

Agilent 7000/7010 Series Triple Quadrupole GC/MS System

Concepts Guide



Notices

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Software Revision

This guide applies to the Agilent Mass-Hunter Workstation Software -- Data Acquisition for 7000/7010 Series Triple Quadrupole program version B.03.00 or higher until superseded.

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In This Guide...

The Concepts Guide presents “The Big Picture” behind the operation of the Agilent 7000/7010 Series Triple Quadrupole GC/MS Systems by helping you understand how the hardware and software work.

1 “Overview”

Learn how 7000/7010 Series Triple Quads help you do your job.

2 “Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS”

Learn the concepts you need to understand how 7000/7010 Series Triple Quads work.

3 “Triple Quad and Sensitivity”

Learn how 7000/7010 Series Triple Quads achieve high sensitivity.

4 “Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad”

Learn concepts behind the design of the Agilent MassHunter Workstation Software – Instrument Control for Triple Quadrupole program.

Contents

In This Guide... 3

1 Overview

System Description	8
Help for applications	8
Help for acquisition	9
Help for data analysis	11

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

Single Quadrupole MS Operation	14
Design for a single quadrupole mass spectrometer	14
How a single quadrupole mass spectrometer works	15
Triple Quadrupole MS Operation	20
Design of the 7000/7010 Series Triple Quads	20
Innovative enhancements in the 7000/7010 Series Triple Quads	21
How a triple quadrupole mass spectrometer works	22

3 Triple Quad and Sensitivity

How the 7000/7010 Series Triple Quads Improve Sensitivity	26
Sensitivity	26
Chemical noise reduction with MRM	28
Sensitivity and reproducibility of the 7000/7010 Series Triple Quads	30
How Each Component Works to Improve Sensitivity	35
GC capillary flow backflush technology	35
Ion sources	35
Electron impact ion sources	35
Chemical ionization ion source	37
Quad mass filters	38

	Pre- and post-filters	38
	Collision cell	39
	Detector	43
	Pumping system	44
4	Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad	
	Description	46
	Tuning	47
	Acquisition	48

1

Overview

System Description	8
Help for applications	8
Help for acquisition	9
Help for data analysis	11

This chapter provides an overview of the Agilent 7000/7010 Series Triple Quadrupole GC/MS components and how they help get the job done.

System Description

An Agilent 7000/7010 Series Triple Quadrupole MS is a standalone triple quadrupole mass spectrometer for use with the Agilent 8890, 9000, and 7890 gas chromatographs. The 7000/7010 Series Triple Quads feature:

- One split flow turbomolecular vacuum pump
- Rotary vane or optional dry scroll foreline pump
- Independently MS-heated electron-ionization ion source
- Two independently MS-heated hyperbolic quadrupole mass filters
- Single hexapole collision cell
- High-energy dynode (HED) electron multiplier detector
- Independently GC-heated GC/MS interface

This configuration has advantages for many applications. The data is interpreted through the use of the MassHunter Workstation software, which provides quantitative and qualitative analyses of the data obtained.

The 7000/7010 Series Triple Quads are the only triple quadrupole GC/MS combinations that incorporate a hexapole collision cell, blanketed with a combination of nitrogen and helium gas, to improve the ion fragmentation prior to final filtration, detection, and quantification.

Help for applications

The 7000/7010 Series Triple Quad GC/MS combinations can quantify trace organic compounds in complex matrices. The following applications use this type of quantification:

- Food safety studies
- Environmental studies
- Drug discovery
- Toxicology
- Forensics

1 Overview

Help for acquisition

Paired with Agilent 8890, 9000, or 7890 GCs, the 7000/7010 Series Triple Quads deliver sensitive, reproducible analyses of target compounds in complex matrices. This provides the following:

- Femtogram-level limits of detection and quantification
- Selective quantification of target compounds in high chemical background samples
- Improved signal-to-noise ratios (S/N) in complex matrices
- Ability to meet stricter regulations regarding sample analytical limits for certain applications
- Simplified operation with Agilent's instrument control and data analysis software

The 7000/7010 Series Triple Quads offer the high sensitivity in GC/MS/MS analyses that is required by many commercial and regulatory applications.

Help for acquisition

The MassHunter Workstation Instrument Control software allows you to perform the following tasks from a single window:

Prepare the instrument

- Start and stop the instruments from the software
- Download settings to the GC and the Triple Quad in real time to control the instrument
- Optimize MS parameters automatically or manually through Agilent tuning programs and print an Autotune report
- Monitor the actual conditions of the instrument
- View the real-time plot for chromatograms and instrument parameters (both GC and MS) and print a real-time plot report
- View the centroid line spectrum of a peak or the mass range profile spectrum of a peak in real time

Set up acquisition methods

- Enter and save parameter values for the GC and the Triple Quad to an acquisition method
- Select and label the total ion chromatograms or extracted ion chromatograms that you want to appear in the real-time plot
- Set up time segments for each scan type and analysis where parameters change with the time segment or with the scans within the time segment
- Print an acquisition method report

Acquire data

- Enter sample information and pre- or post-programs (scripts) and run single samples interactively
- Enter and automatically run both individual samples and samples organized in a sequence of samples
- Set up pre- and post-scripts to run between samples in a sequence
- Set up and run a sequence to optimize MS acquisition parameters
- Print a sequence report
- View system events, including start and stop times, run events, and errors
- Print an event log report

To learn how to get started with the Agilent Triple Quadrupole GC/MS, see the *7000/7010 Series Triple Quad GC/MS Quick Start Guide*.

To learn more about how to use the Agilent Triple Quadrupole GC/MS with real samples and data, see the *7000/7010 Series Triple Quad GC/MS Familiarization Guide*.

To learn how to do individual tasks with the GC/MS, see the online help.

To learn more about your Agilent GC, see the Agilent user documentation for your specific GC model.

Help for data analysis

Quantitative analysis program

Agilent has designed the quantitative analysis program to help quantify very low amounts of material. The program has the following unique features:

- Imports information directly from the acquisition method
- Provides a curve-fit assistant to test all fits and statistics on curve quality
- Integrates with an automated, parameter-free integrator that uses a novel algorithm, optimized for triple quadrupole data
- Presents a batch results window to help you review and operate on an entire batch of data at once
- Automatically detects outliers
- Provides preconfigured templates for basic reporting and provides the capability to create custom reports in Microsoft Excel

Please refer to the *Agilent MassHunter Workstation Software – Quantitative Analysis Familiarization Guide* or the online help for the quantitative analysis program.

Qualitative analysis program

For fast method development, this software is used to quickly review the qualitative aspects of the data, such as the optimum precursor to product ion transitions.

Agilent designed the qualitative analysis program to present large amounts of data for review in one central location. With the program you can do these operations for any type of mass spectrometer data that you open:

- Extract chromatograms
- View and extract peak spectra
- Subtract background
- Integrate the chromatogram
- Find compounds

You can also set up methods to automatically do the tasks in the list, as well as others, when you open the data files.

Refer to the *Agilent MassHunter Workstation Software – Qualitative Analysis Familiarization Guide* or the online Help for the qualitative analysis program.

1 Overview

Help for data analysis

2

Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

Single Quadrupole MS Operation	14
Design for a single quadrupole mass spectrometer	14
How a single quadrupole mass spectrometer works	15
Triple Quadrupole MS Operation	20
Design of the 7000/7010 Series Triple Quads	20
Innovative enhancements in the 7000/7010 Series Triple Quads	21
How a triple quadrupole mass spectrometer works	22

This chapter explains the inner workings of the 7000/7010 Series Triple Quads. The foundation for understanding the operation of a triple quadrupole mass spectrometer is the operation of a single quadrupole mass spectrometer. Therefore, an explanation of the workings of a single quadrupole mass spectrometer is presented first.

Single Quadrupole MS Operation

This section first reviews the fundamental aspects of the single quadrupole mass spectrometer. Understanding the operation of a single quadrupole mass spectrometer provides insight into the specific features of 7000/7010 Series Triple Quads.

Design for a single quadrupole mass spectrometer

Mass spectrometry is based on the analysis of ions moving through a vacuum.

The ionization of a sample occurs in the ion source that is shown, schematically, on the left in **Figure 1**. In this case, the source used is an electron impact ionization source, which ionizes the sample with a charged filament.

The ions are analyzed by a mass analyzer (mass filter) that controls the motion of the ions as they travel to the detector to be converted into actual signals.

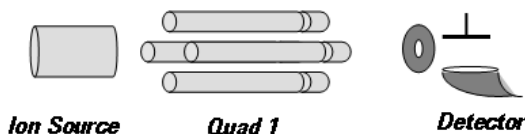


Figure 1. Schematic for single quadrupole mass spectrometer

The quadrupole mass analyzers consist of four parallel rods to which specific DC (direct current) and RF (radio frequency) voltages are applied. These rods filter out all ions except those of one or more particular mass-to-charge (m/z).

The RF is applied to all four rods, but the negative (–) rods are 180 degrees out of phase with the positive (+) rods. The rods are labeled + and – in reference to the DC voltages applied to them.

All ions that comprise the sample are generated at the source. However, when a specific set of voltages is applied, only ions of the corresponding m/z value may pass through the quadrupole to reach the detector. As the voltages are altered, ions with other m/z values are allowed to pass through. A full MS scan is obtained by increasing the DC and RF voltages applied to the four rods over an expanded range of values.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a single quadrupole mass spectrometer works

How a single quadrupole mass spectrometer works

A conceptual model can be used to explain the theory of a single quadrupole mass spectrometer. See **Figure 2**.

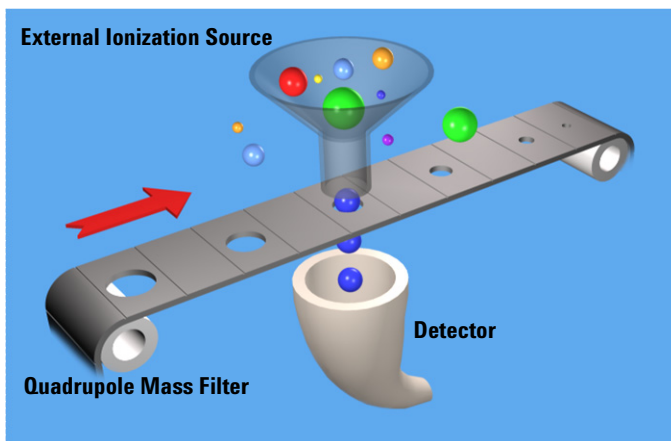


Figure 2. Conceptual model of a single quadrupole mass spectrometer

In the model:

- All of the ions contained in a sample are formed in the external ionization source and collected in a funnel. The balls of different colors and sizes represent different ions having different m/z values.
- The quadrupole mass analyzer is represented by a moving belt that serves to filter the ions as they pass through openings of various sizes. The ions pass from the funnel, through the filter, to the detector.
- The detector is represented by the collecting funnel below the filtering belt.

