Trace element analysis of geological materials by ICP-MS I

DSP analytical geochemistry

C9067

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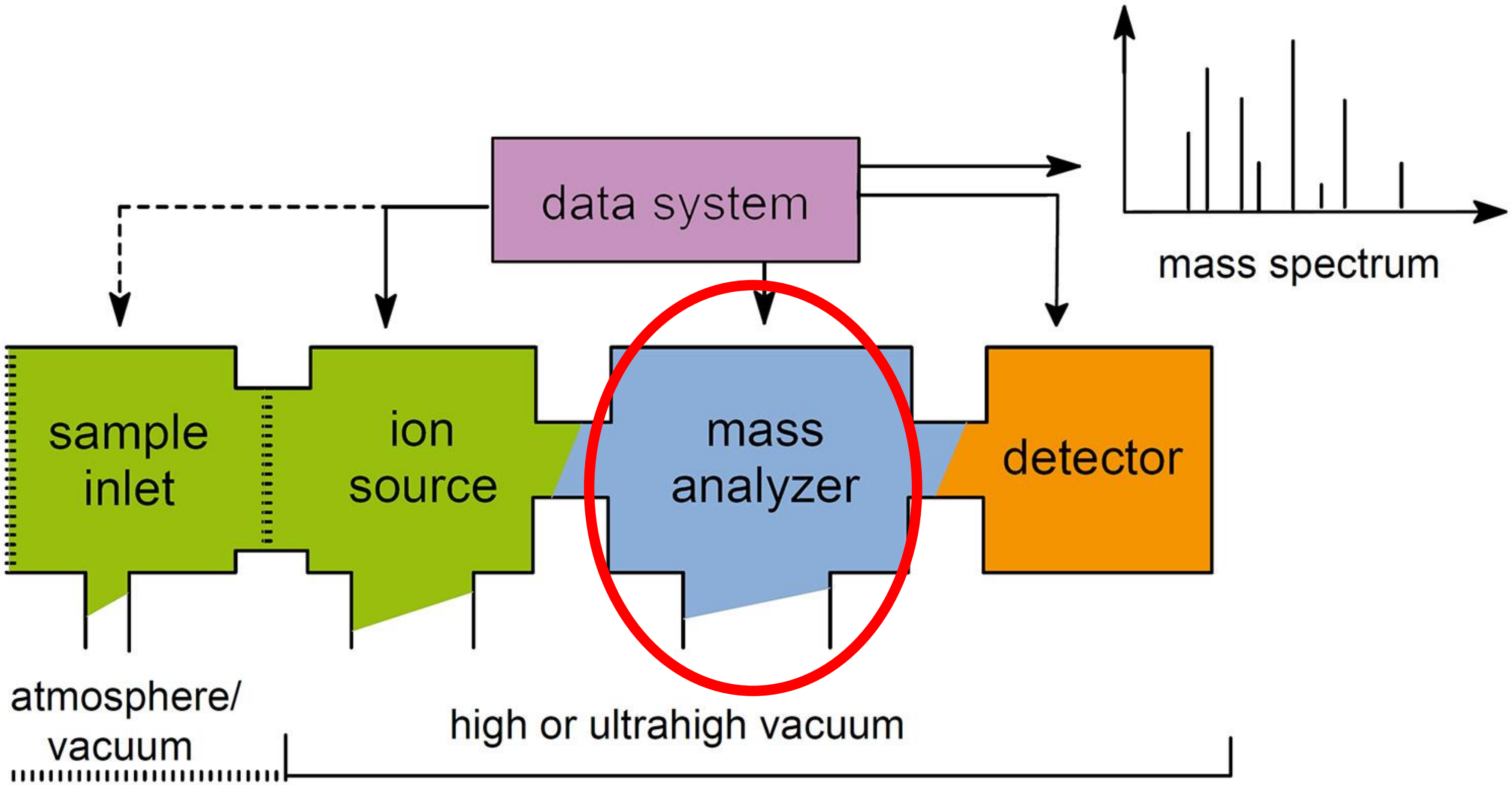
Outline

1. Mass spectrometry. General introduction and history.
2. Ion sources for mass spectrometry. Inductively coupled plasma.
3. Interface. Ion optics. Mass discrimination. Vacuum system.
4. Spectral interferences. Resolution, ion resolution calculations.
5. Mass analyzers. Elimination of spectral interferences.
6. Non-spectral interference.
7. Detectors, expression of results.
8. Introduction of samples into plasma.
9. Laser ablation for ICP-MS.
10. Excursion in the laboratory.



data system

mass spectrum

sample inlet

ion source

mass analyzer

detector

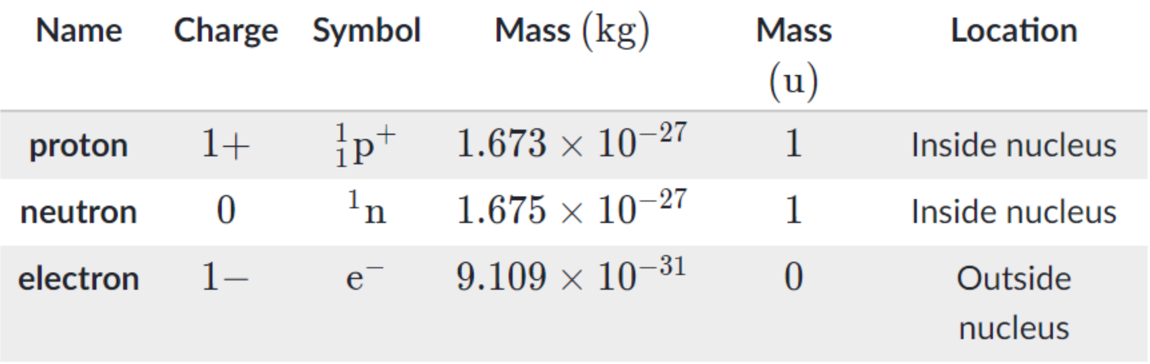
atmosphere/ vacuum

high or ultrahigh vacuum

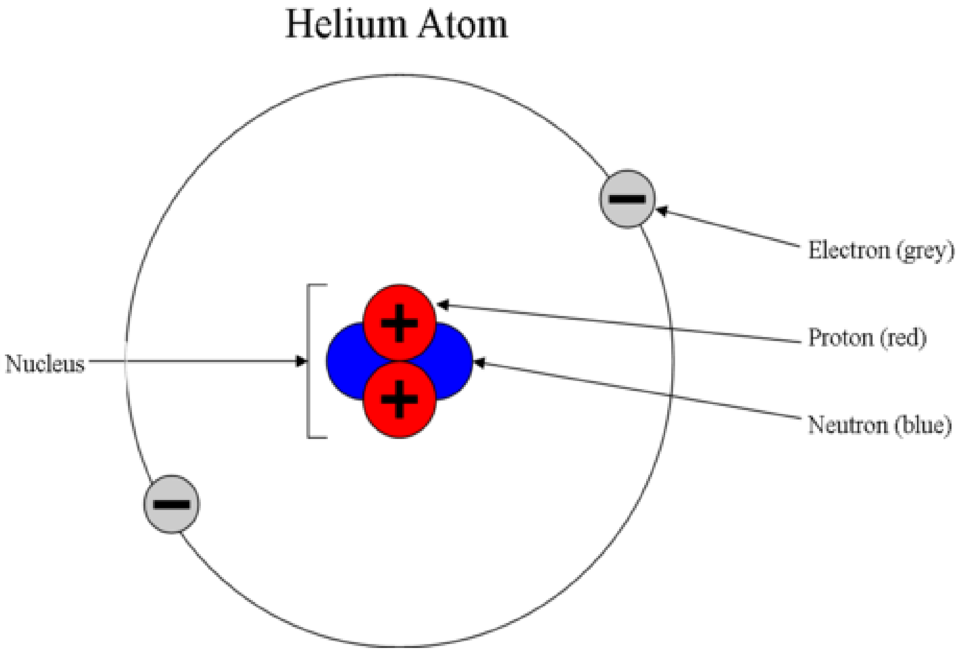
1000 mbar 10^{-5} to 10^{-6} mbar 10^{-6} to 10^{-9} mbar

Mass Spectrometry

inorganic

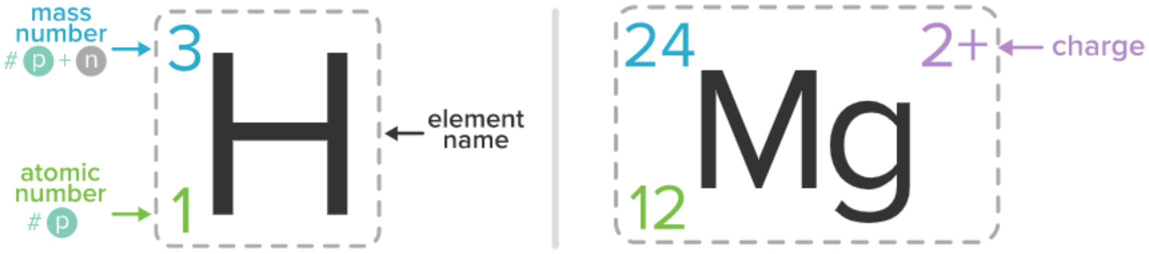


Name	Charge	Symbol	Mass (kg)	Mass (u)	Location
proton	$1+$	$^{1}_{1}\mathrm{p}^{+}$	1.673×10^{-27}	1	Inside nucleus
neutron	0	$^{1}\mathrm{n}$	1.675×10^{-27}	1	Inside nucleus
electron	$1-$	e^{-}	9.109×10^{-31}	0	Outside nucleus



Helium Atom

Mass number=(# protons)+(# neutrons)



Mass number *vs.* Atomic mass unit

Mass number - also called atomic mass number or nucleon number, is the total number of protons and neutrons (together known as nucleons) in an atomic nucleus.

