an inert spray chamber for samples digested with HF, which is also ideal for high matrix samples. The inert spray chamber is more expensive than the standard glass cyclonic spray chamber, but it provides better stability and reduced blockages with high matrix samples, and won't break if dropped during cleaning.

- Use a nebulizer designed for samples with high dissolved solids – the Mira Mist is recommended

- Use smaller diameter peristaltic pump tubing – black/black tubing for the sample and orange/green tubing for the internal standard

- Entrained gasses may bubble out in the nebulizer, causing unreliable results. Use a sample degassing technique e.g. ultrasonication or pre-heating, as part of your sample preparation

- Ensure the temperature of the water cooling system is consistent within ± 1°C. The ambient temperature in the laboratory should also be consistent. This is particularly important when you are measuring elements at very low concentrations (< 1 ppm)

Inaccurate (higher) results for some elements, such as Na and K

Symptoms

The presence of many lithium and other metal ions in the plasma can affect the analysis of easily ionized elements (EIEs), generally the Group I and II elements, such as Na, K, Mg and Ca, leading to falsely high results.
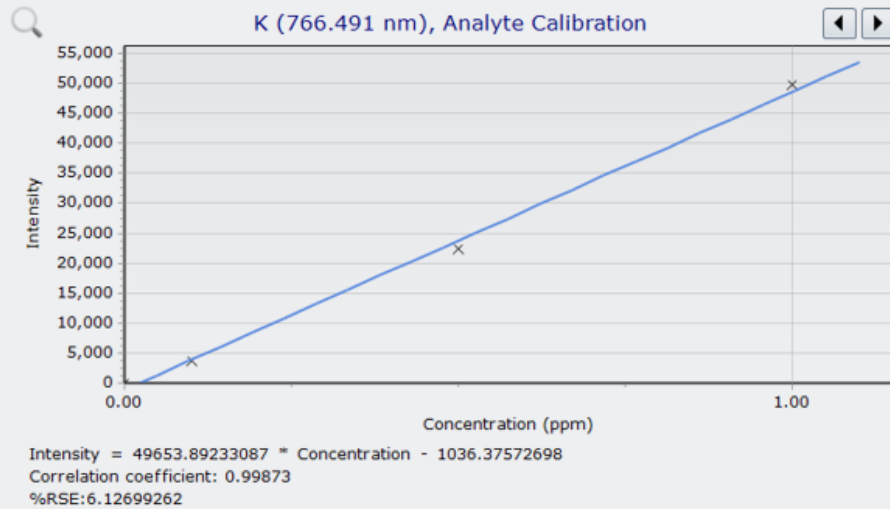
Solutions

To minimize or eliminate the EIE interferences, the following approaches can be used, each has a different level of complexity and cost:

- View the plasma radially. Radial view measurements lack the sensitivity required for the analysis of trace elements, so if the EIE is present in trace concentrations, radial viewing will affect your detection limits.

- The plasma conditions can be optimized during method development to favor the analysis of EIE elements.

- Matrix-matched standards can also be used to create the calibration curve to minimize EIE interferences. However, it can be difficult to obtain standards with the same matrix as that found in battery materials.

- An ionization suppressant such as caesium can also be used, allowing for improved accuracy of the target analyte elements. However, the use of an ionization suppressant can cause changes to emission wavelength and increased wear on sample introduction components.

- The method of standard addition (MSA) is the recommended way to overcome EIE interferences – particularly if using an internal standard is not suitable due to interferences. Standard additions are commonly used to eliminate matrix effects from a measurement, since it is assumed that the matrix affects all solutions equally. Using standard additions as the calibration method also allows Na and K to be measured axially, ensuring that all elements are measured in a single plasma view mode and with the best sensitivity. MSA can be time consuming as it requires the preparation of matrix matched standards to complete analysis.

