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Supplementary Information

Initial results on the coupling of sedimentation field-flow fractionation (SdFFF) to inductively coupled plasma-tandem mass spectrometry (ICP-MS/MS) for the detection and characterization of TiO_2 nanoparticles

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Calculation of the particle size distribution

The SdFFF theoretical basis for the conversion of retention time data into size distribution is described in detail elsewhere.[1,2] Briefly, the retention ratio R obtained experimentally by SdFFF is a function of the layer thickness λ:

$$R = \frac{t_0}{t_r} = 6\lambda\left[coth\left(\frac{1}{2\lambda}\right) - 2\lambda\right]$$

Being t_0 the void time and t_r the retention time.

In SdFFF, the layer thickness λ is expressed as:

$$\lambda = \frac{kT}{m\omega^2 rw}$$

Being k the Boltzmann constant, T the absolute temperature in K, w the channel thickness, ω the angular velocity and r the radius of the centrifuge from rotation axis to the channel. This expression allows the calculation of the mass, m, of the particle retained at its corresponding t_r.

The particle size can be calculated from the retention time obtaining a size distribution profile by the equation:

$$d = \left[\left(\frac{6kT}{\pi G w \Delta\rho t_0}\right) t_r\right]^{1/3}$$

Being G the centrifugal acceleration, and Δρ the difference between the density of the particle and the one of the carrier liquid.

Optimization of Ti detection by ICP-MS/MS

The detection of Ti at ultratrace levels is a challenging task especially when working with complex matrices of biological or environmental origin like serum, cell cultures, tissues or seawater, which normally contain N, S, O, Cl, or P, at high concentrations, resulting in the formation of various polyatomic interferences disturbing the accurate detection of the different Ti isotopes. Moreover, some interfering elements like Cr, V and Ca (see Table S1) are also frequently present in such matrices, especially Ca that can be present at high concentration levels. Therefore, a method capable of sensitive detection of Ti separately from the interferences is of high significance for the analysis of Ti containing nanomaterials.

Table S1. The isotopic abundances and interferences for each of the isotopes of Ti. [3,4] The isotopic abundance for each of the isobaric interferences is shown in brackets.

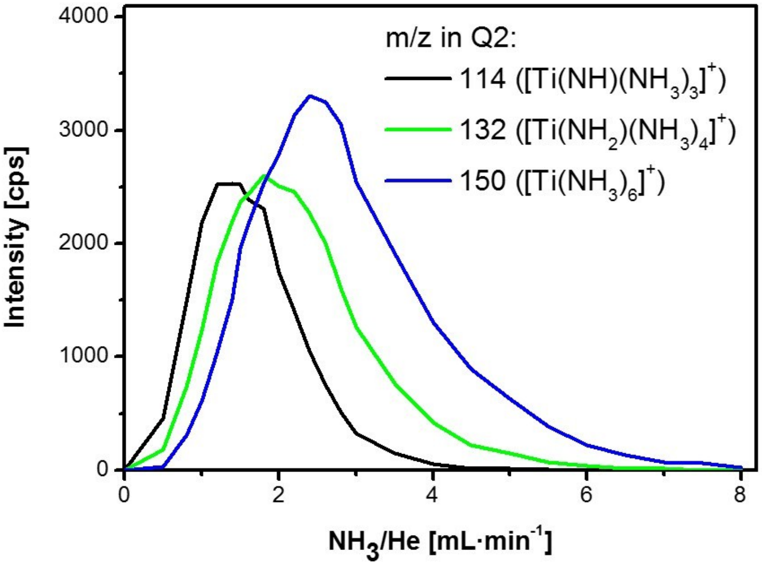
Isotope	**Abundance (%)**	**Isobaric interferences**	**Polyatomic interferences**
^{46}Ti	8.25	$^{46}Ca^{+}$ (0.004)	$^{32}S^{14}N^{+}$, $^{14}N^{16}O_2^{+}$, $^{15}N_2^{16}O^{+}$
^{47}Ti	7.44		$^{32}S^{14}N^{1}H^{+}$, $^{30}Si^{16}O^{1}H^{+}$, $^{32}S^{15}N^{+}$, $^{33}S^{14}N^{+}$, $^{15}N^{16}O_2^{+}$, $^{14}N^{16}O_2^{1}H^{+}$, $^{12}C^{35}Cl^{+}$, $^{31}P^{16}O^{+}$
^{48}Ti	73.72	$^{48}Ca^{+}$ (0.187)	$^{32}S^{16}O^{+}$, $^{34}S^{14}N^{+}$, $^{33}S^{15}N^{+}$, $^{14}N^{16}O^{18}O^{+}$, $^{14}N^{17}N_2^{+}$, $^{12}C_4^{+}$, $^{36}Ar^{12}C^{+}$
^{49}Ti	5.41		$^{32}S^{17}O^{+}$, $^{32}S^{16}O^{1}H^{+}$, $^{35}Cl^{14}N^{+}$, $^{34}S^{15}N^{+}$, $^{33}S^{16}O^{+}$, $^{14}N^{17}O_2^{1}H^{+}$, $^{14}N^{35}Cl^{+}$, $^{36}Ar^{13}C^{+}$, $^{36}Ar^{12}C^{1}H^{+}$, $^{12}C^{37}Cl^{+}$, $^{31}P^{18}O^{+}$
^{50}Ti	5,19	$^{50}Cr^{+}$ (4.345), $^{50}V^{+}$ (0.25)	$^{32}S^{18}O^{+}$, $^{32}S^{17}O^{1}H^{+}$, $^{36}Ar^{14}N^{+}$, $^{35}Cl^{15}N^{+}$, $^{36}S^{14}N^{+}$, $^{33}S^{17}O^{+}$, $^{34}S^{16}O^{+}$, $^{1}H^{14}N^{35}Cl^{+}$, $^{34}S^{15}O^{1}H^{+}$

The use of the ICP-MS/MS involves the transfer of the selected Ti isotopes together with the interfering ions through the first quadrupole into the reaction cell. There, the used reaction gas forms product ions selectively with Ti, while the interfering ions do not react. The shifted mass of Ti resulted from the mentioned reaction between the gas and the analyte is selected in the second quadrupole, avoiding both, the polyatomic and the isobaric interferences of the Ti isotopes.