AMU atomic mass unit - It is a unit of mass used to express atomic or molecule masses. When the mass is expressed in AMU, it roughly reflects the sum of the number of protons and neutrons in the atomic nucleus (electrons have so much less mass that they are assumed to have a negligible effect).

$m_u = m(^{12}C)/12$

$1\ AMU = 1\ m_u = 1\ Da = 1.66053904020 \times 10^{-27}\ kg$

Mass number

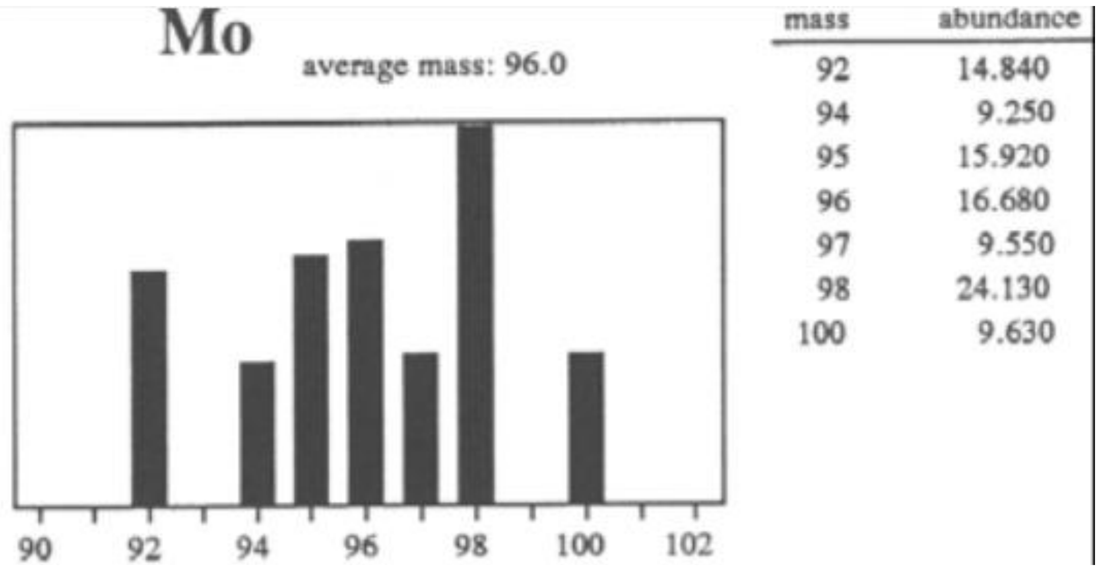
^{56}Fe amu 55.9349363

Mass Spectrometry

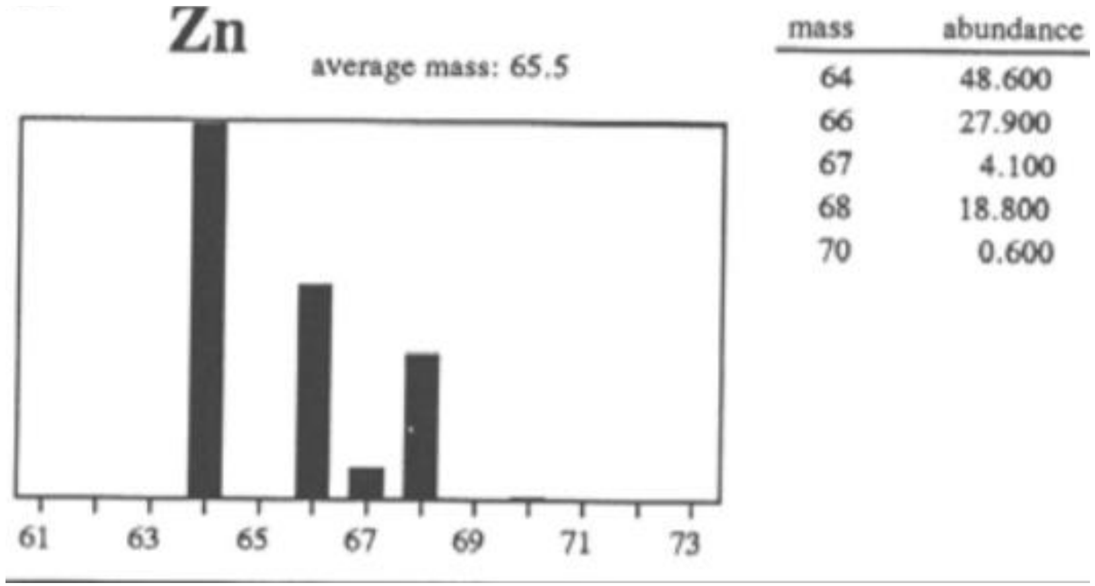
natural isotopes

Isotopes are atoms of the same element, which have different masses – by having varying numbers of neutrons in their nuclei.

Isotopes of elements that occur in nature have a constant abundance relative to another – **RELATIVE NATURAL ABUNDANCE**



mass	abundance
92	14.840
94	9.250
95	15.920
96	16.680
97	9.550
98	24.130
100	9.630



mass	abundance
64	48.600
66	27.900
67	4.100
68	18.800
70	0.600

Relative Isotopic Abundance Table

(unit: %)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
H	99.99	0.01															H
He				100													He
Li						7.59	**92.41**										Li
Be									**100**								Be
B										19.9	**80.1**						B
C												98.93	1.07				C
N														99.64	0.36		N
O																99.76	O

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
O	0.04	0.2															O
F			100														F
Ne				90.48	0.27	9.25											Ne
Na							**100**										Na
Mg								**78.99**	10.00	11.01							Mg
Al											**100**						Al
Si												**92.22**	4.69	3.09			Si
P															**100**		P
S																94.99	S

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	
S	0.75	**4.25**		0.01													S
Cl			**75.76**		24.24												Cl
Ar				0.34		0.06		99.60									Ar
K							**93.26**	0.01	6.73								K
Ca								96.941		0.647	**0.135**	**2.086**		0.004		0.187	Ca
Sc													**100**				Sc
Ti														8.25	**7.44**	73.72	Ti

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
Ti	5.41	5.18															Ti
V		0.25	**99.75**														V
Cr		4.345		**83.79**	9.50	2.365											Cr
Mn							**100**										Mn
Fe						5.85		**91.75**	2.12	0.28							Fe
Co											**100**						Co
Ni										68.08		**26.22**	1.14	3.63		0.93	Ni
Cu															**69.15**		Cu
Zn																49.17	Zn

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
Cu	30.85																Cu
Zn		**27.73**	4.04	18.45		0.61											Zn
Ga					60.11		**39.89**										Ga
Ge						20.57		**27.45**	7.75	36.50		7.73					Ge
As											**100**						As
Se										0.89		9.37	7.63	**23.77**		49.61	Se
Br															**50.69**		Br
Kr														0.35		2.29	Kr

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	
Se		8.73															Se
Br	49.31																Br
Kr		11.59	11.50	56.99		17.28											Kr
Rb					**72.17**		27.83										Rb
Sr				0.56		9.86	7.00	**82.58**									Sr
Y									**100**								Y
Zr										**51.45**	11.22	17.15		17.38		2.80	Zr
Nb													**100**				Nb
Mo												14.53		9.15	**15.84**	16.67	Mo
Ru																5.54	Ru

🟨 : recommended mass number (He mode)