- An internal standard can be used to correct for variation between the matrix of calibration standards and that of the samples. Using an internal standard removes the need to perform matrix matching when measuring complex samples, which are typical of those in lithium ion battery analysis. When selecting an internal standard, use an element that is not present in the sample, does not have interferences from the elements in the sample and is chemically compatible with the sample. The same concentration of the internal standard should be added to all analytical solutions (blanks, calibration standards, and samples). The simplest way to ensure the same concentration is present during analysis is to add it to the sample stream online with the ICP-OES's peristaltic pump. The emission intensity measured for the internal standard element in the blank solution is compared to the intensity of the internal standard element in the sample. The intensity of the elements you are trying to measure can then be corrected for the influence of the sample matrix, using the ratio of the two internal standard measurements. This is also an effective way to correct for the influence of any EIE elements that may be present.

Worked example of dealing with poor linearity for potassium

K (766.491 nm), Analyte Calibration

Intensity = 49653.89233087 * Concentration - 1036.37572698
Correlation coefficient: 0.99873
%RSE:6.12699262

Problem: The calibration graph for K was not meeting 0.999 linearity requirements, the correlation coefficient was 0.99873. As a multi-element standard solution was being used, this was most likely caused by the 'EIE effect", where easily ionized elements (EIE) impact the readings for K. This was confirmed by comparing the calibration graph for a single element potassium standard to that for a multi-element standard (refer to images below). The single element standard shows a correlation coefficient of 0.99982 and the multielement shows 0.99860.
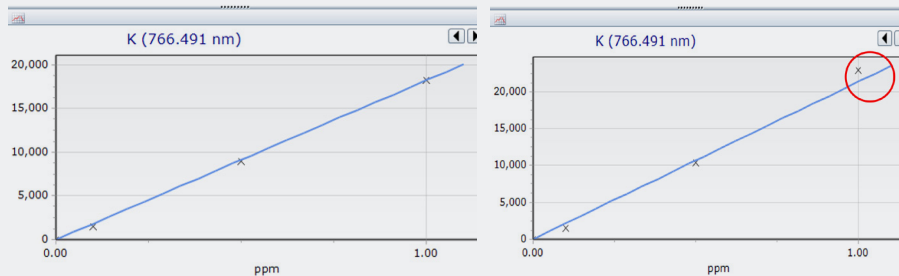
The calibration graph of the multi-element standard (right) is non-linear at the highest concentrations (circled in red), whereas the single element standard (left) is linear at all concentrations.

Solution: Four different ways to overcome the EIE effect were trialled:

– Radial Viewing of the plasma

– Using an Internal Standard (200 ppm Rb)

– Using an Ionization Suppressant (Axial View and 1000 ppm Cs buffer)

– Method Optimization with Axial View (plasma flow 12 L/min, Auxiliary flow 1 L/min, RF power 0.9 kW, nebulizer flow 1.2 L/min,

The results are shown in the table below

Method	Correlation coefficient	Comments
Radial view	0.99973	Good linearity, but low signal-to-root background ratio (SRBR), which negatively impacts the limit of detection.
Internal standard	0.99998	Excellent results and simple to setup, but adds additional cost of the Rb standard to the analysis. Will also improve measurement of other elements (Na and Li) and will produce better quality data for real samples that typically have complex matrices.
Ionization suppressant and Axial view	0.99983	Good linearity, but adds additional cost of the Cs solution to the analysis.
Axial view method optimization	0.99922	Good linearity, but would need to run different settings for different elements e.g. cooler plasma for K and other Group 1 elements, but As, Cd and other elements need hot plasma.

The recommended solution-using an internal standard, is easily automated by using a 'Y' piece to introduce the internal standard solution into the flow of each solution (refer to image). Alternatively, a switching valve, like the Agilent AVS 7 can be used.

Internal standard

Y piece joins flows before nebulizer
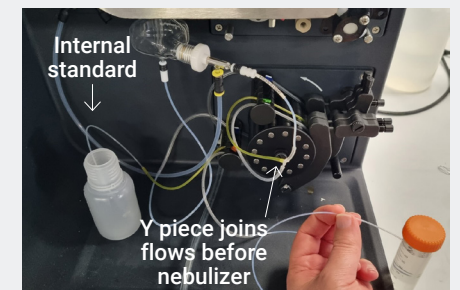
High background signals

Battery material samples often exhibit a high background signal. The matrix can vary from sample-to-sample, making manual selection of background correction points a complex task. A fast, simple, and accurate means of background correction that is independent of the sample matrix is needed.

