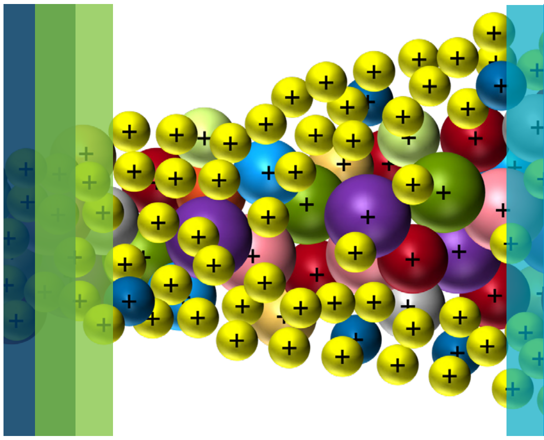

Controlling Space Charge Effects

Agilent ICP-MS technology brief

Where and why space charge occurs

Space charge is a fundamental property of ion beams. In ICP-MS, space charge occurs after the ion beam is extracted into the high vacuum region. As the pressure drops, the ion beam density decreases and the charged particles become more mobile.

Electrons are much lighter and more mobile than ions and are repelled by the (usually) negative ion lens voltages, so the electrons quickly diffuse out of the ion beam (charge separation, Figure 1, top). The positively charged ions that remain repel each other, leading to beam dispersion. Light ions are deflected to the edge of the ion beam, leaving heavier ions in the center (Figure 1, bottom).

Effect on ICP-MS analysis

Mass dependent beam defocusing reduces transmission of light ions. This mass bias effect, leads to lower sensitivity and poorer detection limits for light elements, Li, Be, B, etc.

Controlling space charge in ICP-MS

Space charge is less severe with fewer ions, so sampling the ions from a region of the plasma where the ion density is lower helps control space charge. Using smaller interface cone orifices further reduces the ion density.

A well-designed ion lens also helps control mass bias by focusing a higher proportion of the light ions. This gives a more uniform mass response than a poorly designed lens.

Principles of ion extraction and focusing

Typically, ICP-MS uses a quadrupole mass filter and an electron multiplier (EM) detector to measure positively charged ions. The mass filter and detector require a very low pressure, so the ions must be extracted from the (atmospheric pressure) plasma and focused into a high vacuum region for measurement. Ions are extracted from the plasma via a series of interface cones, then focused using metal plates with voltages applied – ion lenses.

In the high vacuum region, the electrons diffuse out of the ion beam leaving the positive ions. The ions repel each other causing "space charge". Light ions have less kinetic energy (KE) than heavy ions, so the light ions are deflected to the edge of the ion beam, reducing transmission of low masses (mass bias).

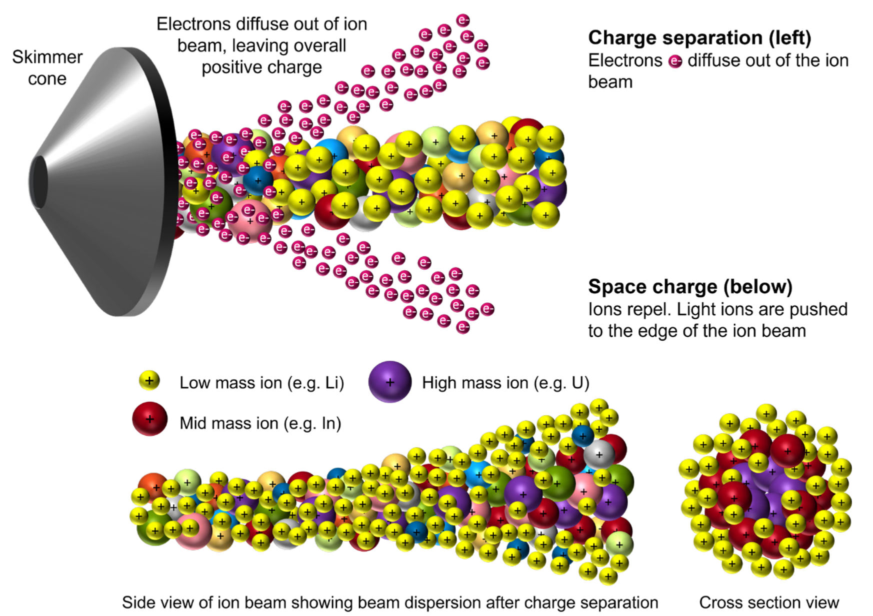

Figure 1. Top: Charge separation. The highly mobile electrons leave the ion beam. Bottom: Space charge. Ions repel each other leading to beam dispersion, defocusing, and mass bias.