	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	
Mo	9.60	24.39		9.82													Mo
Ru		1.87	12.76	12.60	**17.06**	31.55		18.62									Ru
Rh							**100**										Rh
Pd						1.02		11.14	**22.33**	27.33		26.46		11.72			Pd
Ag											**51.84**		48.16				Ag
Cd										1.25		0.89		12.49	**12.80**	24.13	Cd
Sn																0.97	Sn

	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	
Cd	12.22	28.73		7.49													Cd
In	4.29		**95.71**														In
Sn		0.66	0.34	14.54	7.68	**24.22**	8.59	32.58		4.63		5.79					Sn
Sb									**57.21**		42.79						Sb
Te								0.09		2.55	0.89	4.74	**7.07**	18.84		31.74	Te
I															**100**		I
Xe												0.09		0.09		1.91	Xe

	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	
Te		34.08															Te
Xe	26.40	4.07	21.23	26.91		10.44		8.86									Xe
Cs					**100**												Cs
Ba		0.11		0.10		2.42	6.59	7.85	**11.23**	71.70							Ba
La										0.09	**99.91**						La
Ce								0.19		0.25		**88.45**		11.11			Ce
Pr													**100**				Pr
Nd														27.2	12.2	23.8	Nd
Sm																3.07	Sm

	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	
Nd	8.3	**17.2**		5.7		5.6											Nd
Sm			**14.99**	11.24	13.82	7.38		26.75		22.75							Sm
Eu							47.81		**52.19**								Eu
Gd								0.20		2.18	14.80	20.47	**15.65**	24.84		21.86	Gd
Tb															**100**		Tb
Dy												0.06		0.09		2.33	Dy

	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	
Dy	18.89	25.47	**24.90**	28.26													Dy
Ho					**100**												Ho
Er		0.14		1.60		**33.50**	22.87	26.98		14.91							Er
Tm									**100**								Tm
Yb								0.12		2.98	14.09	**21.68**	16.10	32.03		13.00	Yb
Lu															**97.40**	2.60	Lu
Hf														0.16		5.26	Hf

	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	
Hf	18.60	**27.28**	13.62	35.08													Hf
Ta				0.01	**99.99**												Ta
W				0.12		**26.50**	14.31	30.64		28.43							W
Re									**37.40**		62.60						Re
Os								0.02		1.59	1.96	13.24	**16.15**	26.26		40.78	Os
Ir															37.3		Ir
Pt														0.012		0.782	Pt

	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	
Ir	**62.7**																Ir
Pt		32.86	**33.78**	25.21		7.356											Pt
Au					**100**												Au
Hg				0.15		9.97	16.87	23.10	**13.18**	**29.86**		6.87					Hg
Tl											29.52		**70.48**				Tl
Pb												1.4		24.1	22.1	**52.4**	Pb

	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	
Bi	**100**																Bi

	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	
Th								**100**									Th
U										0.005	0.720			**99.274**			U

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Interferences

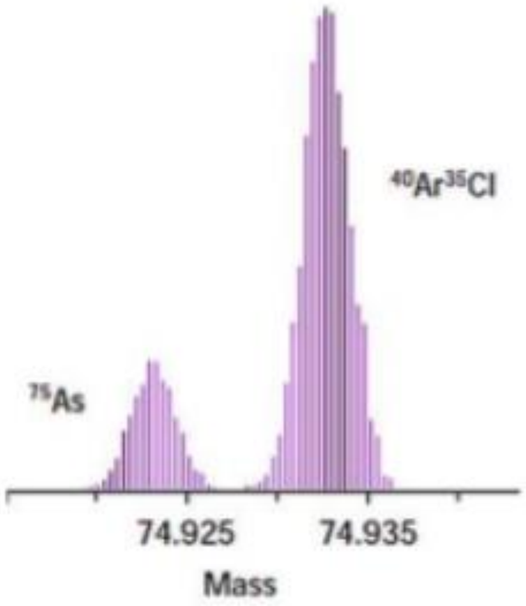
ICP-MS

- **Spectral**

mass overlap of the interfering particle and the measured isotope (same m/z - indistinguishable from each other)

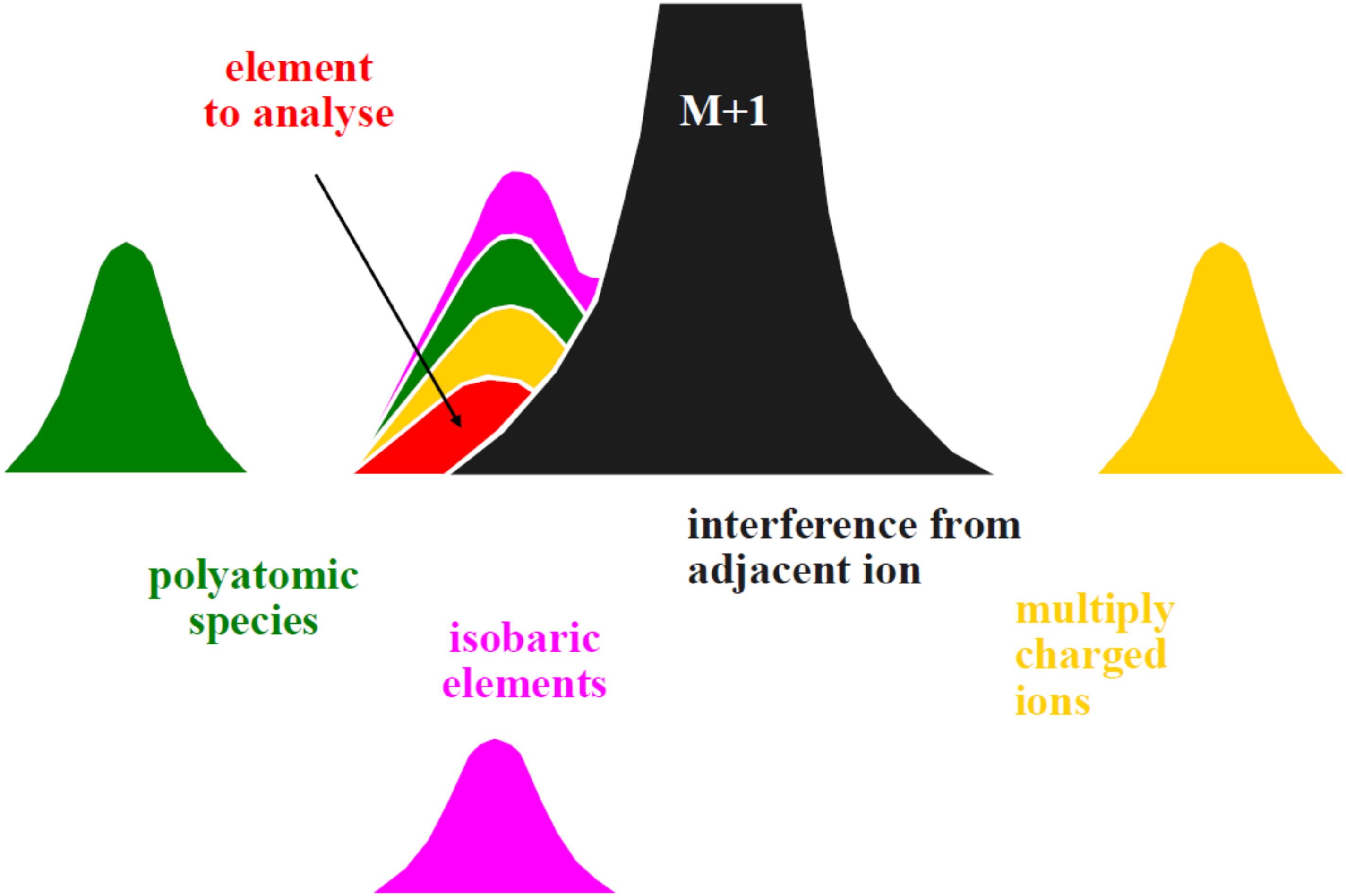
- **Non-spectral**

influencing the signal intensity of the analyte by the presence of various substances in the sample matrix