Symptoms

The complex background signals arising from the matrix of battery materials need to be corrected for when determining the final sample result. In Figure 1, the emission peak (C) is incorrectly high, due to the sloping baseline, caused by strong broadband emissions in the sample matrix – this would result in an inaccurate result that is higher than it actually is in the sample.

Solutions

A baseline correction technique, such as the Agilent Fitted background correction (FBC) technique can be used to remove the effects of the sloping baseline. The Agilent Fitted background correction function not only improves data accuracy, it also improves detection limits and reduces over-correction, which is common when using an off-peak background correction technique.
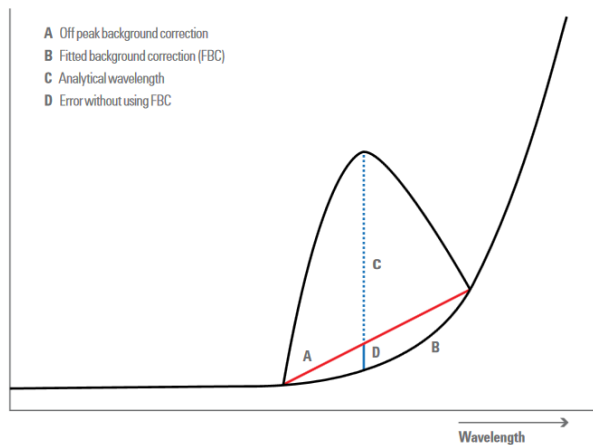

Figure 1. Background correction

Difficulty Placing Background Markers

Battery components often contain varying amounts of different elements. This combination of high levels of some elements with low levels of other elements may cause complex background signals. Background emissions from non-analyte wavelengths may be adjacent to the analyte wavelength you wish to use, which may make it difficult to determine the true background for your analysis and therefore cause errors in your results.

Symptoms

Complex background signals need to be corrected to ensure accurate results. In Figure 2, the emission peak at 213.618 nm for Phosphorus (P) is surrounded by taller peaks from other elements. It is difficult to determine where to place the background peak markers, therefore leading to inaccurate results for P.

Solutions

Use a baseline correction technique, such as Agilent Fitted background correction (FBC), which applies a mathematical algorithm to automatically correct for the background in complex samples. FBC removes the guesswork and error associated with manual placement of background peak markers, improving data accuracy and detection limits.
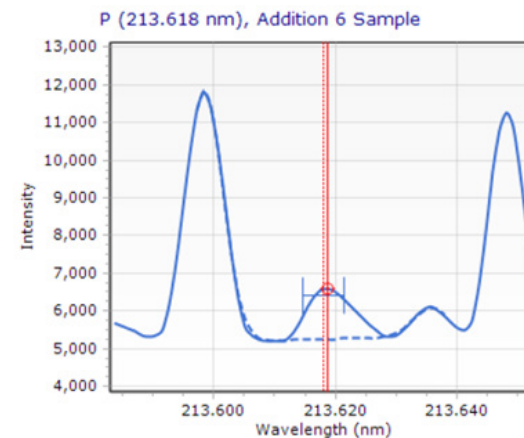

Figure 2. Spectrum of P 213.618 nm in a battery cathode material, with Fitted Background Correction applied, ensuring accurate correction with the complex, sloping background

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Sample introduction components require frequent replacement

Having to frequently replace ICP-OES torches, nebulizers, pump tubing etc is time consuming and expensive. It's important to select the right components for each analysis.

Symptoms

Lithium is notoriously harsh on plasma torches. If you are having to frequently replace the torch, it's likely due to the impacts of lithium in the sample.

If you use hydrofluoric acid to digest samples this will degrade all glass sample introduction components, resulting in a dramatic reduction in performance and requiring premature replacement.

Measuring electrolytes containing organic chemicals can damage conventional pump tubing. As the tubing degrades, it goes hard, stretches, and loses elasticity. You may notice poor result precision, and possibly measurement drift during the analysis as the pumping efficiency of the tubing changes with use.