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Analytical impact of mass bias

ICP-MS is a multielement technique used to measure elements from Li (*m/z* 7) to U (*m/z* 238) and sometimes beyond. This means the interface and ion lenses must be designed to efficiently focus ions with widely varying masses. As we have seen, it is much more difficult to focus light (low mass) ions than heavy ions, because light ions are easily deflected and defocused away from the center of the ion beam.

This becomes apparent when you consider that ICP-MS concentrations are usually expressed in terms of wt/vol or wt/wt, so the number of atoms (= counts) should be much higher for a light element than a heavy element. For example, 1 ng of Li (atomic weight 6.941) contains about 34 times as many atoms as 1 ng of U (atomic weight 238). If ion transmission was equal for all masses, Li should give 34 times as many counts per ppb as U.

The theoretical ICP-MS mass response for equal transmission of all masses is shown in Figure 2 (top). In reality, ICP-MS mass response curves look more like the inset plot in red, with lower transmission for light elements. This difference is largely due to the impact of space charge and it significantly degrades the detection limits (DLs) that can be achieved for low mass analytes on some ICP-MS systems.

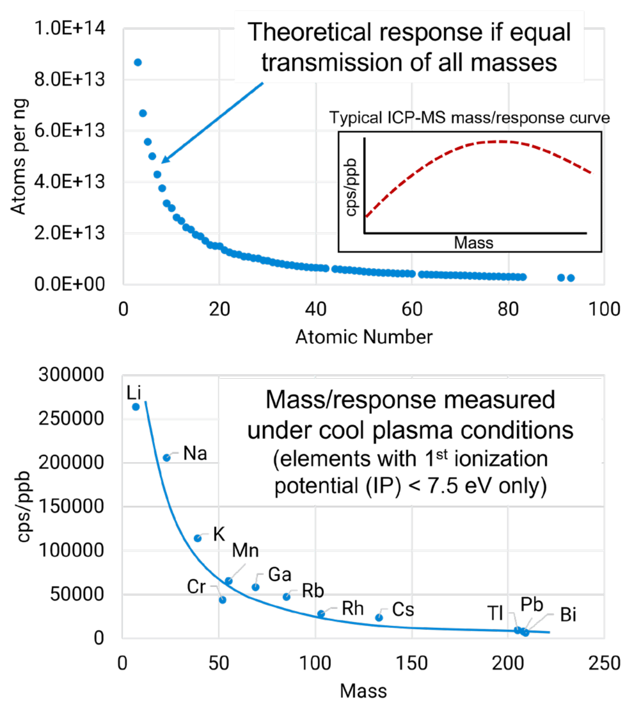

Figure 2. Top: Mass response if equal transmission for all masses. Inset. Typical ICP-MS mass response. Bottom: Mass response measured in cool plasma conditions (easily ionized elements (1st IP <7.5 eV) only, corrected for isotopic abundance)

Space charge can be practically eliminated by using cool plasma conditions. The low power plasma cannot ionize the major background species (Ar, N, O, N_2, NO, O_2, etc.) so the number of ions in the extracted ion beam is much lower. This gives a mass response (Figure 2, bottom) close to the theoretical response for equal transmission.

Cool plasma is not suitable for high matrix applications and gives lower ionization for high 1st IP analytes. So, Agilent ICP-MS systems control mass bias by using an optimized geometry for the interface and ion lens. The aim is to achieve high transmission and consistent, low detection limits for analytes across the mass range.

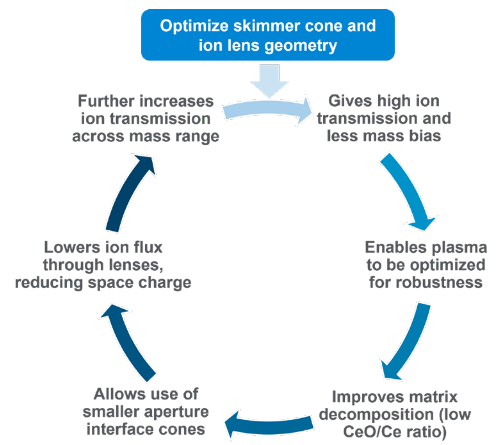

Figure 3. The optimized skimmer cone and ion lens geometry of Agilent ICP-MS instruments allows system development for higher overall performance.

Agilent ICP-MS works together

Controlling space charge and minimizing mass bias leads to further performance benefits, shown in Figure 3. An optimum geometry interface and ion lens gives high ion transmission, so the plasma can be optimized for robustness, which allows smaller interface cone orifices to be used. A robust plasma and small cone orifices lead to lower ion beam density, reducing space charge and further increasing ion transmission. The result is improved sensitivity and DLs, particularly for light elements.

Learn more:

www.agilent.com/chem/icpms

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