Spectral interferences

isobaric, polyatomic, multiply charged ions



Spectral interferences

isobaric, polyatomic, double charged species

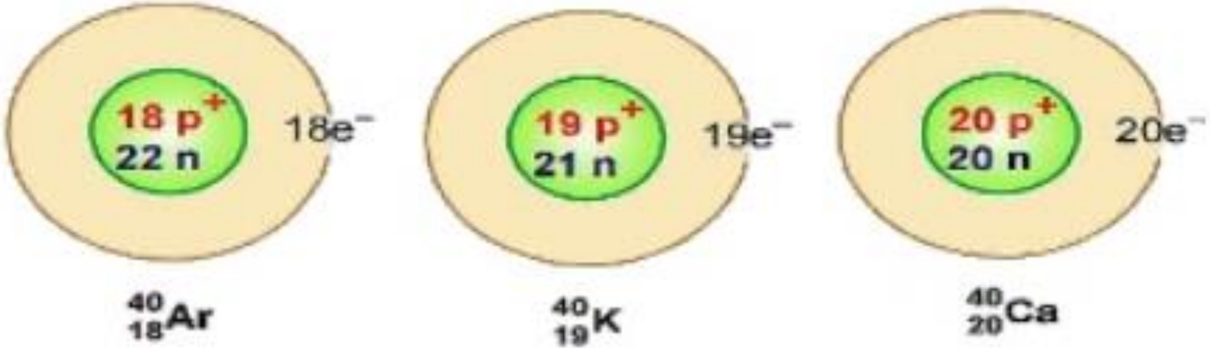
Mass interferences on a given mass-to-charge-ratio (m/z) are possible due to the presence of **isobars** (e.g. ^{204}Hg, ^{204}Pb),

polyatomic/molecular species (e.g., $^{40}Ar^{16}O$ vs ^{56}Fe, $^{40}Ar{:}^{40}Ar$ vs. ^{80}Se) formed by various recombinations of sample, matrix and Ar ions in cooler parts of the plasma

multiply charged ions (e.g., $^{138}Ba^{2+}$ vs. $^{69}Ga^{+}$), also formed in the plasma.

Spectral interferences

isobaric



- Are cause by isotopes of different elements forming atomic ions with the same nominal mass-to-charge ratio (m/z)
- ^{58}Fe on ^{58}Ni, ^{64}Ni on ^{64}Zn, ^{48}Ca on ^{48}Ti
- They are bet avoided by choosing alternative, noninterfered analyte isotopes, if available
- Given acknowledge of the natural abundances of the isotopes of all elements, isobaric interferences are easily corrected by measuring the intensity of another isotope of the interfering element and substracting the appropriate correction factor from the intensity of the interfered isotope.

Tabulka 1: Přehled atomárních izobarických interferencí a volba alternativních izotopů

dominantní izotop	interferující izotop	alternativní izotop
^{40}Ca (96,9 %)	^{40}Ar (99,6)	^{42}Ca (0,65 %), ^{43}Ca (0,14 %), ^{44}Ca (2,09 %)
^{48}Ti (73,7 %)	^{48}Ca (0,19 %)	^{46}Ti (8,25 %)
^{58}Ni (68,1 %)	^{58}Fe (0,28 %)	^{60}Ni (26,2 %)
^{64}Zn (48,6 %)	^{64}Zn (0,93 %)	^{66}Zn (27, 9 %)
^{74}Ge (35,9 %)	^{74}Se (0,89 %)	^{72}Ge (27,7 %)
^{80}Se (49,6 %)	^{80}Kr (2,28 %)	^{77}Se (7,64 %)
^{96}Mo (16,7 %)	^{96}Zr (2,80 %), ^{96}Ru (5,54 %)	^{95}Mo (15,9 %)
^{102}Ru (31,6 %)	^{102}Pd (1,02 %)	^{101}Ru (17,1 %)
^{106}Pd (27,3 %)	^{106}Cd (1,25 %)	^{105}Pd (22,3 %)
^{114}Cd (28,7 %)	^{114}Sn (0,66 %)	^{111}Cd (12,8 %)
^{115}In (95,7 %)	^{115}Sn (0,34 %)	------
^{113}In (4,3 %)	^{113}Cd (12,2 %)	------
^{120}Sn (32,6 %)	^{120}Te (0,10 %)	^{118}Sn (24,2 %)
^{130}Te (33,8 %)	^{130}Xe (4,1 %), ^{130}Ba (0,1 %)	^{125}Te (7,14 %)
^{138}Ba (71,7 %)	^{138}La (0,1 %), ^{138}Ce (0,25 %)	^{137}Ba (11,2 %)
^{142}Nd (27,2 %)	^{142}Ce (11,1 %)	^{146}Nd (17,2 %)
^{152}Sm (26,7 %)	^{152}Gd (0,2 %)	^{147}Sm (15,0 %)
^{164}Dy (28,2 %)	^{164}Er (1,61 %)	^{163}Dy (24,9 %)
^{174}Yb (31,8 %)	^{174}Hf (0,16 %)	^{172}Yb (21,8 %)
^{180}Hf (35,1 %)	^{180}Ta (0,01 %),^{180}W (0,12 %)	^{178}Hf (27,3 %)
^{184}W (30,6 %)	^{184}Os (0,02 %)	^{182}W (26,5 %)
^{187}Re (62,6 %)	^{187}Os (1,96 %)	^{185}Re (37,4 %)
^{192}Os (40,8 %)	^{192}Pt (0,78 %)	^{189}Os (16,1 %)

Isobaric interferences

geochronology

U-(Th)-Pb system

$$\left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_P = \left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_I + \left(\frac{^{235}\mathrm{U}}{^{204}\mathrm{Pb}}\right)_P (e^{\lambda_{235}t} - 1)$$

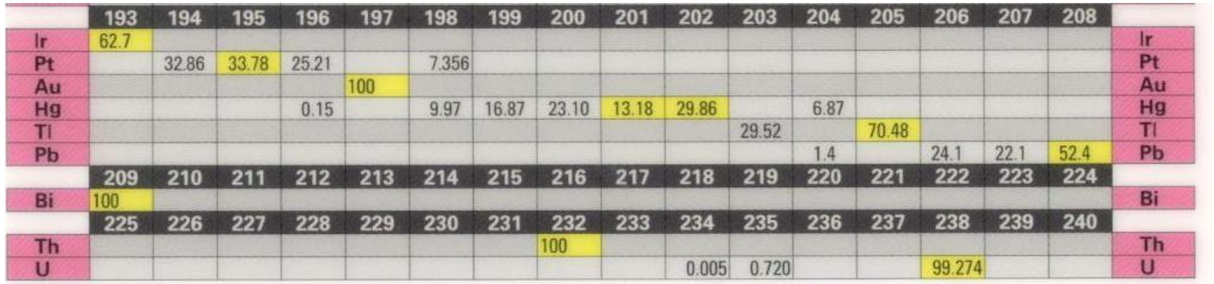
$$\left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_P = \left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_I + \left(\frac{^{238}\mathrm{U}}{^{204}\mathrm{Pb}}\right)_P (e^{\lambda_{238}t} - 1)$$

$$\left[\frac{\left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_P - \left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_I}{\left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_P - \left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_I}\right] = \left(\frac{1}{137.88}\right)\left(\frac{e^{\lambda_{235}t} - 1}{e^{\lambda_{238}t} - 1}\right)$$

Accurate masses: $^{203.973481}\mathrm{Hg}$; $^{203.973037}\mathrm{Pb}$

$$R = \frac{203.973037}{203.973481 - 203.973037} \cong 459400$$

$^{238}\mathrm{U}$
$^{235}\mathrm{U}$
$^{232}\mathrm{Th}$
$^{208}\mathrm{Pb}$
$^{207}\mathrm{Pb}$
$^{206}\mathrm{Pb}$
$^{204}\mathrm{Pb}$
$^{202}\mathrm{Hg}$



	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	
Ir	62.7																Ir
Pt		32.86	33.78	25.21		7.356											Pt
Au					100												Au
Hg				0.15		9.97	16.87	23.10	13.18	29.86		6.87					Hg
Tl											29.52		70.48				Tl
Pb												1.4		24.1	22.1	52.4	Pb
	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	
Bi	100																Bi
	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	
Th								100									Th
U										0.005	0.720			99.274			U

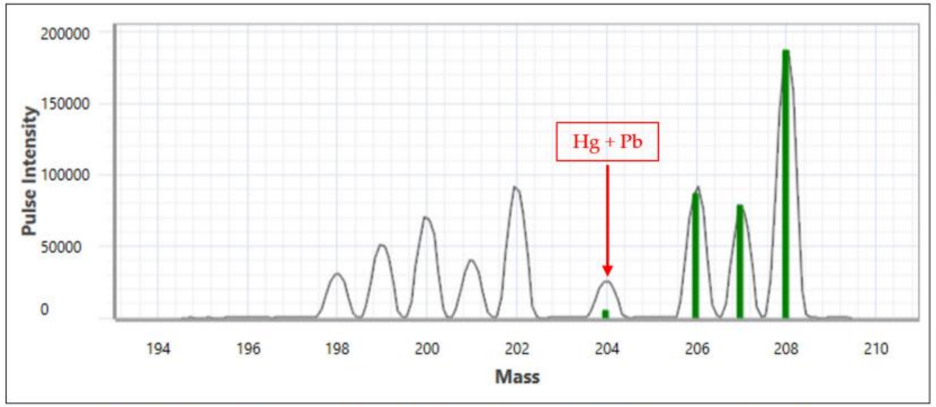


Figure 9. Standard mode scan of 1 ppb Hg and 1 ppb Pb. Pb isotope abundances shown as green bars.