As the belt (the analyzer) moves, or the voltages on the rods are changed, ions with different m/z values are filtered through the mass spectrometer.

As the analyzer moves from a small m/z value to increasingly larger values, a full MS scan is created.

If the belt does not move, the detector continues to monitor the same single m/z value over the entire scan period. This type of analysis is known as selected ion monitoring, or SIM. It is the most sensitive operating mode for a single quadrupole mass spectrometer.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a single quadrupole mass spectrometer works

The scan period is selected (fixed) by the user. The user may set the dwell time to scan a specific mass range (for example, m/z 50 to 1,000) or to remain on one selected ion (SIM) or to move to several selected ions during the scan period. The quadrupole mass filter is not scanned over a range in the SIM mode. The required RF and DC voltages are set to filter a single mass for a specified time before moving to the setting for the next SIM.

Single quadrupole: SIM

To obtain the best sensitivity or quantitative measurement, the single quadrupole is operated in SIM mode (**Figure 3**). The duty cycle is the measure of the instrument's time actually devoted to measuring signals. In SIM mode, the single quadrupole analyzes the signal of a specific m/z ion almost all of the time. This results in nearly 100 percent acquisition during the duty cycle.

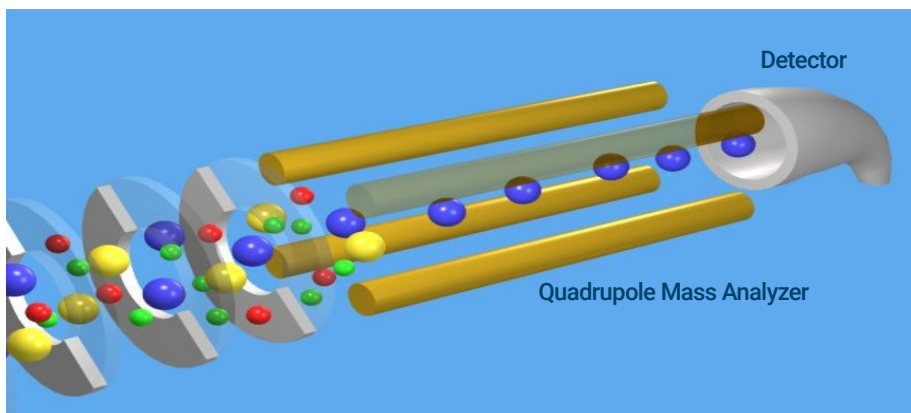


Figure 3. Single quadrupole: SIM

In this example:

- 1 All of the ions (+, -, and neutrals) are formed in the ionization source. The Agilent ion sources consist of a series of lenses and a repeller assembly that directs the ion beam into the analyzer.
- 2 Ion optics guide the ions to the quadrupole mass analyzer.
- 3 In the analyzer, only ions of a particular m/z value, represented in **Figure 3** by blue balls, are allowed to pass through to the detector.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a single quadrupole mass spectrometer works

- 4 The detector generates an electrical signal proportional to the number of ions reaching it..

This system has several advantages:

- Provides the best sensitivity for quantitation
- Increases selectivity
- Improves chromatographic specificity

Single quadrupole: full MS scan

In a full MS scan, the quadrupole serves as a mass filter over time, and a scan is carried out by stepping through increasing DC and RF voltages. This provides filtering through the corresponding m/z values across a mass spectrum. See **Figure 4**.

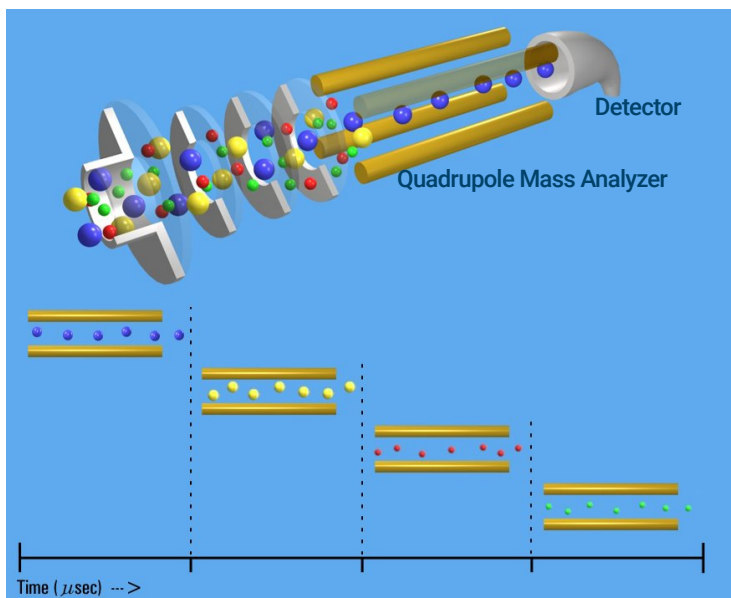


Figure 4. Single quadrupole: full scan MS

The full scan MS mode is less sensitive because the duty cycle for each m/z value is considerably less than 100 percent. The quadrupole mass analyzer scans sequentially, passing each m/z value in the selected mass range to the detector.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a single quadrupole mass spectrometer works

A full scan MS is still a useful mode of operation because it shows all of the ions that are being formed in the ion source. This alerts analysts to other compounds co-eluting with compounds of interest, and is helpful information for developing SIM acquisitions.

What about fragment ions?

Full scans with a single quadrupole instrument can also be used to study fragment ions. See **Figure 5**.

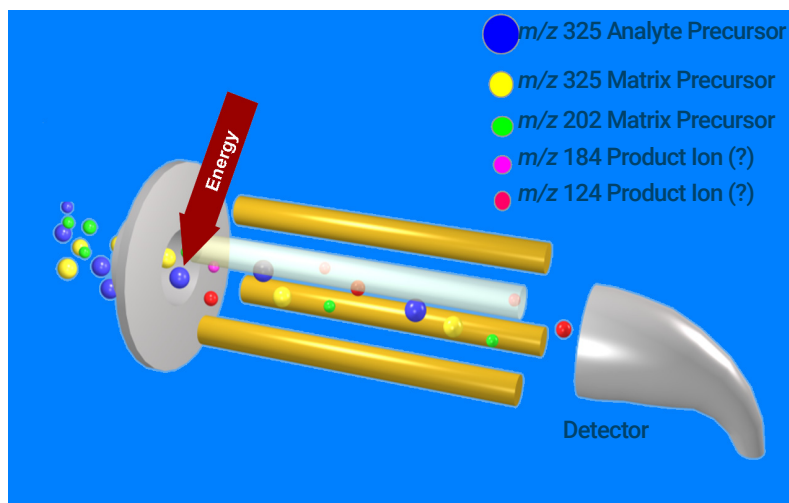


Figure 5. Fragment ions with single quadrupole MS

The diagram shows that fragment ions, also known as product ions, are formed by fragmenting or breaking apart precursor ions. Precursor ions formed in the ion source travel through the mass analyzer without change, unless extra energy is applied to their motion in a region where fragmentation can occur. If the ions run into gas molecules and the translational energy is high enough, these collisions convert the translational energy into molecular vibrations that can cause the ions to fragment. This is called collision-induced dissociation (CID).

Fragmentation, or CID, can be carried out in a low-pressure region between the ion source and the mass analyzer. The outlet of the ion source is under vacuum, which is created by a two-stage vacuum pump. On the Agilent single quadrupole mass spectrometer, the region between the ion source and the quadrupole exhibits a gas pressure of about 10 to 20×10^{-5} Torr, which is well below atmosphere pressure (760 Torr). Under normal operation, a voltage is applied

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a single quadrupole mass spectrometer works

across this region to keep the ions passing through to continue on to the mass analyzer. Even if these ions collide with the gas molecules in this region, they usually do not have enough energy to fragment.

However, as the voltage is increased, the ions have more translational energy. Then, if the ions run into gas molecules (**Figure 6**), CID can occur. Even though this fragmentation does not occur where the ions are formed, this type of fragmentation is still referenced as “in-source CID.”

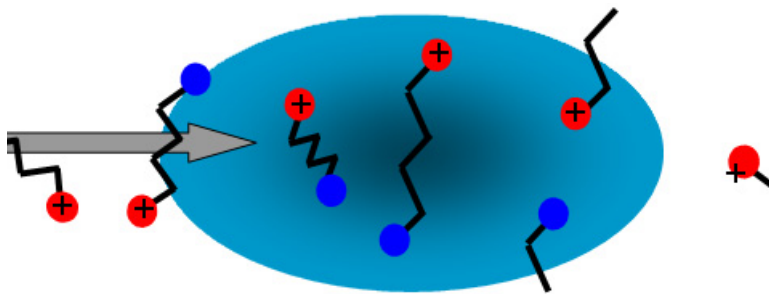


Figure 6. Ion fragmentation caused by collision-induced dissociation

A triple quadrupole mass spectrometer can do MS/MS, with fragmentation within its collision cell as described in the next section.

Triple Quadrupole MS Operation

The previous section regarding the operation of the single quadrupole mass spectrometer helps to clarify the principles of the triple quadrupole mass spectrometer.

Design of the 7000/7010 Series Triple Quads

The triple quadrupole mass spectrometer consists of an ion source, followed by ion optics that transfer the ions to the first quadrupole. A diagram of the current 7000/7010 Series Triple Quads is shown in **Figure 7**.

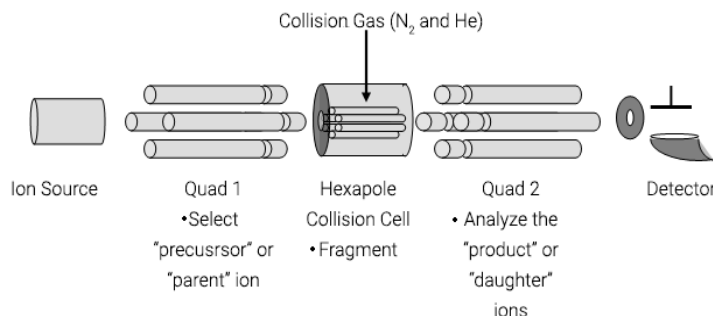


Figure 7. 7000/7010 Series Triple Quad basic components

As in the single quadrupole MS, the analyzers consist of four parallel hyperbolic rods through which selected ions are filtered. After passing through the first quad, the filtered ions then enter a collision cell where they are fragmented. The collision cell is typically called the second quadrupole, but in this case, geometrically it is actually a hexapole filled with a combination of nitrogen and helium.