Solutions

When analyzing lithium, use a fully demountable torch, instead of a one-piece torch. A fully demountable torch will allow you to replace just the damaged components, instead of the whole thing. Fit a radial view outer torch component to the demountable torch. The shorter outer tube will last longer in this situation.

Figure 3. Use a fully demountable torch when analyzing lithium-rich matrices. This makes it easier to replace just the components that are damaged by lithium.

Use an inert sample introduction kit if you are using hydrofluoric acid (HF) for digestions. These are made from HF-resistant materials that ensure high performance and long lifetime of components.

Figure 4. The Agilent inert spray chamber and OneNeb nebulizer are ideal for the analysis of samples digested with HF.

Standard pump tubing is fine for most battery component analyses, but use tubing that tolerates organic chemicals for electrolyte analysis. Agilent solvent flexible tubing (SolvaFlex) is suitable for organic solvents.

Installing a switching valve on the ICP-OES instrument will reduce the time the sample introduction components are in contact with damaging solutions improving component lifetime and reducing costs. A switching valve will also improve sample throughput, by reducing the sample-to-sample time.
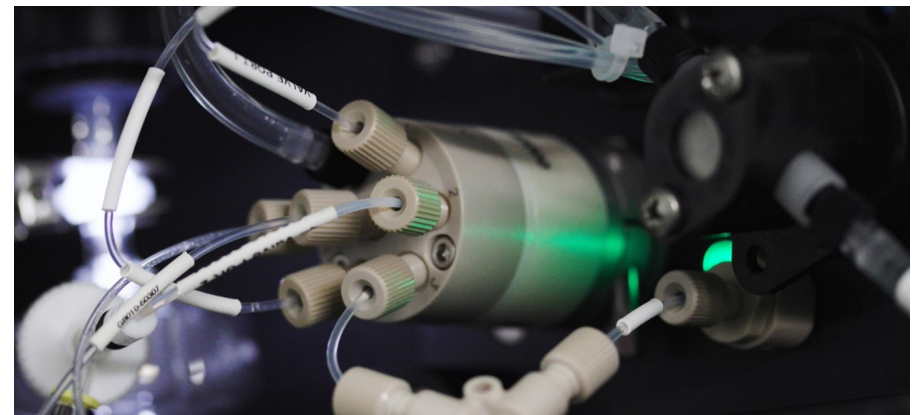

Figure 5. The AVS 7 switching valve reduces the time that sample introduction components are in contact with corrosive solutions.

Poor measurement accuracy

There are several possible causes of inaccurate ICP-OES measurements, including:

- Spectral interferences
- Contamination
- Matrix impacts
- Calibration problems

Symptoms

The wrong results are being reported for elements of known concentration.

Solutions

There are very few certified reference materials (CRMs) available for the lithium battery industry currently. CRMs are representative samples of a particular type e.g. lithium ore, that are supplied with certified concentration values for the elements in the CRM. A CRM is used to check the accuracy of a method, by measuring the CRM in a sample batch and then comparing the results obtained to the certified values. If a CRM is not available that's representative of your sample, then check the accuracy of a method by spiking samples. If you compare a sample with a known amount of an element added (called a spike) to the same sample without the spike, the difference should be the concentration attributable to the spike.

Spectral interferences

In all ICP-OES analysis, one particularly problematic source of errors are unexpected spectral interferences.

Across the UV-Vis wavelength range, there are tens of thousands of elemental emission lines. Sometimes, emissions from different elements in the sample will occur at wavelengths that are close together, as shown in Figure 6.

An element that you either didn't know was there, or is present at a high concentration, might cause an erroneously high result for your analyte of interest if it overlaps on the emission line used for measurement (see Figure 7).