https://resources.perkinelmer.com/

Spectral interferences

polyatomic

- are formed in the plasma by a combination of different ions
- the degree of interference can be influenced by the conditions in the plasma - ionization conditions (power input to the plasma, position of the plasma torch…) - tuning of the device
- Ions originate from:

  working gas (argon, laser ablation He)

  sample matrix

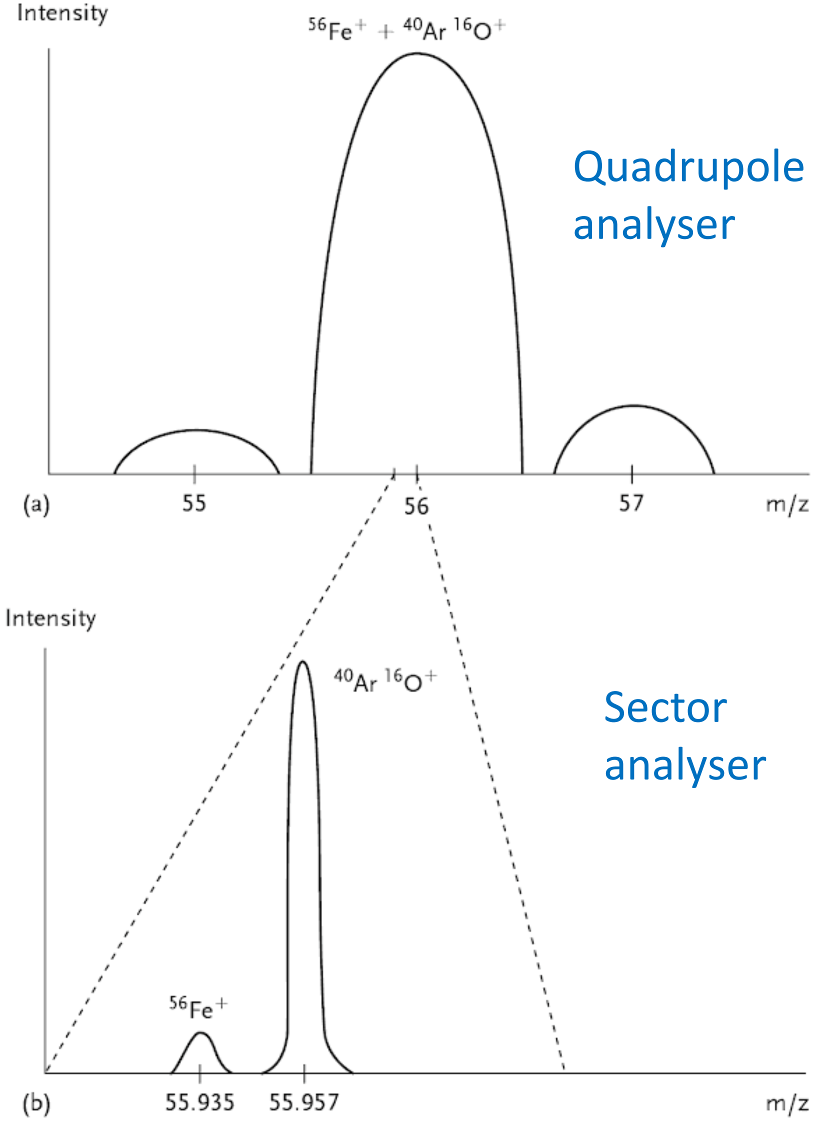
  solvent

example $^{40}Ar^{16}O$ vs. ^{56}Fe

solutoin: use of alternative isotope ^{57}Fe

analyser with high resolution (10 000)

$^{40}Ar^{16}O$ 55,957 *vs.* ^{56}Fe 55,935



Quadrupole analyser

Sector analyser

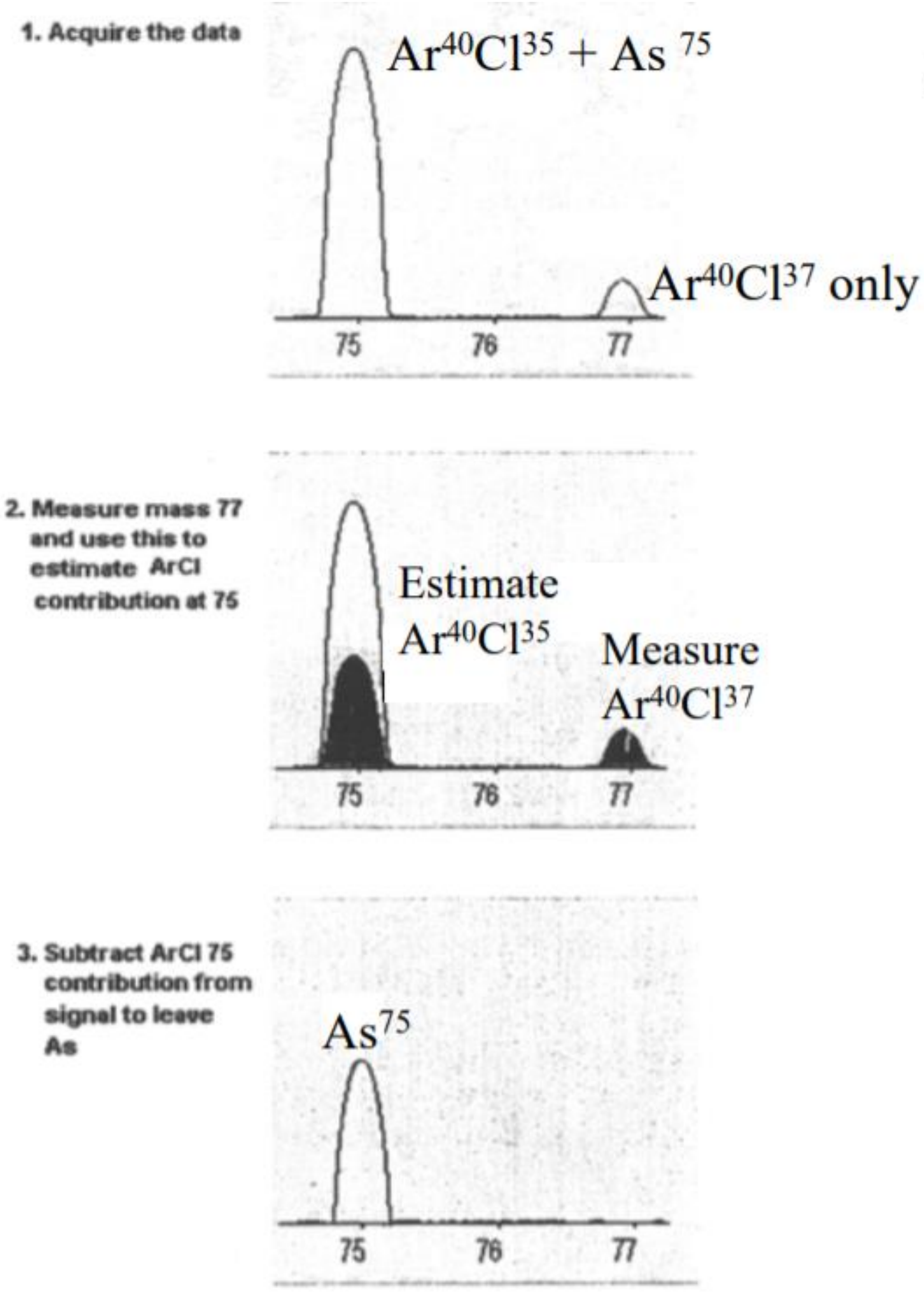


figure 6.1 - Interference correction

Interference Correction Equations

- $Ar^{40}Cl^{35}$ interferes with the analyte of interest, As^{75}, at mass 75.
- Assuming that the other ArCl peak at mass 77 is not itself being interfered with, its peak intensity can be used to estimate the contribution of $Ar^{40}Cl^{35}$ to the peak at mass 75.
- Because Cl^{35} and Cl^{37} are in a fixed natural ratio, the ArCl contribution at mass 75 can be estimated by multiplying the signal at mass 77 by the natural isotope ratio Cl^{35}/Cl^{37}.
- Once the contribution of ArCl at mass 75 is estimated, its intensity can be simply subtracted from the total signal intensity at mass 75, leaving the intensity due to the analyte of interest, As^{75}.

$$As75=I75-(I77*(75.77/24.23))$$

A Table of Polyatomic Interferences in ICP-MS

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Spectroscopic interferences are probably the largest class of interferences in ICP-MS and are caused by atomic or molecular ions that have the same mass-to-charge as analytes of interest. Current ICP-MS instrumental software corrects for all known atomic "isobaric" interferences, or those caused by overlapping isotopes of different elements, but does not correct for most polyatomic interferences. Such interferences are caused by polyatomic ions that are formed from precursors having numerous sources, such as the sample matrix, reagents used for preparation, plasma gases, and entrained atmospheric gases.