The product ions formed in the collision cell are then sent to the third quadrupole for a second filtering stage to enable isolation and examination of multiple precursor to product ion transitions.

Innovative enhancements in the 7000/7010 Series Triple Quads

Ions enter the MS from the GC. One of several enhancements to Agilent 7000/7010 Series Triple Quadrupole GC/MS systems is the backflush technology that can be found in many Agilent GCs. Backflush technology minimizes column bleed and provides better sample splitting. This results in less sample dilution at low flows and a reduction in chemical noise with the elimination of ghost peaks in the data.

After separation in the GC, the sample components are transferred to an ionization source where ions are generated. The available electron impact (EI) ion sources contain dual filaments, which can be tuned separately and selected for use based upon their performance. The dual filament design allows the user to continue running with one filament even if the other needs to be replaced or cleaned.

Once the sample is ionized, a repeller directs the ions through a set of lenses and into the first quadrupole analyzer, where they are filtered based on their mass-to-charge ratio.

The ions passing through the first quadrupole analyzer are directed into an improved collision cell, where they are fragmented. In the 7000/7010 Series Triple Quads, the addition of a post-filter focuses the ion beam exiting the first quadrupole, which ensures effective concentration of the ions.

The collision cell is actually a hexapole filled with a nitrogen and helium combination gas stream. The innovative collision cell design features axial acceleration for high-speed MS/MS analysis. The use of helium as a quench gas in the collision cell reduces noise from helium neutrals as well as enhances the efficiency of the fragmentation process. The addition of helium to the collision cell gas stream provides stabilization to high-mass ions, allows more control over the fragmentation process, and reduces neutral noise in the data.

Fragment ions formed in the collision cell are then sent through a prefilter, prior to the third quadrupole. Similar to the post-filter on the first analyzer, the prefilter focuses the ion beam into the quad. The third quadrupole provides a second filtering stage.

Finally, the ions that pass through the third quadrupole are detected using a high-energy detector. Additional improvement in sensitivity is achieved in the 7000/7010 Series Triple Quads through the triple axis high-energy dynode (HED). The HED uses an off-axis configuration that pulls the charged ions away from the neutrals, allowing the neutrals to be eliminated by the turbo pump.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a triple quadrupole mass spectrometer works

The split flow high-performance turbo pump provides vacuum and efficiently eliminates carrier gas and un-ionized material to allow for accurate product quantification.

Once through the HED, the ions are quantitated by an electron multiplier detector. Gain normalized tuning of this detector provides consistent sensitivity over the life of the electron multiplier.

How a triple quadrupole mass spectrometer works

Triple quadrupoles provide the potential for MS/MS in several ways (see **Figure 8**).

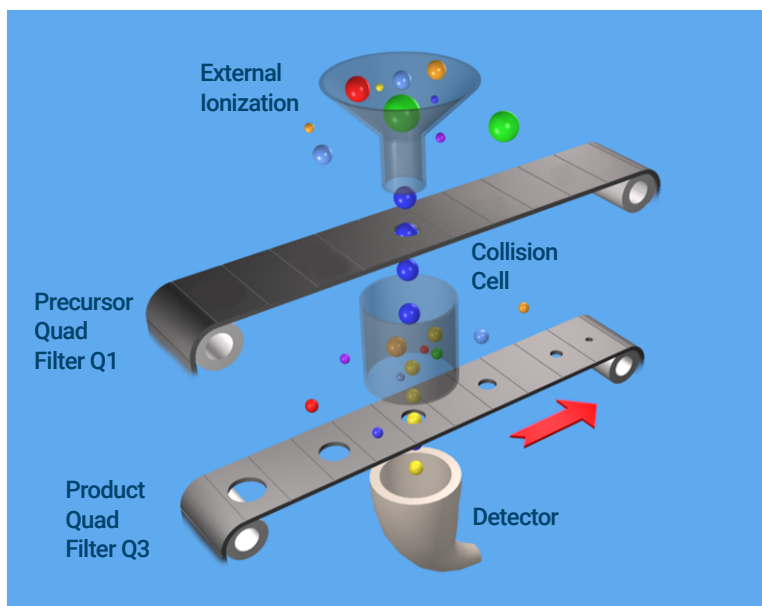


Figure 8. Conceptual model of a triple quadrupole mass spectrometer: With MS1 (Q1) in SIM mode passing a single precursor m/z and MS2 (Q3) in scan mode to analyze the product ions.

Representing the quadrupole mass analyzers as moving belts, a collision cell can be placed between the belts to fragment the ions. The first belt can be fixed to select which precursor ion travels to the collision cell. Different types of collision cells can be used.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a triple quadrupole mass spectrometer works

The cell can be another quadrupole, a hexapole (six rods like the one used in the 7000/7010 Series Triple Quads), an octopole (eight rods), or even a transverse wave guide.

Whichever geometry is used, an inert, nonreactive gas is required for use as the collision gas. In addition, the voltages applied to the collision cell must be different from those applied to the quadrupoles to accelerate the movement of all of the ions so that their collision energy is sufficient to cause fragmentation.

In the example shown in **Figure 8** on page 22, a precursor ion is selected using the first quadrupole and is sent to the collision cell for fragmentation. The fragments are then scanned through the third quadrupole, resulting in a product-ion scan MS/MS. Since the fragment ions are pieces of the precursor, they represent portions of the overall structure of the precursor molecule. They are selected by the third quadrupole according to their m/z ratio in the same way the precursor ions are chosen by the first quadrupole. In this manner, a triple quad provides enhanced selectivity for accurate target compound analysis.

Full scan MS/MS (first belt remains steady, second belt moves) using a triple quadrupole MS is not the most sensitive mode for the same reason that a full scan MS using a single quadrupole is not the most sensitive mode. The most sensitive mode of operation for the triple quadrupole MS instrument is to fix both belts and only monitor a specific precursor ion and a specific product ion. This mode is called selected reaction monitoring or SRM.

In normal operation, a triple quadrupole MS instrument involves running multiple SRMs for the same precursor ions. This is called multiple reaction monitoring or MRM.

2 Inner Workings – Triple Quadrupole MS vs. Single Quadrupole MS

How a triple quadrupole mass spectrometer works

3

Triple Quad and Sensitivity

How the 7000/7010 Series Triple Quads Improve Sensitivity	26
Sensitivity	26
Chemical noise reduction with MRM	28
Sensitivity and reproducibility of the 7000/7010 Series Triple Quads	30
How Each Component Works to Improve Sensitivity	35
GC capillary flow backflush technology	35
Ion sources	35
Quad mass filters	38
Pre- and post-filters	38
Collision cell	39
Detector	43
Pumping system	44

This chapter shows how the 7000/7010 Series Triple Quad reduces chemical and electronic noise and how each component contributes to enhanced instrument sensitivity.

3 Triple Quad and Sensitivity

How the 7000/7010 Series Triple Quads Improve Sensitivity

How the 7000/7010 Series Triple Quads Improve Sensitivity

Sensitivity is a performance standard for 7000/7010 Series Triple Quads. It is expressed as the signal-to-noise ratio (S/N). Triple quadrupole mass spectrometers exhibit multiple sources of noise, including interference from chemical and cluster backgrounds and electronics.

Sensitivity

In the design of the 7000/7010 Series Triple Quads, sensitivity was addressed within all stages of instrumentation, from the ion source to the detector. See **Figure 9**.

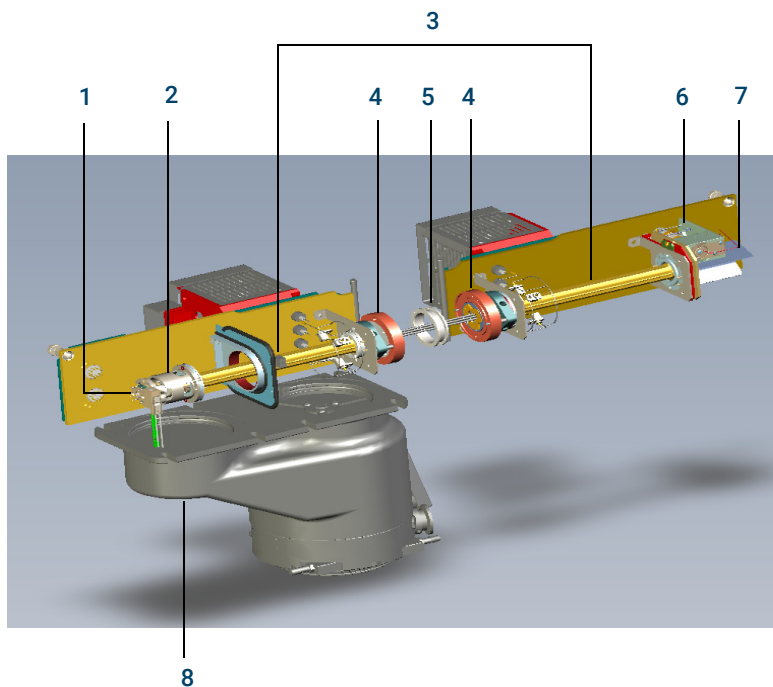


Figure 9. Design elements that improve sensitivity

How the 7000/7010 Series Triple Quad instruments increase sensitivity

- 1 Sample enters the Triple Quad from the GC. Capillary flow backflush technology produces better separation and reduce column bleed, providing a cleaner sample.
- 2 Electron ionization ion sources incorporate dual filaments with tuning capabilities to optimize ionization and filament use.
- 3 Front and rear analyzers use hyperbolic quadrupoles to optimize ion transmission and spectral resolution.
- 4 RF quadrupole segments (pre- and post-filters) enhance ion transmission into and out of the collision cell.
- 5 High-pressure collision cell with linear acceleration optimizes MS/MS fragmentation while eliminating crosstalk, even at very low dwell times. A small-diameter high-frequency hexapole assembly assists with capturing and focusing fragmented ions. Helium quench gas assists in the fragmentation process while reducing the neutral noise in the data.
- 6 Off-axis high-energy dynode detector with log amp signal compression permits a high gain, long life, and low noise. This design allows neutrals to pass without hitting the detector.
- 7 Multiplier has a long life since only electrons impact its surface, never ions. Gain normalized tuning of the detector provides consistent sensitivity over the life of the multiplier.
- 8 Vacuum system incorporating the use of a split flow turbomolecular pump efficiently eliminates neutral materials prior to the detector.

Chemical noise reduction with MRM

MRM can only be performed with a triple quadrupole MS. In this operation, the front analyzer is run in SIM mode to monitor for a specific ion. After filtration in the first quadrupole, it is expected that only ions with a single m/z ratio will pass through (see [Figure 10](#)). After fragmentation in the collision cell, the third quadrupole is also run in SIM for specific m/z values, to capture product ions resulting from the precursor. The third graph in [Figure 10](#) shows how the data can be easily read for product identification and quantification.