Agilent IntelliQuant Screening is also useful in this situation. You can use it to quickly screen samples to see which elements are in the sample, and in what proportions. You can then adjust your method to choose an alternative wavelength. If an alternative wavelength is not available, interference correction algorithms can be applied to eliminate interferences from spectral overlaps.
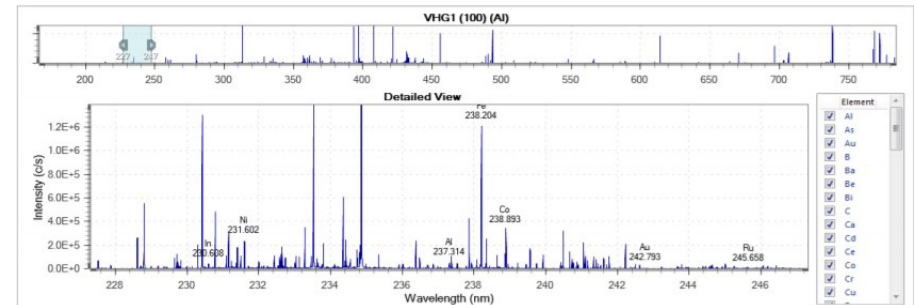

Figure 6. Across the UV-Vis wavelength range (approximately 160 to 450 nm) there are tens of thousands of elemental emission lines. Shown here are the emission lines in just a 25 nm region from 225 nm to 250 nm.
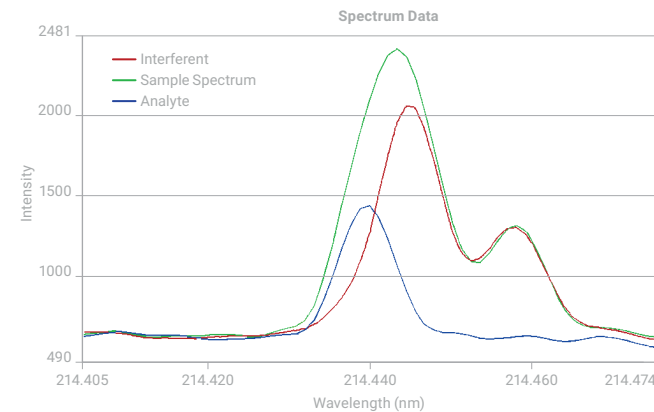

Figure 7. This diagram illustrates how spectral interference occurs. The analyte of interest (shown in blue) has an emission line that is very close to another element (shown in red). The combined signal (shown in green) is measured as the emission for the analyte.

Contamination

Contamination can cause inaccurate results, usually of elements present in very low concentrations. Contamination can be introduced by poor lab practices e.g. not cleaning glassware properly. A previously analyzed sample can also cause contamination due to the carryover of highly adsorptive or "sticky" elements such as boron, molybdenum, or tungsten. These elements stick to the components of the sample introduction system. These situations cause erroneous results in subsequent samples.

Calibration

When measuring battery component samples, calibration can be a major source of result error. Just because your calibration graph is linear doesn't mean your results are accurate. Interactions between elements and other matrix components can impact result accuracy. The simplest approach to improve the calibration accuracy is to use Internal Standardization (ISTD). Refer to the method on page 10 that provides an example of ISTD being used with calibration.

Manual sampling

Presenting each sample to the instrument by hand can introduce errors and reduce productivity. The operator may pick up the wrong sample by mistake or not rinse between samples for long enough. Automating sample presentation using an autosampler will reduce the risk of errors. An autosampler, used in combination with a switching valve will reduce the sample-to-sample time, so you can measure the most samples within a period of time. It also allows you to measure samples without an operator present in front of the instrument, allowing that operator resource to be used elsewhere in laboratory operations.

Metals content in different types of lithium batteries

Type of battery	Metals in battery	Ni content	Co content	Mn content	Li content	Rare Earth
Nickel-metal hydride (NiMH) battery	Ni, Co	35%	4%	1%	–	8%
Lithium cobalt-acid batteries	Li, Co	–	18%	–	2%	–
Lithium iron phosphate battery	Li	–	–	–	1.1%	–
Lithium manganate batteries	Li, Mn	–	–	10.7%	1.4%	–
Ternary batteries	Li, Ni, Mn, Co	12%	5%	7%	1.2%	–

Regulations and Standards for Batteries and Battery Materials

There are several regulatory bodies working on regulations and standards for batteries and battery materials. These bodies include: the IEC, ISO and SAC (China national standards). There are also environment, health and safety regulations that impact battery manufacture, use, and end of life.