The reaction gases tested in this work were O_2 that easily produce oxides with Ti, and NH_3/He (the use of He is mandatory as NH_3 is a corrosive gas and it is not safe for the system to work with pure NH_3), which forms different reaction products with the analysed Ti isotopes.

For the selection of the most suitable product ion mass for the interference-free detection of Ti with the ICP-MS/MS system, a scan of the entire mass range was carried out with the second quadrupole. The first quadrupole was adjusted in a way that only the mass of the most abundant isotope of Ti (^{48}Ti) was allowed to pass. The influence of the NH_3/He gas flow showed a preferred formation of $[^{48}Ti(NH_3)_6]^+$ at about 2.5 mL min^{-1}.

Figure S1. Influence of the NH_3/He gas flow on the formation of three different reaction products of $^{48}Ti^+$.



Use of O_2 as reaction gas

The mass shifts obtained from the combination of Ti with O_2 were mainly +16 and +32 (TiO^+ and TiO_2^+), allowing the Ti detection at the masses 64 and 80, being 64 the m/z ratio with the highest sensitivity. In MilliQ water the utilization of the, TiO^+ product ion provides high sensitivities, good linearity, and limits of detection for the five isotopes of Ti below 10 ng·L^{-1}.

However, after testing the influence of Ca (10 mg L^{-1}) as an isobaric interference of ^{48}Ti, it was observed that Ca is also able to form oxides easily and therefore interfere the signal of the mass 64 ($^{48}CaO^+$). Under such conditions the presence of Ca in the sample matrix, which is typical for biological or environmental matrices, prevent the analysis of the most abundant isotope of Ti, ^{48}Ti, via its product ions when using O_2 as reaction gas.

Determination of particle size using TEM analysis

For the TEM experiments, a solution of tetrahydrofuran (THF) containing 5 mg mL-1 of each of the two samples of TiO_2 NP was prepared and a few drops were put onto a carbon coated copper grid. The grids were dried overnight inside a clean bench (Class 100) and store isolated and preserved from the light, until their examination by TEM microscopy. The images were analysed using ImageJ software and counting and measure particles and creating histograms.

The histograms obtained from the TEM images (n = 30) showed that the mean size of the particles lay around 250 nm for the 21 nm TiO_2, and 150 nm for the 50 nm TiO_2 (see figure S1, S2).

Figure S2. TEM-Analysis of 50 nm TiO_2 NPs (5 mg L^{-1}) samples suspended in THF

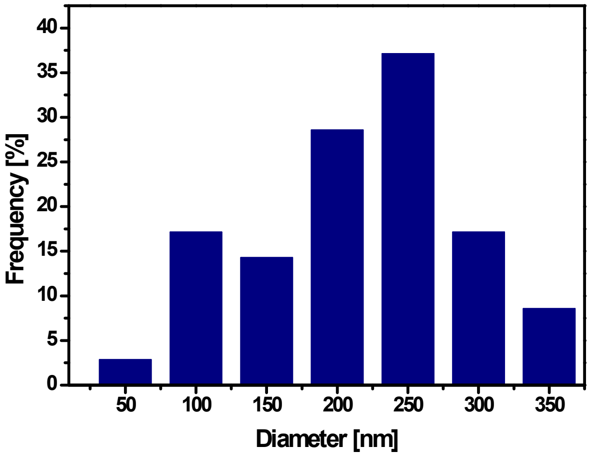
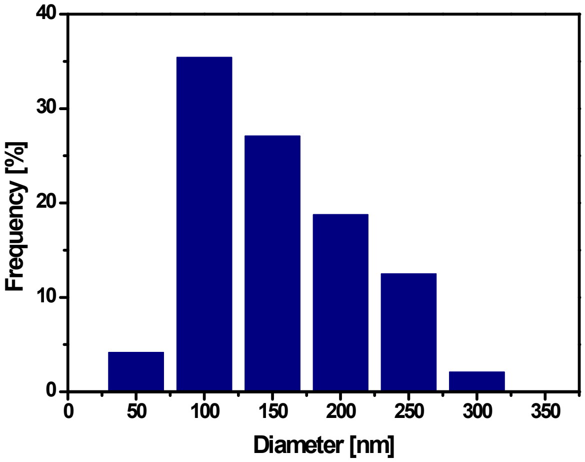


Figure S3. TEM-Analysis of 21 nm TiO_2 NPs (5 mg L^{-1}) samples suspended in THF



References

1 R. Beckett, G. Nicholson, B. T. Hart, M. Hansen, J. Calvin Giddings, *Water Res.*, 1988, **22**, 1535-1545.

2 J. C. Giddings, P. S. Williams, R. Beckett, *Anal. Chem.*, 1987, **59**, 28-37.

3 M. Shima, N. Torigoye, *Int. J. Mass Spectrom. Ion Process.*, 1993, **123**, 29-39.

4 T. W. May, R. H. Wiedmeyer, *At. Spectrosc.*, 1998, **19**, 150-155.