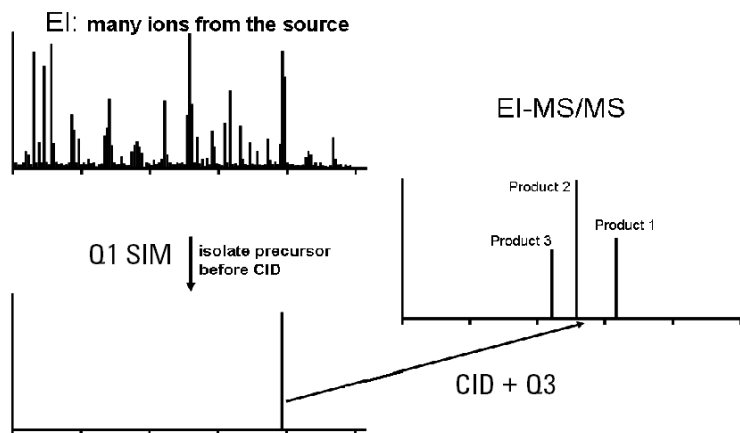


Figure 10. Sensitivity with MRM

3 Triple Quad and Sensitivity

Chemical noise reduction with MRM

The 7000/7010 Series Triple Quads pass through four transitional steps in translating a signal in the MRM process (**Figure 11**).

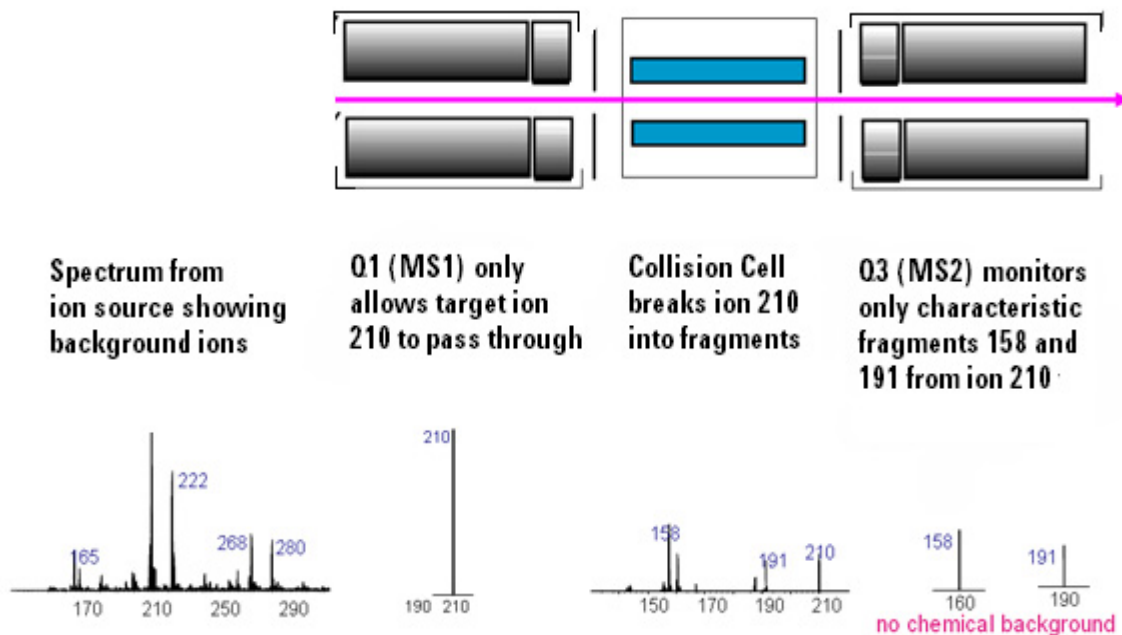


Figure 11. Multiple reaction monitoring (MRM)

Step 1 The spectrum at the far left represents everything that is being ionized at the ion source. A triple quad GC/MS reduces chemical noise for low-level quantitation in a dirty matrix more than a single quad GC/MS does.

Step 2 This step is accomplished by first selecting the chemical of interest at 210 *m/z* from the coeluting interferences seen in the rest of the spectrum. The second spectrum shows the result after passing through the first quadrupole, or Q1 (MS1).

Step 3 After Q1 (MS1), fragment ions are generated in the collision cell. The corresponding MS/MS spectrum is shown below the collision cell.

Step 4 Particular fragment ions can be selected to pass through the Q3 (MS2) quadrupole. These are selected for quantitation and confirmation.

3 Triple Quad and Sensitivity

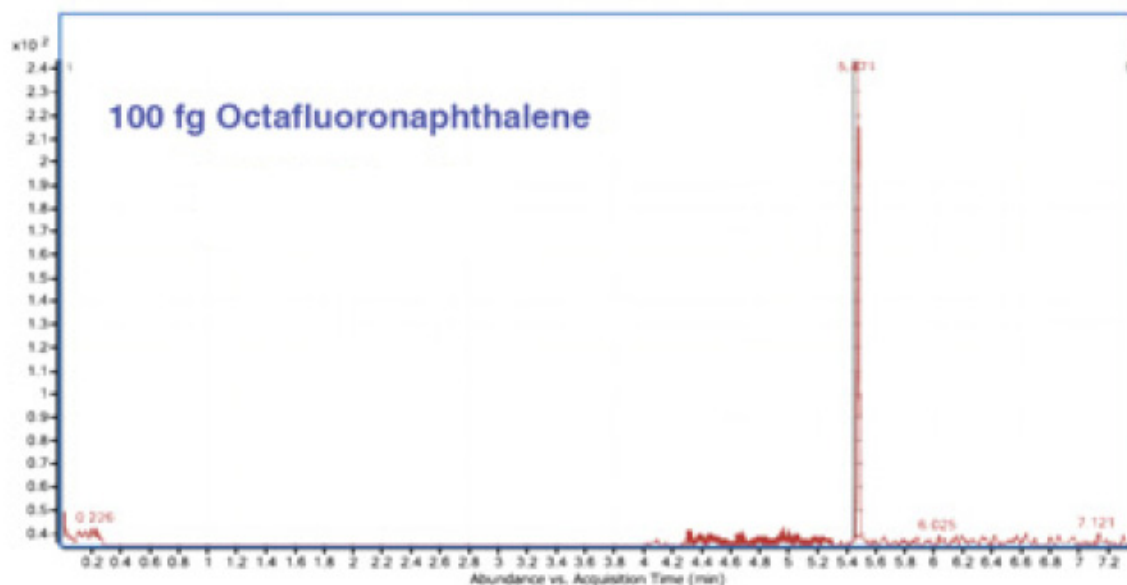
Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

The second stage of selectivity using the Q3 (MS2) quadrupole removes much of the chemical background. Typically, the chance of an isobaric interference at the same exact mass as the fragmentation ion is remote.

Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

Sensitivity in MS data is affected by detection limits, sample dilution, and sample contamination. Improvements in MS sensitivity are made through increased signal strength and a reduction in chemical noise.

The sensitivity specifications for the 7000/7010 Series Triple Quads are at femtogram to sub-femtogram levels, depending on the instrument model and compound being measured. This is demonstrated at customer sites upon installation. (See [Figure](#)).



Analysis of 100 fg sample of OFN in MRM (272 → 222 m/z)

3 Triple Quad and Sensitivity

Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

Triple quad GC/MS analysis is useful for identifying quantities of target compounds in complex matrices. The 7000/7010 Series Triple Quads provide improved analysis in complex matrices. **Figure 12** illustrates a chromatogram of two PCB congeners (PCB 153 and PCB 138) injected at 400 fg each on column. Quantitation transition is performed at $360 \rightarrow 290$ m/z, with the qualifier transition measured at $360 \rightarrow 325$ m/z for simultaneous quantitation and confirmation at the lowest detection limit. Resulting data produce strong signals on a flat baseline.

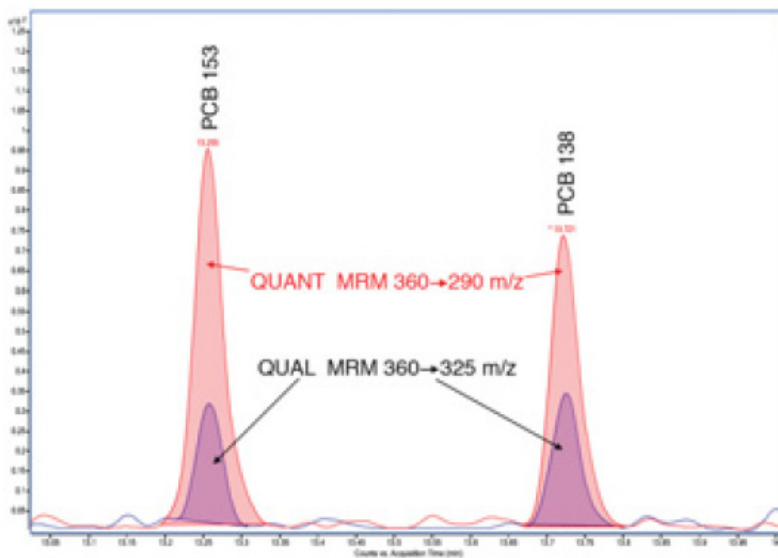


Figure 12. Identifying target PCBs in complex matrices

3 Triple Quad and Sensitivity

Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

Another performance standard of 7000/7010 Series Triple Quads is high sensitivity for contaminated samples. **Figure 13** illustrates HCB analysis in diesel fuel. Data from the single quad in SIM show a low signal-to-noise ratio (S/N), with many peaks and chemical background noise. In the second graph, the sample run in RMS mode results in a S/N of 86:1 with quantitative transition of 283.8→213.9 *m/z*. This demonstrates high sensitivity in a “dirty” matrix.