Some examples of existing regulations and standards include:

IEC

- IEC/SC21A Secondary cells and batteries containing alkaline or other non-acid electrolytes
- IEC/TC 35 Primary cells and batteries
- IEC/TC21 & TC 69 Secondary cells and batteries
- IEC 62660 Secondary lithium-ion cells for the propulsion of electric road vehicles

ISO

- ISO - ISO/TC 333 – Lithium
- ISO TC22/SC37 Electrically propelled vehicles
- ISO/TC 79 Light metals and their alloys
- ISO/TC 82 Mining
- ISO/TC 188 Small Craft

EU

- Battery regulation (EU) No 2019/1020 (effective on Jan 1, 2022), replacing EU battery directive 2006/66/EC since Jul 1, 2023.
- Hg≤0.1% & Cd≤0.01% (counted in terms of the homogeneous materials) in vehicle battery; Hg≤0.0005% & Cd≤0.002% (Counted in terms of individual cells in other batteries.
- The prohibited/restricted substances in Annex XVII in the REACH regulations.

ISO Standards on Battery Raw Materials Testing

Analytes	Sample Matrix	Standard #	Standard Title	Analysis Technique	Status
Metal ions content	lithium hexafluorophosphate	ISO/WD 10655	Methods for analysis of lithium hexafluorophosphate — Determination of metal ions content by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).	ICP-OES	Working draft (WD) study initiated
Al, B, Ca, Co, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, S and Zn	Lithium carbonate	ISO/AWI 11757	Lithium carbonate — Determination of elemental impurities by ICP-OES	ICP-OES	New project registered in TC/SC work program
Impurities	Lithium chloride	ISO/AWI 16398	Lithium chloride — Determination of impurities — ICP-OES method	ICP-OES	
Impurities	Lithium hydroxide monohydrate	ISO/AWI 16423	Lithium hydroxide monohydrate — Determination of impurities — ICP-OES method	ICP-OES	
Chemical analysis	NMC	ISO/AWI 12467-1	Chemical analysis of lithium composite oxides — Part 1: Determination of main components		
Impurities	Lithium carbonate	ISO/AWI 12386	Lithium carbonate — Determination of metallic magnetic impurities by ICP-OES	ICP-OES	

China Standards on Li Batteries Materials

China currently has the most extensive list of standard methods for lithium batteries, as shown in the table below.