A prior knowledge of polyatomic interferences cited in the literature for a particular analyte mass may be helpful to the analyst for selecting reagents and conditions that would preclude or at least reduce the possibility of their formation. A good perspective of known polyatomic interferences is difficult because of the number of affected masses, the number of interferences themselves, and the number of literature references in which they are reported. In a review of the ICP-MS literature, reported polyatomic interferences were consolidated to produce a table that may serve as a useful tool for the ICP-MS analyst. For quick reference, the masses are arranged in alphabetical order by elemental symbol. This list of interferences is not intended to be complete, but does cover those more frequently reported.

A Table of Polyatomic Interferences in ICP-MS

Isotope	Abundance	Interference	Reference
^{107}Ag	51.8	$^{91}Zr^{16}O^+$	(6)(9)
^{109}Ag	48.2	$^{92}Zr^{16}O^1H^+$	(9)
^{27}Al	100.	$^{12}C^{15}N^+$, $^{13}C^{14}N^+$, $^{14}N^2$ spread, $^1H^{12}C^{14}N^+$	(11)(18)(29)
^{75}As	100.	$^{40}Ar^{35}Cl^+$, $^{59}Co^{16}O^+$, $^{36}Ar^{38}Ar^1H^+$, $^{38}Ar^{37}Cl^+$, $^{36}Ar^{39}K$, $^{43}Ca^{16}O_2$, $^{23}Na^{12}C^{40}Ar$, $^{12}C^{31}P^{16}O_2{}^+$	(2)(9)(15)(19)(22)(33)(34) (35)
^{197}Au	100.	$^{181}Ta^{16}O^+$	(9)
^{11}B	80.09	^{12}C spread	(18)
^{130}Ba	0.106	$^{98}Ru^{16}O_2{}^+$	(32)
^{132}Ba	0.101	$^{100}Ru^{16}O_2{}^+$	(32)
^{134}Ba	2.417	$^{102}Ru^{16}O_2{}^+$	(32)
^{136}Ba	7.854	$^{104}Ru^{16}O_2{}^+$	(32)
^{209}Bi	100.	$^{193}Ir^{16}O^+$	(32)
^{79} Br	50.54	$^{40}Ar^{39}K^+$, $^{31}P^{16}O_3{}^+$, $^{38}Ar^{40}Ar^1H^+$	(19)(22)
^{81}Br	49.46	$^{32}S^{16}O_3{}^1H^+$, $^{40}Ar^{40}Ar^1H^+$, $^{33}S^{16}O_3{}^+$	(19)(22)
^{40}Ca	96.97	$^{40}Ar^+$	(4)(22)
^{42}Ca	0.64	$^{40}Ar^1H_2$	(12)(22)
^{43}Ca	0.145	$^{27}Al^{16}O^+$	(21)
^{44}Ca	2.06	$^{12}C^{16}O_2$, $^{14}N_2{}^{16}O^+$, $^{28}Si^{16}O^+$	(12)(22)(29)
^{46}Ca	0.003	$^{14}N^{16}O_2{}^+$, $^{32}S^{14}N^+$	(22)
^{48}Ca	0.19	$^{33}S^{15}N^+$, $^{34}S^{14}N^+$, $^{32}S^{16}O^+$	(22)
^{110}Cd	12.5	$^{39}K_2{}^{16}O^+$	(6)
^{111}Cd	12.8	$^{95}Mo^{16}O^+$, $^{94}Zr^{16}O^1H^+$, $^{39}K_2{}^{16}O_2{}^1H^+$	(1)(6)
^{112}Cd	24.1	$^{40}Ca_2{}^{16}O_2$, $^{40}Ar_2{}^{16}O_2$, $^{96}Ru^{16}O^+$	(6)(32)
^{113}Cd	12.22	$^{96}Zr^{16}O^1H^+$, $^{40}Ca_2{}^{16}O_2{}^1H^+$, $^{40}Ar_2{}^{16}O_2{}^1H^+$, $^{96}Ru^{17}O^+$	(1)(6)(32)
^{114}Cd	28.7	$^{98}Mo^{16}O^+$, $^{98}Ru^{16}O^+$	(6)(32)
^{116}Cd	7.49	$^{100}Ru^{16}O^+$	(32)

A Table of Polyatomic Interferences in ICP-MS (cont'd)