300 fg HCB in Diesel

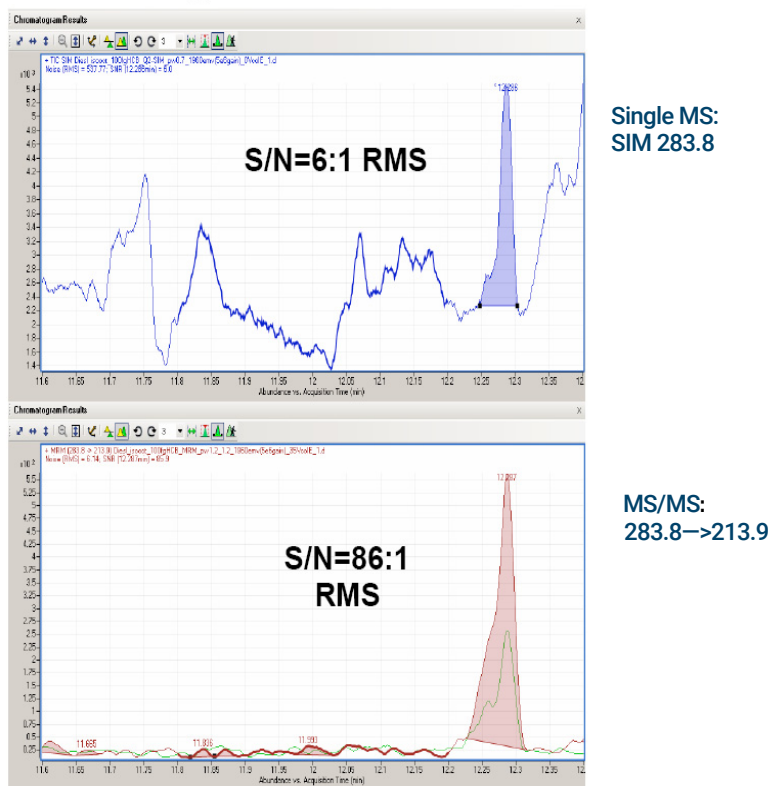


Figure 13. HCB analysis by 7000/7010 Series Triple Quad in MRM mode

3 Triple Quad and Sensitivity

Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

The 7000/7010 Series Triple Quads produce clear data to help evaluate complex samples at lower levels. **Figure 14** illustrates a chromatogram of multiple PCB congeners in mussel extract measured at 2 pg on-column. The resulting data provide strong signals on a flat baseline for clear data interpretation.

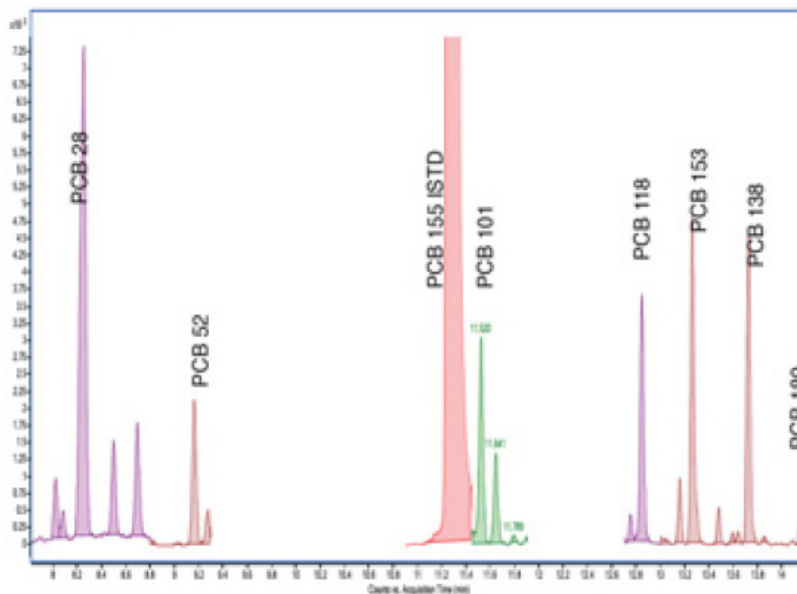


Figure 14. Detection of multiple PCBs at low detection limits

3 Triple Quad and Sensitivity

Sensitivity and reproducibility of the 7000/7010 Series Triple Quads

Reproducibility is an expression of how well the data agrees from test to test.

Figure 15 illustrates the GC/MS results when the organophosphorous insecticide cyanophos, spiked into garlic at 0.5 ppb, is analyzed in MRM mode. An overlay of five injections showing the quantitation transition of 243→109 m/z demonstrates strong reproducibility.

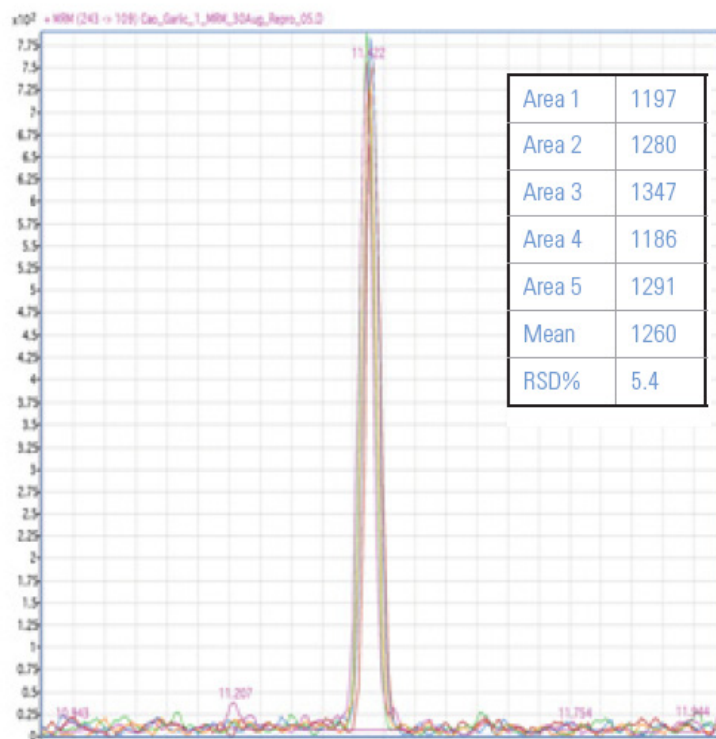


Figure 15. Reproducibility in 7000/7010 Series Triple Quad data

How Each Component Works to Improve Sensitivity

This section describes in more detail how each of the components of the 7000/7010 Series Triple Quads contributes to reducing noise (**Figure 9** on page 26).

GC capillary flow backflush technology

Many Agilent GCs provide improved sample transmission through backflush technology. Backflushing eliminates late eluters from the column, reducing the sample contamination and chemical noise that they create. This technology is integral in the integrity and consistency of the MS data.

Ion sources

The 7000/7010 Series Triple Quads offer the same ionization methods as the single quadrupole mass spectrometers: electron impact ionization (EI) and chemical ionization (CI).

Electron impact ion sources

Electron impact is the standard ionization mode for 7000/7010 Series Triple Quads. Sample components separated by the GC column enter the source through the GC/MS interface. The sample components are ionized in the ionization chamber.

A filament attached to the source body emits electrons into the ionization chamber through the guidance of a magnetic field. These electrons interact with sample molecules, ionizing and fragmenting them. The EI ion sources available for the 7000/7010 Series Triple Quads (see **Figure 16** on page 36 and **Figure 19** on page 38 for the EI XTR) contain two filaments, which allows for a choice of filament depending upon tuning results.

Once the sample has been ionized, the ions are directed by the repeller through a stack of electrostatic lenses. The repeller contains a positive voltage, which pushes positive ions into the lens stack. There the ions are concentrated into a tight beam and pushed into the analyzer. Slots in the source body allow the

3 Triple Quad and Sensitivity

Electron impact ion sources

vacuum system to pump away ions of carrier gas and un-ionized material as the sample ions enter the quad, thereby reducing neutral noise and improving sensitivity.

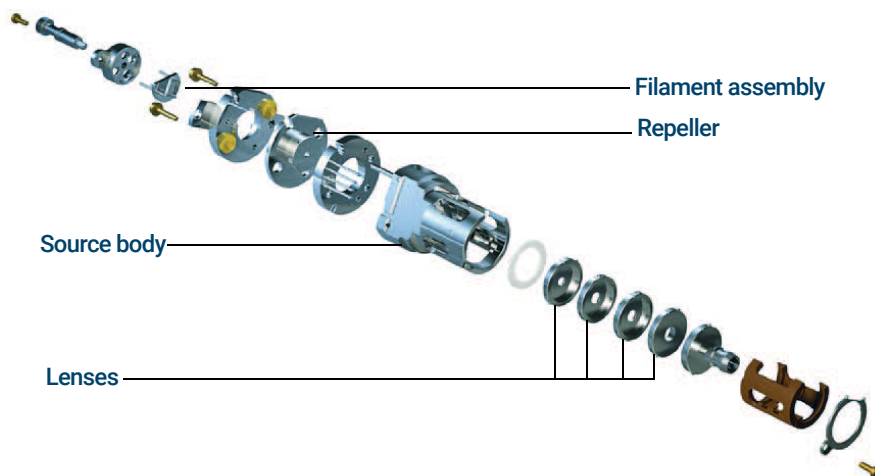


Figure 16. EI high efficiency source (HES)

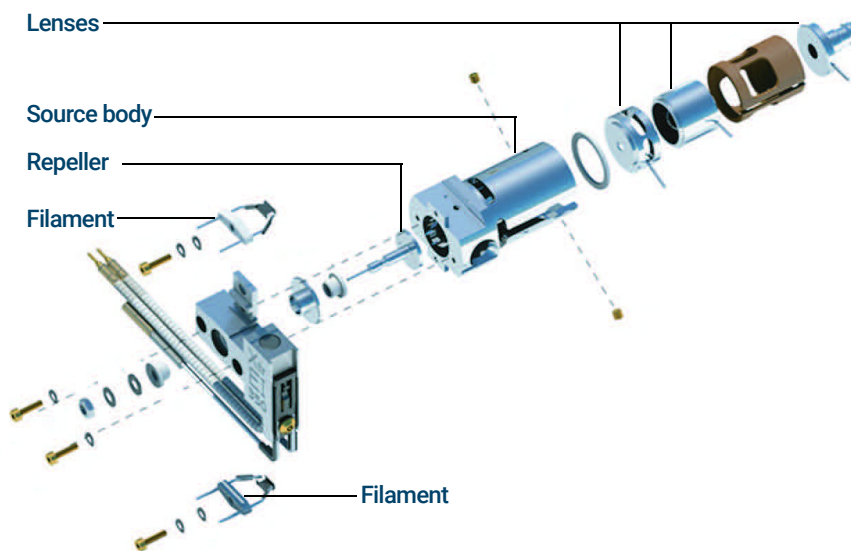


Figure 17. EI Extractor ion source (XTR)

Chemical ionization ion source

The 7000/7010 Triple Quads can be equipped with an optional chemical ionization ion source (see **Figure 18** on page 37). In chemical ionization, the ionization chamber is flooded with large quantities of reagent gas. Electrons from a filament ionize the highly abundant reagent gas molecules, which then, by a variety of chemical reactions, ionize the sample molecules.

Chemical ionization is a “softer” ionization technique. It causes less fragmentation than EI so CI spectra usually show a high abundance of the molecular ion. For this reason, CI is often used to determine the molecular weights of sample compounds.