Samples	Specification	Standard #	Standard Title	Analysis Technique
Graphite negative electrode materials	Fe, Na, Cr, Cu, Ni, Al, Mo, S (<5~50ppm); magnetic substance (Fe+Cr+Ni+Zn+Co) < 0.1 ppm; Cd, Pb, Hg, Cr^{VI}, PBB, PBDE (<5ppm for each); F-. Cl-, Br-, NO_3^-, SO_4^{2-} (<10~50 ppm); Acetone, Isopropanol, toluene, ethylbenzene, xylene, benzene, ethanol (<1ppm for each)	GB/T 24533-2019	Graphite negative electrode materials for lithium ion battery	ICP-OES for Fe, Na, Cr, Cu, Ni, Al, Mo, Co, Zn, S and magnetic substance (Fe+Co+Cr+Ni+Zn); ICP, AAS, ICP-MS for Cd, Pb, Hg; GC-MS for PBB, PBDE; UV for Cr6+; GC, GC-MS for VOCs; IC or anion.
Lithium titanium oxide & its carbon composite anode materials	Li, Fe, Magnetic material (Fe+Cr+Ni), Cd, Pb, Hg, Cr^{6+}, Cl-, SO_4^{2-}	GB/T 30836-2014	Lithium titanium oxide and its carbon composite anode materials for lithium ion battery	ICP-OES, for Li, Fe; ICP-OES,AAS or ICP-MS for Cd, Pb, Hg; UV for Cr^{6+}
Lithium iron phosphate-carbon composite cathode materials	Li, Fe, P, Fe ion dissolution rate; Cd, Pb, Hg, Cr^{6+}	GB/T 30835-2014	Lithium iron phosphate-carbon composite cathode materials for lithium ion battery	ICP-OES, for Li, Fe ion dissolution rate; ICP-OES, AAS or ICP-MS for Cd, Pb; CVAAS for Hg; UV for Cr^{6+}
Lithium hexafluorophosphate	Al, Fe, K, Ca, Cd, Cr, Cu, Hg, Mg, Ni, Pb, Zn, As, Cl ≤1ppm for each; Na ≤2 ppm; SO_2 ≤5 ppm	HG/T 4067-2015	Cell liquor of lithium hexafluorophosphate	ICP-OES for metals.
Lithium hydroxide monohydrate	Na, K, Fe, Ca, Cu, Mg, Mn, Si, B, Cl-, SO_4^{2-}, CO_3^{2-}	GB/T26008-2020	Battery grade lithium hydroxide monohydrate	ICP-OES for Na, K, Fe, Ca, Cu, Mg, Mn, B; UV/Vis for Si, Cl-, SO_4^{2-}, CO_3^{2-}
Nickel cobalt manganese composite hydroxide	Ni, Co, Mn, Ca, Cu, Fe, Mn, Na, Zn, Pb, Al, SO_4^{2-}	GB/T 26300-2020	Nickel cobalt manganese composite hydroxide	ICP for Ni, Co, Mn, Fe, Ca, Mg, Cu, Zn. Al. Na; As for Ni+Co+Mn, Pb & SO_4^{2-}, use the method which agreed by both the buyer and seller
Lithium cobalt oxide	Co, Li, K, Na, Ca, Fe, Cu, Cr, Cd, Pb	GB/T 20252-2014	Lithium cobalt oxide	ICP-OES (follow up GB/T 23367)
Lithium nickel oxide	Ni, Co, Li, K, Fe, Na, Ca, Cu, Cr	GB/T 26031-2010	Lithium nickel oxide	Use the method which agreed by both the buyer and seller
Lithium carbonate	Na, Fe, Ca, Mg, Cl-, SO_4^{2-}	GB/T 11075-2013	Lithium carbonate	Follow up GB/T11064
Lithium nickel cobalt manganese oxide	Ni, Co, Mn, Li, Na, Mg, Ca, Fe, Zn, Cu, Si, Cl-, SO_4^{2-}	YS/T 798-2012	Lithium nickel cobalt manganese oxide	Use the method which agreed by both the buyer and seller
Lithium manganese oxide	Mn, Li, K, Na, Ca, Fe, Cu, S, magnetic substance	YS/T 677-2016	Lithium manganese oxide	Use the method which agreed by both the buyer and seller
Lithium carbonate	Na, Mg, Ca, K, Fe, Zn, Cu, Pb, Si, Al, Mn, Ni, Cl-, SO_4^{2-}	YS/T 582-2013	Battery grade lithium carbonate	Follow up GB/T11064 for product compositions; follow up IEC62321 for hazard substances; ICP-OES for magnetic substance
Lithium chloride	Na, K, Ca, Fe, Ba, Mg, Cu, SO_4^{2-}	YS/T 744-2010	Battery grade anhydrous lithium chloride	Follow up GB/T11064, or Use the method which agreed by both the buyer and seller
Lithium dihydrogen phosphate	Na, K, Ca, Fe, Pb, Cl-, SO_4^{2-}	YS/T 967-2014	Battery grade lithium dihydrogen phosphate	Use the method which agreed by both the buyer and seller
Lithium oxide	Li_2CO_3, Ca, Na, Mg, Cu, Cr, Si, Zn, Ni, Fe	YS/T 968-2014	Battery grade lithium oxide	Use the supplier's method. For arbitration, use the method agreed by both the buyer & seller.
Lithium fluoride	Na, K, Ca, Mg, Fe, Al, Pb, Ni, Cu, Si, Cl-, SO_4^{2-}	YS/T 661-2016	Battery grade lithium fluoride	Follow up GB/T 22660
Pollutant emission	15 specs for wastewater; 12 specs for air	GB 30484-2013	Emission standard of pollutants for battery industry	ICP-OES, ICP-MS, FAAS, GFAA, GC, UV/Vis, IC

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