Isotope	Abundance	Interference	Reference
^{35}Cl	75.77	$^{16}O^{18}O^1H^+$, $^{34}S^1H^+$, $^{35}Cl^+$	(22)
^{37}Cl	24.23	$^{36}Ar^1H^+$, $^{36}S^1H^+$, $^{37}Cl^+$	(22)
^{59}Co	100.	$^{43}Ca^{16}O^+$, $^{42}Ca^{16}O^1H^+$, $^{24}Mg^{35}Cl^+$, $^{36}Ar^{23}Na^+$, $^{40}Ar^{18}O^1H^+$, $^{40}Ar^{19}F^+$	(5)(8)(9)(13)(19)(22)(29)(34)
^{50}Cr	4.35	$^{34}S^{16}O^+$, $^{36}Ar^{14}N^+$, $^{35}Cl^{15}N^+$ $^{36}S^{14}N^+$, $^{32}S^{18}O^+$, $^{33}S^{17}O^+$	(2)(15)(22)
^{52}Cr	83.76	$^{35}Cl^{16}O^1H^+$, $^{40}Ar^{12}C^+$, $^{36}Ar^{16}O^+$, $^{37}Cl^{15}N^+$ $^{34}S^{18}O^+$, $^{36}S^{16}O^+$, $^{38}Ar^{14}N^+$, $^{36}Ar^{15}N^1H^+$, $^{35}Cl^{17}O^+$	(1)(2)(9)(15)(18) (19)(22)(29)(35)
^{53}Cr	9.51	$^{37}Cl^{16}O^+$, $^{38}Ar^{15}N^+$, $^{38}Ar^{14}N^1H^+$, $^{36}Ar^{17}O^+$, $^{36}Ar^{16}O^1H^+$, $^{35}Cl^{17}O^1H^+$, $^{35}Cl^{18}O^+$, $^{36}S^{17}O^+$, $^{40}Ar^{13}C^+$	(1)(22)(29)(34)
^{54}Cr	2.38	$^{37}Cl^{16}O^1H^+$, $^{40}Ar^{14}N^+$, $^{38}Ar^{15}N^1H^+$, $^{36}Ar^{18}O^+$, $^{38}Ar^{16}O^+$, $^{36}Ar^{17}O^1H^+$, $^{37}Cl^{17}O^+$, $^{19}F_2{}^{16}O^+$	(2)(22)(29)(34)
^{133}Cs	100.	$^{101}Ru^{16}O_2{}^+$	(32)
^{63}Cu	69.1	$^{31}P^{16}O_2{}^+$, $^{40}Ar^{23}Na^+$, $^{47}Ti^{16}O^+$, $^{23}Na^{40}Ca^+$, $^{46}Ca^{16}O^1H^+$, $^{36}Ar^{12}C^{14}N^1H^+$, $^{14}N^{12}C^{37}Cl^+$, $^{16}O^{12}C^{35}Cl^+$	(2)(9)(19)(28)(29)
65Cu	30.9	$^{49}Ti^{16}O^+$, $^{32}S^{16}O_2{}^1H^+$, $^{40}Ar^{25}Mg^+$, $^{40}Ca^{16}O^1H^+$, $^{36}Ar^{14}N_2{}^1H^+$, $^{32}S^{33}S^+$, $^{32}S^{16}O^{17}O^+$, $^{33}S^{16}O_2{}^+$, $^{12}C^{16}O^{37}Cl^+$, $^{12}C^{18}O^{35}Cl^+$, $^{31}P^{16}O^{18}O^+$	(5)(15)(17)(21)(22)(29)(34)
^{163}Dy	24.97	$^{147}Sm^{16}O^+$	(27)(38)
^{166}Er	33.6	$^{160}Nd^{16}O$, $^{150}Sm^{16}O$	(38)
^{167}Er	22.94	$^{151}Eu^{16}O^+$	(27)
^{151}Eu	47.82	$^{135}Ba^{16}O^+$	(23)(27)
^{153}Eu	52.2	$^{137}Ba^{16}O^+$	(9)(38)
^{54}Fe	5.82	$^{37}Cl^{16}O^1H^+$, $^{40}Ar^{14}N$, $^{38}Ar^{15}N^1H^+$, $^{36}Ar^{18}O^+$, $^{38}Ar^{16}O^+$, $^{36}Ar^{17}O^1H^+$, $^{36}S^{18}O^+$, $^{35}Cl^{18}O^1H^+$, $^{37}Cl^{17}O$	(15)(18)(22)(29)(36)
^{56}Fe	91.66	$^{40}Ar^{16}O^+$, $^{40}Ca^{16}O^+$, $^{40}Ar^{15}N^1H^+$, $^{38}Ar^{18}O^+$, $^{38}Ar^{17}O^1H^+$ $^{37}Cl^{18}O^1H^+$	(3)(22)(29)
^{57}Fe	2.19	$^{40}Ar^{16}O^1H^+$, $^{40}Ca^{16}O^1H^+$, $^{40}Ar^{17}O^+$, $^{38}Ar^{18}O^1H^+$, $^{38}Ar^{19}F^+$	(8)(9)(21)(22)(29)(34)
^{58}Fe	0.33	$^{40}Ar^{18}O^+$, $^{40}Ar^{17}O^1H^+$	(22)
^{69}Ga	60.16	$^{35}Cl^{16}O^{18}O^+$, $^{35}Cl^{17}O_2{}^+$, $^{37}Cl^{16}O_2{}^+$, $^{36}Ar^{33}S^+$, $^{33}S^{18}O_2{}^+$, $^{34}S^{17}O^{18}O^+$, $^{36}S^{16}O^{17}O^+$, $^{33}S^{36}S^+$	(22)
^{71}Ga	39.84	$^{35}Cl^{18}O_2{}^+$, $^{37}Cl^{16}O^{18}O^+$, $^{37}Cl^{17}O_2{}^+$, $^{36}Ar^{35}Cl^+$, $^{36}S^{17}O^{18}O^+$, $^{38}Ar^{33}S^+$	(22)
^{155}Gd	14.8	$^{139}La^{16}O^+$	(3)
^{157}Gd	15.68	$^{138}B^{19}F^+$, $^{141}Pr^{16}O^+$	(26)(27)
^{70}Ge	20.51	$^{40}Ar^{14}N^{16}O^+$, $^{35}Cl^{17}O^{18}O^+$, $^{37}Cl^{16}O^{17}O^+$, $^{34}S^{18}O_2{}^+$, $^{36}S^{16}O^{18}O^+$, $^{36}S^{17}O_2{}^+$, $^{34}S^{36}S^+$, $^{36}Ar^{34}S^+$, $^{38}Ar^{32}S^+$, $^{35}Cl_2{}^+$	(22)(30)
^{72}Ge	27.4	$^{36}Ar_2{}^+$, $^{37}Cl^{17}O^{18}O^+$, $^{35}Cl^{37}Cl^+$, $^{36}S^{18}O_2{}^+$, $^{36}S_2{}^+$, $^{36}Ar^{36}S^+$ $^{56}Fe^{16}O^+$, $^{40}Ar^{16}O_2{}^+$, $^{40}Ca^{16}O_2{}^+$, $^{40}Ar^{32}S^+$	(22)(28)
^{73}Ge	7.76	$^{36}Ar_2{}^1H^+$, $^{37}Cl^{18}O_2{}^+$, $^{36}Ar^{37}Cl^+$, $^{38}Ar^{35}Cl^+$, $^{40}Ar^{33}S^+$	(22)
^{74}Ge	36.56	$^{40}Ar^{34}S^+$, $^{36}Ar^{38}Ar^+$, $^{37}Cl^{37}Cl^+$, $^{38}Ar^{36}S^+$	(22)
^{76}Ge	7.77	$^{36}Ar^{40}Ar^+$, $^{38}Ar^{38}Ar^+$, $^{40}Ar^{36}S^+$	(22)
^{177}Hf	18.5	$^{161}Dy^{16}O^+$	(27)
^{165}Ho	100.	$^{149}Sm^{16}O$	(27)

A Table of Polyatomic Interferences in ICP-MS (cont'd)

Isotope	Abundance	Interference	Reference
^{113}In	4.3	$^{96}Ru^{17}O^+$	(32)
^{39}K	93.08	$^{38}Ar^1H^+$	(22)(29)
^{40}K	0.01	$^{40}Ar^+$	(22)
^{41}K	6.91	$^{40}Ar^1H^+$	(22)
^{78}Kr	0.35	$^{38}Ar^{40}Ar^+$	(22)
^{80}Kr	2.27	$^{40}Ar_2^+$, $^{32}S^{16}O_3^+$	(22)
^{82}Kr	11.56	$^{40}Ar^{40}Ar^1H_2^+$, $^{34}S^{16}O_3^+$, $^{33}S^{16}O_3^1H^+$	(22)
^{83}Kr	11.55	$^{34}S^{16}O_3^1H^+$	(22)
^{84}Kr	56.9	$^{36}S^{16}O_3^+$	(22)
^{175}Lu	97.41	$^{159}Tb^{16}O^+$	(27)(38)
^{24}Mg	78.7	$^{12}C_2^+$	(29)
^{25}Mg	10.13	$^{12}C_2^1H^+$	(29)
^{26}Mg	11.17	$^{12}C^{14}N^+$, $^{12}C_2^1H_2^+$, $^{12}C^{13}C^1H^+$	(29)
^{55}Mn	100.	$^{40}Ar^{14}N^1H^+$, $^{39}K^{16}O^+$, $^{37}Cl^{18}O^+$, $^{40}Ar^{15}N^+$, $^{38}Ar^{17}O^+$, $^{36}Ar^{18}O^1H^+$ $^{38}Ar^{16}O^1H^+$, $^{37}Cl^{17}O^1H^+$, $^{23}Na^{32}S^+$, $^{36}Ar^{19}F^+$	(2)(9)(11)(19)(22)(29)(34) (35)
^{94}Mo	9.3	$^{39}K_2^{16}O^+$	(11)
^{95}Mo	15.9	$^{40}Ar^{39}K^{16}O^+$, $^{79}Br^{16}O^+$	(11)
^{96}Mo	16.7	$^{39}K^{41}K^{16}O^+$, $^{79}Br^{17}O^+$	(11)
^{97}Mo	9.6	$^{40}Ar_2^{16}O^1H^+$, $^{40}Ca_2^{16}O^1H^+$, $^{40}Ar^{41}K^{16}O^+$, $^{81}Br^{16}O^+$	(6)(11)
^{98}Mo	24.1	$^{81}Br^{17}O^+$, $^{41}K_2O^+$	(6)(11)
^{144}Nd	23.80	$^{96}Ru^{16}O_3^+$	(32)
^{146}Nd	17.19	$^{98}Ru^{16}O_3^+$	(32)
^{148}Nd	5.76	$^{100}Ru^{16}O^{3+}$	(32)
^{150}Nd	5.64	$^{102}Ru^{16}O_3^+$	(32)
^{58}Ni	67.77	$^{23}Na^{35}Cl^+$, $^{40}Ar^{18}O^+$, $^{40}Ca^{18}O^+$, $^{40}Ca^{17}O^1H^+$, $^{42}Ca^{16}O^+$, $^{29}Si_2^+$, $^{40}Ar^{17}O^1H^+$, $^{23}Na^{35}Cl^+$	(9)(16)(18)(19)(20)(22)(29)
^{60}Ni	26.16	$^{44}Ca^{16}O^+$, $^{23}Na^{37}Cl^+$, $^{43}Ca^{16}O^1H^+$	(3)(13)(26)(29)
^{61}Ni	1.25	$^{44}Ca^{16}O^1H^+$, $^{45}Sc^{16}O^+$	(1)(25)
^{62}Ni	3.66	$^{46}Ti^{16}O^+$, $^{23}Na^{39}K^+$, $^{46}Ca^{16}O^+$	(1)(9)(25)
^{64}Ni	1.16	$^{32}S^{16}O_2^+$, $^{32}S_2^+$	(22)(29)
^{31}P	100.	$^{14}N^{16}O^1H^+$, $^{15}N^{15}N^1H^+$, $^{15}N^{16}O^+$, $^{14}N^{17}O^+$, $^{13}C^{18}O^+$, $^{12}C^{18}O^1H^+$	(3)(22)(29)
^{206}Pb	24.1	$^{190}Pt^{16}O^+$	(32)
^{207}Pb	22.1	$^{191}Ir^{16}O^+$	(32)
^{208}Pb	52.4	$^{192}Pt^{16}O^+$	(32)
^{105}Pd	22.3	$^{40}Ar^{65}Cu^+$	(9)
^{103}Rh	100.	$^{40}Ar^{63}Cu^+$	(9)(26)
^{101}Ru	17.0	$^{40}Ar^{61}Ni^+$, $^{64}Ni^{37}Cl^+$	(9)
^{32}S	95.02	$^{16}O_2^+$, $^{14}N^{18}O^+$, $^{15}N^{17}O^+$, $^{14}N^{17}O^1H^+$, $^{15}N^{16}O^1H^+$, $^{32}S^+$ $^{14}N^{16}O^1H_2^+$	(9)(22)(29)
^{33}S	0.75	$^{15}N^{18}O^+$, $^{14}N^{18}O^1H^+$, $^{15}N^{17}O^1H^+$, $^{16}O^{17}O^+$, $^{16}O_2^1H^+$, $^{33}S^+$, $^{32}S^1H^+$	(22)(29)
^{34}S	4.21	$^{15}N^{18}O^1H^+$, $^{16}O^{18}O^+$, $^{17}O_2^+$, $^{16}O^{17}O^1H^+$, $^{34}S^+$, $^{33}S^1H^+$	(22)(29)
^{121}Sb	57.36	$^{105}Pd^{16}O^+$	(32)