Unlike EI sources, which generate only positive ions, the CI source can also be operated so as to produce negative ions, making it useful for analyzing compounds that do not analyze well or at all in positive ion mode. For a subset of samples, negative CI can provide very high sensitivity.

The CI source available for the 7000/7010 Series Triple Quads can operate with a variety of reagent gases, allowing the user to select the reagent gas that produces the best sensitivity for a particular sample.

The CI source is superficially similar to the EI XTR source. The CI source, however, has a single filament and much smaller orifices for the ion chamber. Its lenses are also subtly different from, and not interchangeable with, corresponding EI source parts.

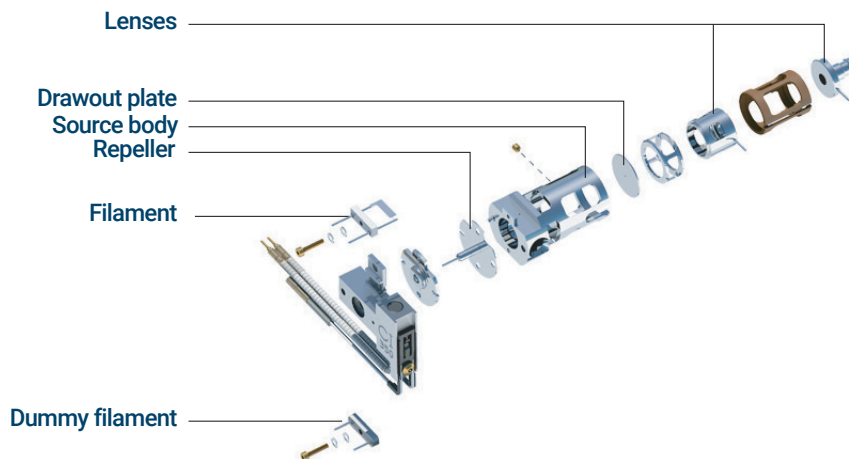


Figure 18. CI ion source

3 Triple Quad and Sensitivity

Quad mass filters

Quad mass filters

The quadrupoles consist of hyperbolic rods that optimize ion transmission and spectral resolution. The quadrupole configuration tends to generate less ion loss than circular rods. The gold-plated quartz material allows the analyzer to operate at high temperatures and low vacuum, eliminating the contamination that occurs with lower temperatures.

Pre- and post-filters

The end section of the Q1 (MS1) quadrupole assembly also consists of short hyperbolic rods, but their RF voltages are only high enough to guide ions into the collision cell. A similar set of rods on the exit side of the collision cell are part of the Q3 (MS2) quadrupole. These short RF-only rods act as pre- and post-filters to the quads to ensure optimum ion transmission into and out of the collision cell.

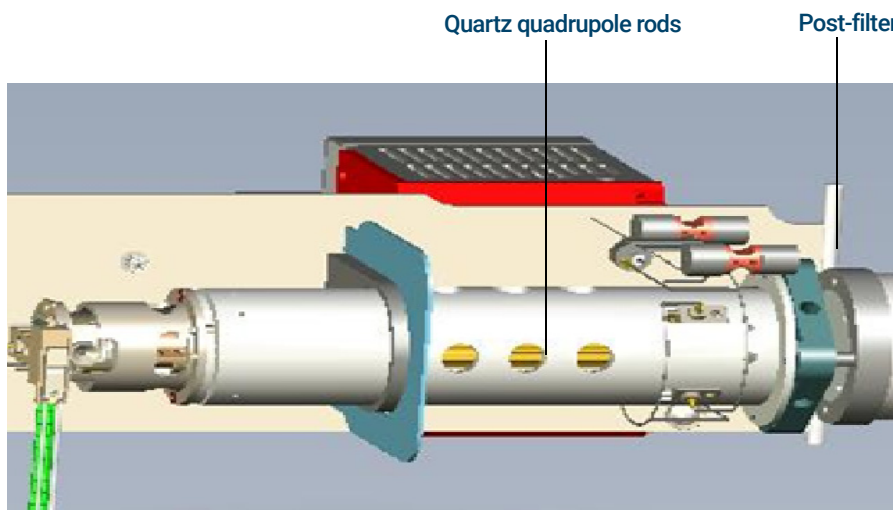


Figure 19. Q1 (MS1) quadrupole assembly

Collision cell

What is the collision cell?

The collision cell collects precursor ions selected by the first quadrupole mass filter and fragments them. The resulting product ions are transmitted to the second quadrupole mass filter. In the 7000/7010 Series Triple Quads, the collision cell is a high-pressure hexapole assembly with its linear acceleration adjusted to optimize MS/MS fragmentation while eliminating crosstalk even at very low dwell times (**Figure 20**).

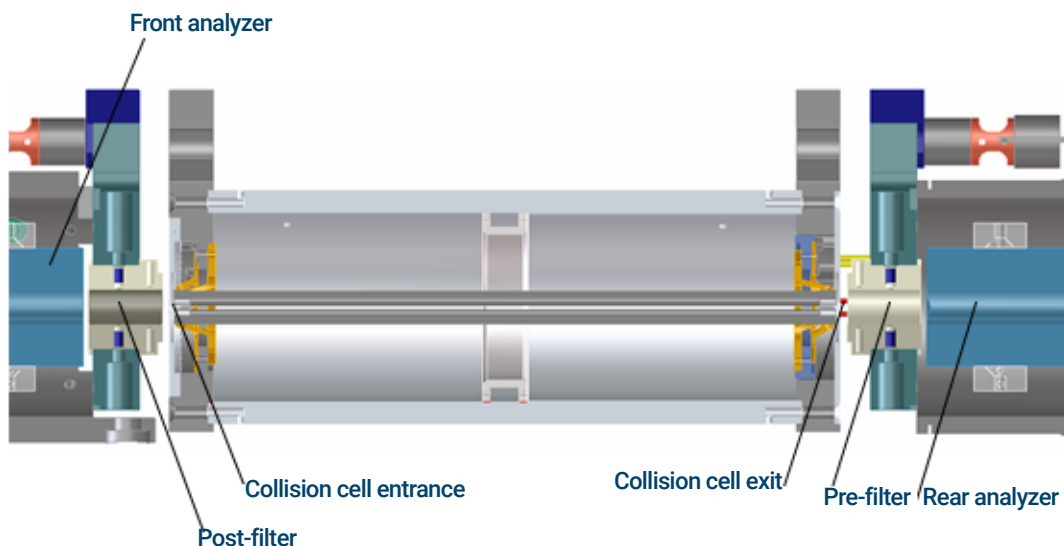


Figure 20. Collision cell technology produces higher sensitivity and faster responses without memory or cross-talk effects

The components that contribute to this higher sensitivity and faster response are:

- Small diameter hexapole collision cell
- High frequency hexapole collision cell
- Linear axial acceleration
- High pressure collision cell
- High speed digital electronics

3 Triple Quad and Sensitivity

Collision cell

The collision cell contains nitrogen and helium. Helium has been shown by Agilent to provide more control over the fragmentation process, especially with higher mass ions. It was added to the nitrogen stream to reduce neutral noise by thermalizing metastables without letting them hit the detector. The helium is then eliminated by the vacuum pump along with carrier gas and unfragmented sample ions. The small diameter of the hexapole assembly assists in capturing fragmented ions.

Why a hexapole?

The geometry of a hexapole provides advantages in two domains: ion focusing and ion transmission (**Figure 21**).

- The first advantage is in ion focusing. Studies have shown that a quadrupole provides better ion focusing than a hexapole and a hexapole provides better ion focusing than an octopole. Therefore, ion focusing improves with a lower number of poles in the filter.
- The second advantage involves ion transmission across a wide mass range, or m/z bandwidth. In this case, the octopole is better than the hexapole, which is better than the quadrupole.

The hexapole was chosen after extensive modeling, simulation, and experimentation because it offered the best compromise between the focusing of a quadrupole and the ion transmission of an octopole.

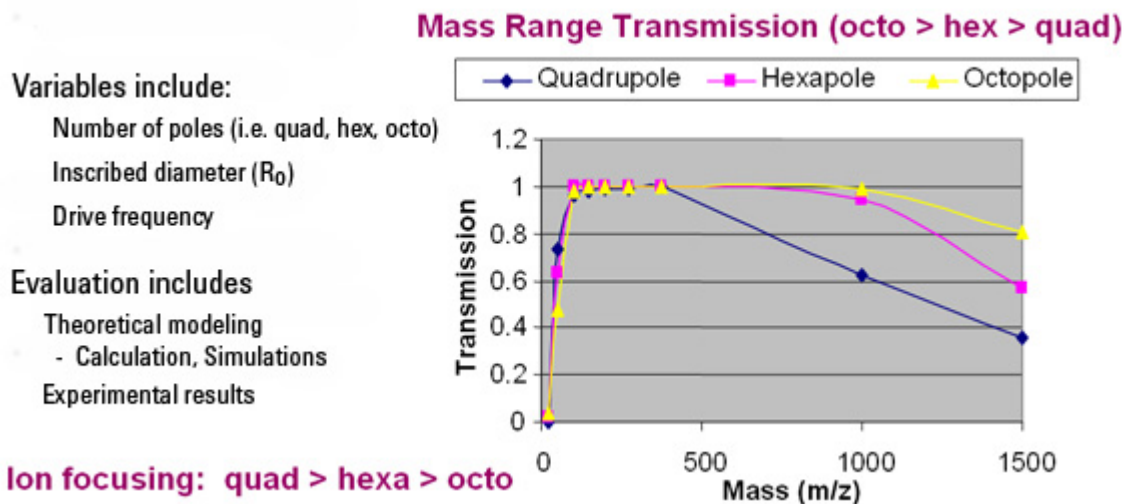


Figure 21. Broad mass range transmission and improved transmission efficiency using a hexapole

3 Triple Quad and Sensitivity

Collision cell

Collision cell design

The collision cell hexapole consists of six resistively coated rods used to generate a potential difference across the length of the collision cell (**Figure 22**).

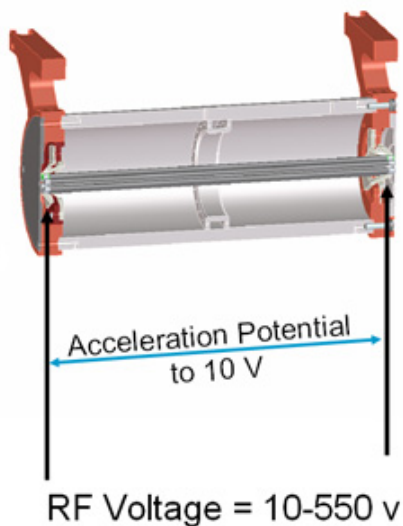


Figure 22. Collision cell design

A potential difference is always present. This ensures that the precursor ions coming from Q1 (MS1), or fragment ions generated in the collision cell, are transmitted and not allowed to drift around at random.

