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Quadruple isotope dilution challenge

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Meet the isotope dilution challenge

Isotope dilution mass spectrometry (IDMS) is considered the most accurate quantitation strategy in chemistry [1-2]. An experiment of isotope dilution bases the quantitation of an analyte upon mass spectrometric analysis of a blend of sample (A) and isotopic internal standard (B). The latter material is prepared from an isotopically enriched form of the analyte. Isotopic materials, in general, are ideal internal standards because their behavior toward sample preparation and instrumental analysis is nearly identical respect to the native analyte, but they can be detected by mass spectrometry on different channels. If the analyte is monoisotopic (e.g., iodine) and the internal standard is constituted entirely by artificial isotopes not present in the sample (e.g., iodine-129), the calculation of the amount of analyte (n_A) is simply given by equation:

$$n_A = n_B \cdot R_{AB} \tag{1}$$

where n_B is the amount of internal standard and R_{AB} is the isotope amount ratio in the resulting blend (AB) of the analyte and the standard.

This formulation, however, overlooks the fact that in practice natural materials contain isotopes that make up the isotopic standard and vice versa. This overlap can be accounted for by applying the following equation:

$$w_A = w_B \cdot \frac{m_{B(AB)}}{m_{A(AB)}} \cdot \frac{r_B - r_{AB}}{r_{AB} - r_A} \cdot \frac{\sum R_A}{\sum R_B} \cdot \frac{M_A}{M_B} \tag{2}$$

Eq. 2, known as single isotope dilution, represents an important milestone in analytical chemistry. This model bases the quantitation of the analyte in the sample on the isotopic internal standard which is used as a primary calibrator (w_B). This is a limitation because the chemical purity of most isotopic standards is not known with adequate accuracy. This problem has been resolved in the fifties by the introduction of the double isotope dilution [3-4] where variable w_B of Eq. 2 has been determined in an experiment of reverse isotope dilution, against a primary standard of natural isotopic composition (A*):

$$w_A = w_{A^*} \cdot \frac{m_{A^*(A^*B)} \cdot m_{B(AB)}}{m_{B(A^*B)} \cdot m_{A(AB)}} \cdot \frac{(r_{A^*B} - r_A) \cdot (r_B - r_{AB})}{(r_B - r_{A^*B}) \cdot (r_{AB} - r_A)} \qquad (3)$$

where A*B is the blend of primary standard of natural isotopic composition and isotopic standard used for the reverse isotope dilution experiment. In this case the preparation and measurement of an additional blend A*B allows for avoiding direct knowledge of w_B that is now embedded into the model. Eq. 3 lies on the assumption of the linearity of response of the detector in the range investigated ($R = K \cdot r$) and of the identical isotopic composition of the analyte in A and in A*. Double isotope dilution is a widely used quantitation model. Eq. 3, however, still depends from the isotopic composition of the natural (r_A) and enriched (r_B) material. These two variables, in practice, can be difficult to define and tedious to measure. The topic of this challenge consists in the illustration of an alternative isotope dilution design able to bypass the direct knowledge of r_A and r_B.

The challenge

The determination of bromide on a sample of groundwater was carried on accordingly to a known GCMS procedure [5-6] and a [79]Br-enriched bromide was used as isotopic standard. For this purposes the isotopic composition of the natural material (r_A) and of the isotopic standard (r_B) have been measured experimentally. At this point, one blend of sample and isotopic standard (AB) and three blends of primary standard and isotopic standard (A*B-1, A*B-2, A*B-3) were gravimetrically prepared and measured by GCMS. All the experimental data are reported in Table 2.

The mass fraction of bromide in the groundwater sample can be determined, by applying Eq. 3. However, the preparation of a second and third blend, A*B-2 and A*B-3, allows to obviate the need to know variables r_A and r_B, much in the same fashon as double isotope dilution obviates w_B.

*Can you design a mathematical model, analytical or graphical, able to calculate the result using only the gravimetric data and isotope ratios reported for blends AB, A*B-1, A*B-2, A*B-3?*

Table 1. Symbols and quantities

Symbol	Description
A	Analyte in the sample (natural isotopic composition)
A*	Analyte in the primary standard (natural isotopic composition)
B	Analyte in the isotopic standard (isotopically enriched composition)
AB	Blend of sample (A) and isotopic standard (B)
A*B	Blend of primary standard (A*) and isotopic standard (B)
n_X	Amount of X (X = A, A*, or B)
M_X	Molar mass of X (X = A, A*, or B)
w_X	Mass fraction of X in the aqueous solution (X = A, A*, or B)
$m_{X(XY)}$	Mass of the aqueous solution of X used to prepare the blend of X and Y (X, Y = A, A*, or B)
R_X	Isotope amount ratio corresponding to material X
r_X	Isotope amount ratio in material X as measured by the mass spectrometer
ΣR_X	Sum of all isotope amount ratios of the same denominator

Table 2. Experimental data

Blend	m_A /g	m_{A^*} /g	m_B /g	r_{AB} /(V/V)	r_{A^*B} /(V/V)
AB	2.00811	n/a	0.06002	4.226	n/a
A*B-1	n/a	1.02652	0.05992	n/a	6.143
A*B-2	n/a	2.00312	0.06013	n/a	4.215
A*B-3	n/a	4.10538	0.05989	n/a	2.764

$r_A = r_{A^*} = 1.018$.
$r_B = 15.81$.
$w_{A^*} = 97.44$ ng/g of bromide.

References

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