3 Triple Quad and Sensitivity

Collision cell

Sweeping out the ions in this manner avoids the issue of crosstalk, where residual product ions from a previous MRM experiment can interfere with the product ion spectrum of a subsequent MRM experiment (see [Figure 23](#)). A collision energy voltage is applied over the accelerating linear voltage to generate fragments or product ions.

Length of time for collision cell flushing

The low degree of crosstalk can be demonstrated by examining how long it takes to evacuate ions from the collision cell ([Figure 23](#)).

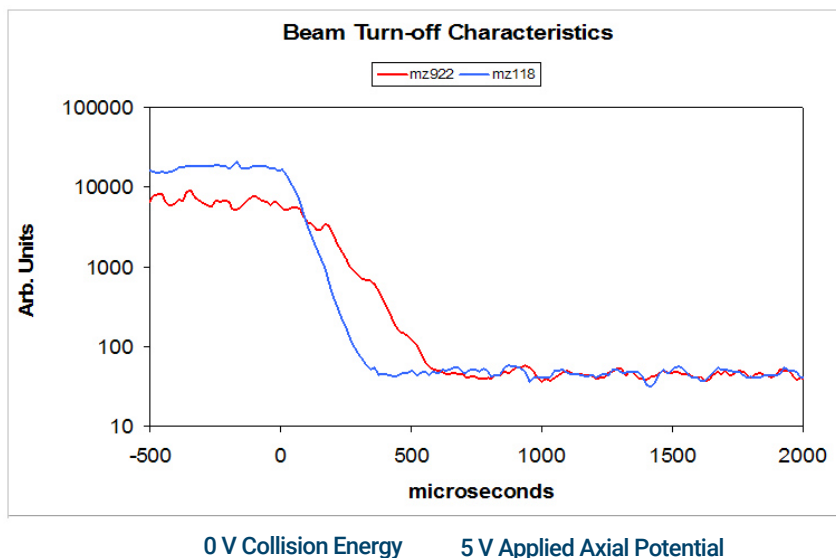


Figure 23. Collision cell clearing profile (500 pg Alprazolam, 20 ms dwell time)

The figure illustrates a sample analysis that is typically performed with an LC triple quad MS. The model is useful to show that the higher the mass of the compound moving through the triple quad, the longer it takes to evacuate the collision cell. For example, m/z 922 takes about 600 μsec to evacuate the collision cell using the linear potential, while m/z 118 only takes 350 μsec . This also demonstrates a low degree of crosstalk since the Y axis is logarithmic, showing complete clearance of the cell. This means that an inter-scan delay of 1 msec will be more than adequate to flush the collision cell of all ions.

Detector

The detector assembly is unique to Agilent (Figure 24). It is a high-energy dynode coupled with an electron multiplier.

Triple-Axis Detector

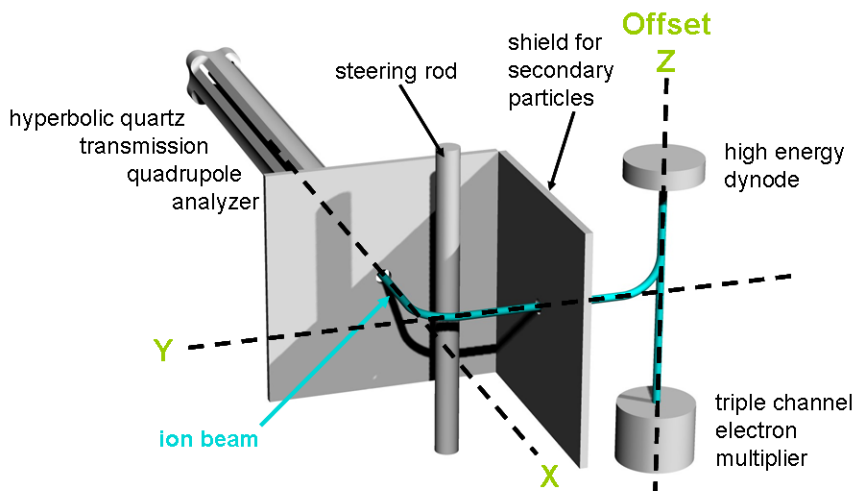


Figure 24. Detector components

The high-energy dynode is located off-axis from the center of the rear quad analyzer. This orientation reduces the possibility of neutral molecules impacting the detector while at the same time attracting the ions with high voltages. When the ion beam hits the dynode, the ions are converted to electrons before they impact the multiplier. These electrons are attracted to the more positively charged electron multiplier horn. The off-axis design of the detector allows neutrals to pass through and be eliminated by the vacuum system without hitting the detector.

The multiplier has a long lifetime since only electrons are allowed to impact it. Ions never impact its surface. Gain normalized tuning provides consistent sensitivity over the life of the electron multiplier. This also translates into consistency from MS to MS, and lab to lab.

Pumping system

A single split flow turbomolecular pump is used for the entire vacuum system. Sufficient vacuum for the entire process is achieved by partitioning the turbo pump to create multiple vacuum stages. The vacuum system removes molecules of carrier gas and any un-ionized or unfragmented sample molecules from the ion source outlet, the collision cell, and both analyzers. This pump is backed by a single mechanical foreline (roughing) pump (**Figure 25**).

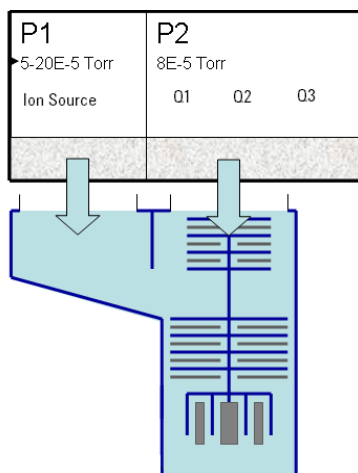


Figure 25. Split flow turbomolecular pump

4 Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad

Description	46
Tuning	47
Acquisition	48

This section will help you understand the design and operation of the Agilent MassHunter Workstation Software for GC/MS Instrument Control for the 7000/7010 Series Triple Quads.

Description

The Instrument Control program (**Figure 26**) has the following features:

- Showing the instrument at work through real-time plots
- Running multiple samples through the sequence table, a spreadsheet-like interface
- Controlling and monitoring instrument settings
- Tuning the instrument
- Setting up acquisition parameters for the GC and the Triple Quad
- Monitoring the chromatogram and mass spectra as samples are analyzed
- Setting up sequences of samples

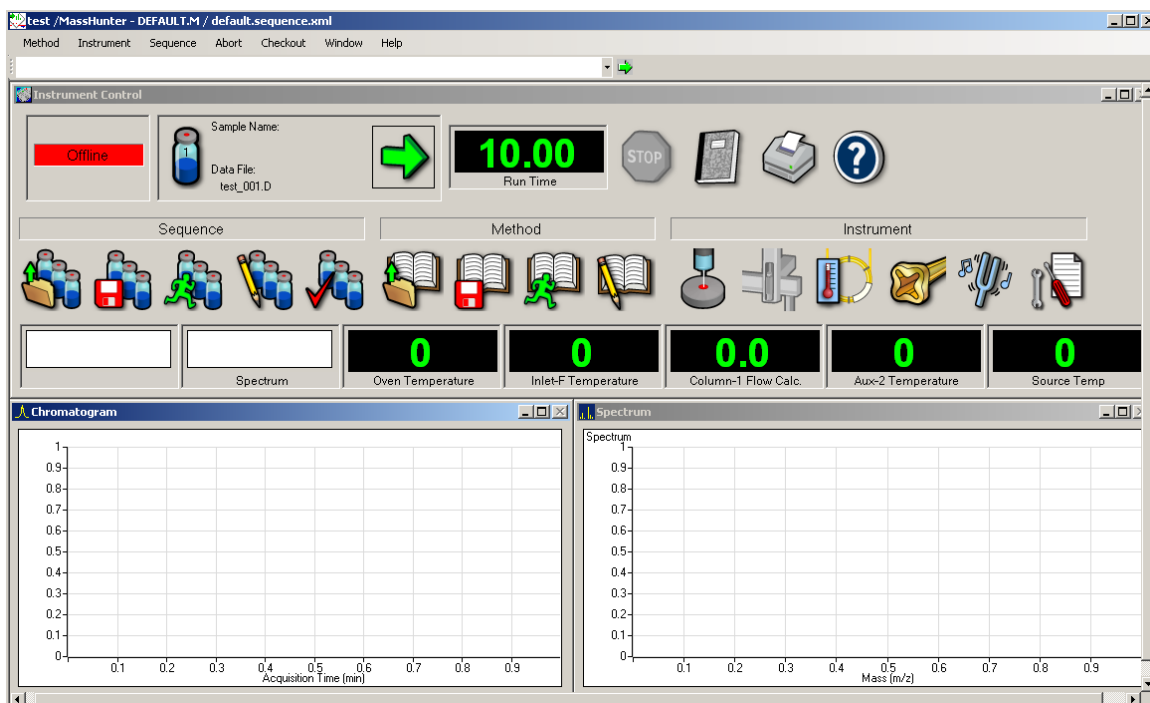


Figure 26. Instrument control

Tuning

Autotune

An autotune taking about 8 minutes can be used when an extensive tune is recommended (Figure 27). In this mode, everything is automatic. The tuning mix is delivered by the calibrant delivery system (CDS), which is switched on automatically during the tune.

Manual tune

A manual tune of user-defined ion masses with six corresponding profile masses is available.

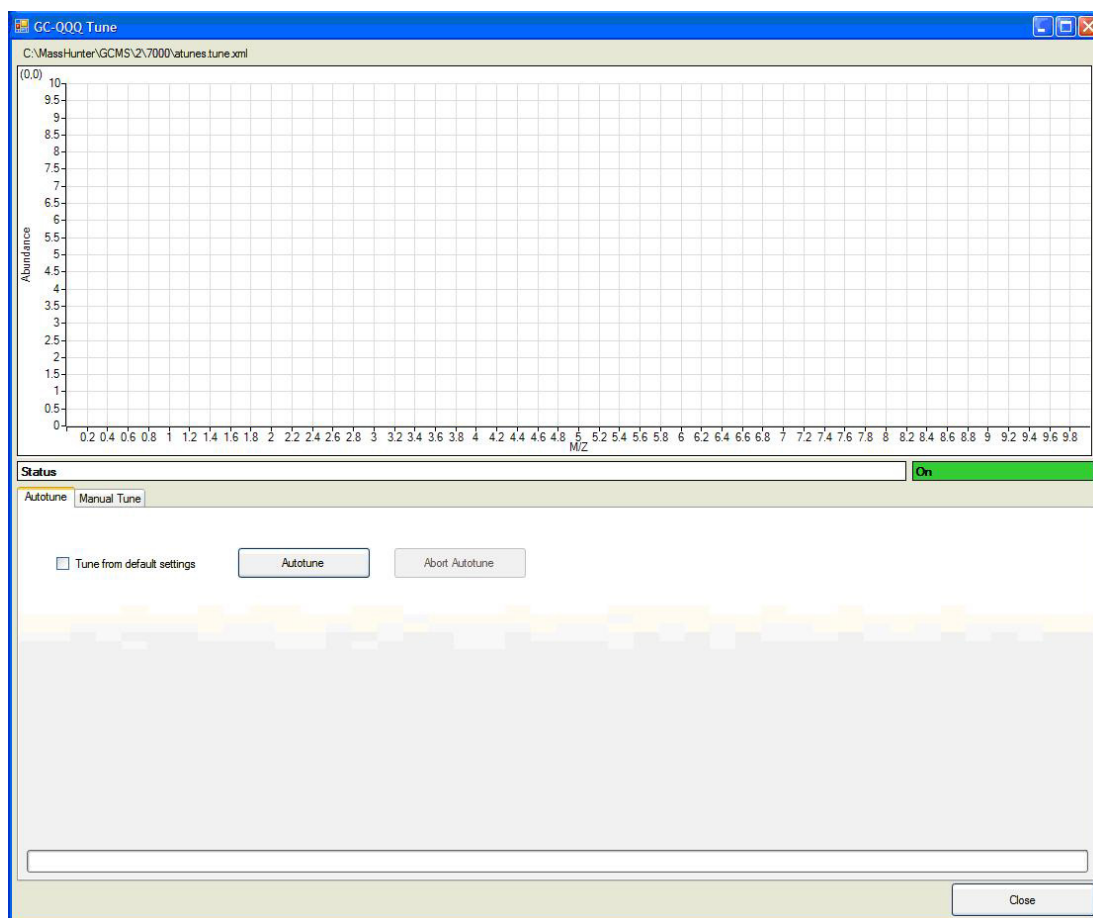


Figure 27. Autotune in progress

4 Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad Acquisition

Tune reports

Tune reports are also available.

Acquisition

The 7000/7010 Series Triple Quad GC/MS systems can be controlled and monitored from the Instrument Control panel, which is the window used for accessing acquisition settings and sequence lists (**Figure 28**, **Figure 29** on page 49, and **Figure 30** on page 50).

The real-time plot pane also can show the MS and GC results in real time.

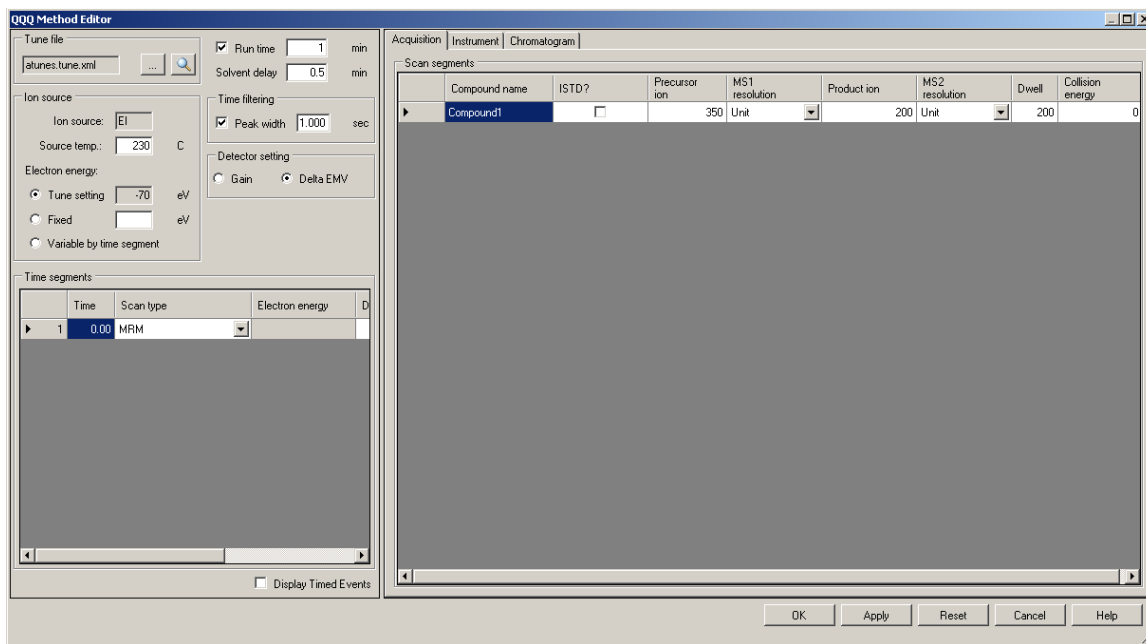


Figure 28. MS acquisition settings

4 Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad Acquisition

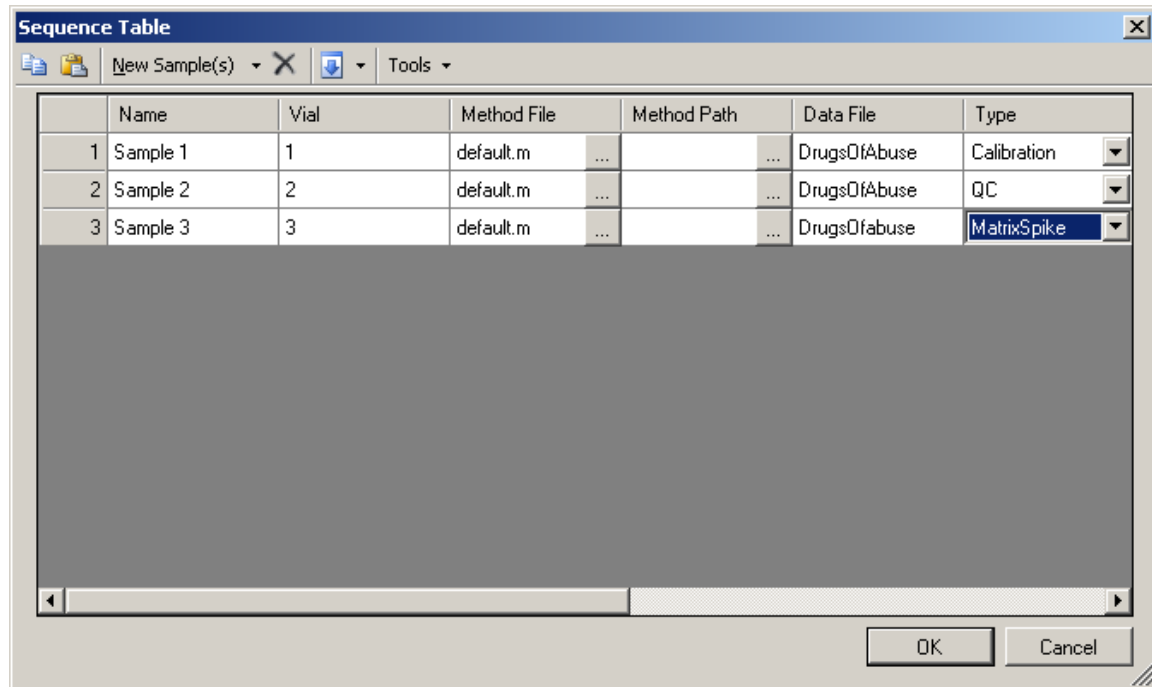


Figure 29. Sequence table

4 Agilent MassHunter Workstation Software – Instrument Control for the Triple Quad Acquisition

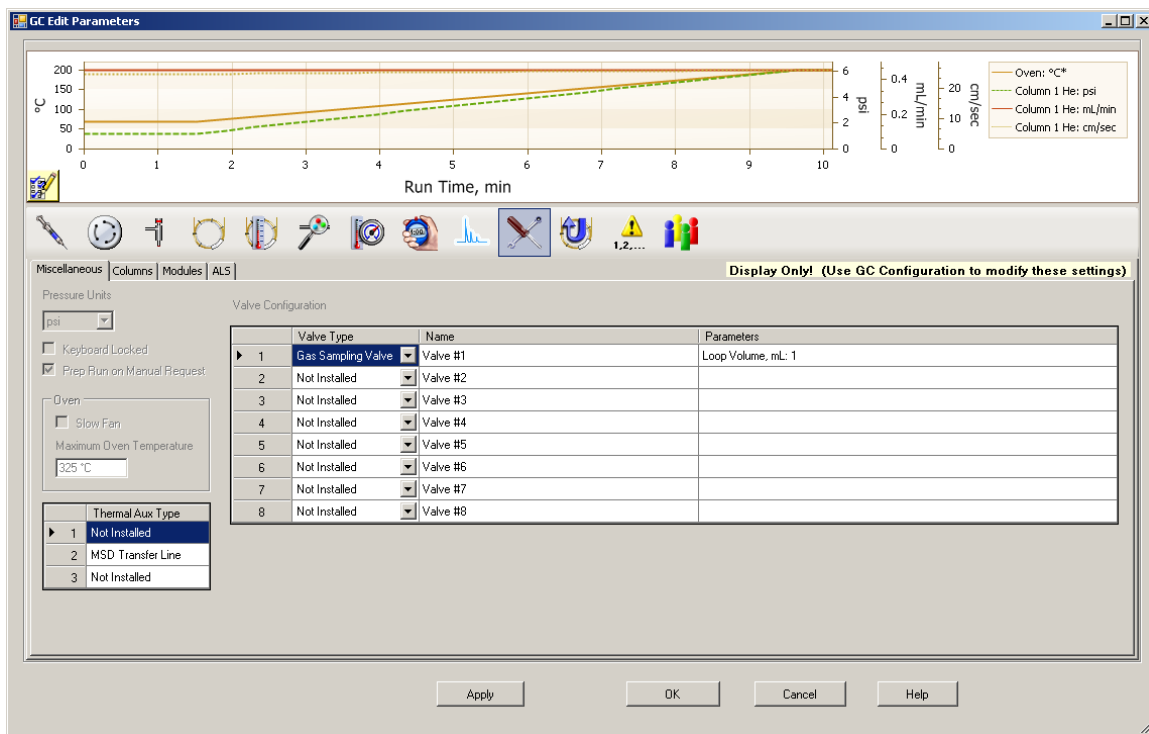


Figure 30. GC acquisition settings

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