A Table of Polyatomic Interferences in ICP-MS (cont'd)

Isotope	Abundance	Interference	Reference
^{123}Sb	47.6	$^{94}Zr^{16}O_2$	(1)
^{45}Sc	100.	$^{12}C^{16}O_2^1H^+$, $^{28}Si^{16}O^1H^+$, $^{29}Si^{16}O^+$, $^{14}N_2^{16}O^1H^+$, $^{13}C^{16}O_2^+$	(2)(9)(22)(29)
^{74}Se	0.87	$^{37}Cl^{37}Cl^+$, $^{36}Ar^{38}Ar^+$, $^{38}Ar^{36}S^+$, $^{40}Ar^{34}S^+$	(9)(22)(35)
^{76}Se	9.02	$^{40}Ar^{36}Ar^+$, $^{38}Ar^{38}Ar^+$	(2)(10)(22)(35)
^{77}Se	7.58	$^{40}Ar^{37}Cl^+$, $^{36}Ar^{40}Ar^1H^+$, $^{38}Ar_2^1H^+$, $^{12}C^{19}F^{14}N^{16}O_2^+$	(2)(15)(19)(22)(34)
^{78}Se	23.52	$^{40}Ar^{38}Ar^+$, $^{38}Ar^{40}Ca^+$	(2)(24)(35)
^{80}Se	49.82	$^{40}Ar_2^+$, $^{32}S^{16}O_3^+$	(7)(19)(22)
^{82}Se	9.19	$^{12}C^{35}Cl_2^+$, $^{34}S^{16}O_3^+$, $^{40}Ar_2^1H_2^+$	(9)(11)(22)
^{28}Si	92.21	$^{14}N_2^+$, $^{12}C^{16}O^+$	(21)(22)(29)
^{29}Si	4.7	$^{14}N^{15}N^+$, $^{14}N_2^1H^+$, $^{13}C^{16}O^+$, $^{12}C^{17}O^+$, $^{12}C^{16}O^1H^+$	(22)(29)
^{30}Si	3.09	$^{15}N_2^+$, $^{14}N^{15}N^1H^+$, $^{14}N^{16}O^+$, $^{12}C^{18}O^+$, $^{13}C^{17}O^+$, $^{13}C^{16}O^1H^+$, $^{12}C^{17}O^1H^+$, $^{14}N_2^1H_2^+$, $^{12}C^{16}O^1H_2^+$	(22)(29)(31)
^{144}Sm	3.1	$^{96}Ru^{16}O_3^+$	(32)
^{147}Sm	15.0	$^{99}Ru^{16}O_3^+$	(32)
^{148}Sm	11.3	$^{100}Ru^{16}O_3^+$	(32)
^{149}Sm	13.8	$^{101}Ru^{16}O_3^+$	(32)
^{150}Sm	7.4	$^{102}Ru^{16}O_3^+$	(32)
^{152}Sm	26.7	$^{104}Ru^{16}O_3^+$	(32)
^{112}Sn	0.97	$^{96}Ru^{16}O^+$	(32)
^{115}Sn	0.34	$^{99}Ru^{16}O^+$	(32)
^{116}Sn	14.53	$^{100}Ru^{16}O^+$	(32)
^{117}Sn	7.68	$^{101}Ru^{16}O^+$	(32)
^{118}Sn	24.23	$^{102}Ru^{16}O^+$, $^{102}Pd^{16}O^+$	(32)
^{119}Sn	8.59	$^{103}Rh^{16}O^+$	(32)
^{120}Sn	32.59	$^{104}Ru^{16}O^+$, $^{104}Pd^{16}O^+$	(32)
^{122}Sn	4.63	$^{106}Pd^{16}O^+$	(32)
^{124}Sn	5.79	$^{108}Pd^{16}O^+$	(32)
^{84}Sr	0.56	$^{36}S^{16}O_3^+$	(22)
^{86}Sr	9.86	$^{85}Rb^1H^+$	(26)(27)
^{181}Ta	99.988	$^{165}Ho^{16}O^+$	(27)
^{159}Tb	100.	$^{143}Nd^{16}O^+$	(27)(38)
^{122}Te	2.603	$^{106}Pd^{16}O^+$	(32)
^{124}Te	4.816	$^{108}Pd^{16}O^+$	(32)
^{126}Te	18.95	$^{110}Pd^{16}O^+$	(32)
^{128}Te	31.69	$^{96}Ru^{16}O_2^+$	(32)
^{130}Te	33.80	$^{98}Ru^{16}O_2^+$	(32)
^{46}Ti	7.99	$^{32}S^{14}N^+$, $^{14}N^{16}O_2^+$, $^{15}N_2^{16}O^+$	(3)(22)(29)
^{47}Ti	7.32	$^{32}S^{14}N^1H^+$, $^{30}Si^{16}O^1H^+$, $^{32}S^{15}N^+$, $^{33}N^{14}N^+$, $^{33}S^{14}N^+$, $^{15}N^{16}O_2^+$, $^{14}N^{16}O_2^1H^+$, $^{12}C^{35}Cl^+$, $^{31}P^{16}O^+$	(3)(9)(22)(29)(37)
^{48}Ti	73.98	$^{32}S^{16}O^+$, $^{34}S^{14}N^+$, $^{33}S^{15}N^+$, $^{14}N^{16}O^{18}O^+$, $^{14}N^{17}N_2^+$, $^{12}C_4^+$, $^{36}Ar^{12}C^+$	(3)(18)(19)(22)(29)
^{49}Ti	5.46	$^{32}S^{17}O^+$, $^{32}S^{16}O^1H^+$, $^{35}Cl^{14}N^+$, $^{34}S^{15}N^+$, $^{33}S^{16}O^+$, $^{14}N^{17}O_2^1H^+$, $^{14}N^{35}Cl^+$, $^{36}Ar^{13}C^+$, $^{36}Ar^{12}C^1H^+$, $^{12}C^{37}Cl^+$, $^{31}P^{18}O^+$	(3)(22)(29)(37)

A Table of Polyatomic Interferences in ICP-MS (cont'd)

Isotope	Abundance	Interference	Reference
^{50}Ti	5.25	$^{32}S^{18}O^+$, $^{32}S^{17}O^1H^+$, $^{36}Ar^{14}N^+$, $^{35}Cl^{15}N^+$, $^{36}S^{14}N^+$, $^{33}S^{17}O^+$ $^{34}S^{16}O^+$, $^1H^{14}N^{35}Cl^+$, $^{34}S^{15}O^1H^+$	(3)(22)(29)
^{203}Tl	29.5	$^{187}Re^{16}O^+$, $^{186}W^{16}O^1H^+$	(3)
^{169}Tm	100.	$^{153}Eu^{16}O^+$	(27)
^{50}V	0.24	$^{34}S^{16}O^+$, $^{36}Ar^{14}N^+$, $^{35}Cl^{15}N^+$, $^{36}S^{14}N^+$, $^{32}S^{18}O^+$, $^{33}S^{17}O^+$	(2)(22)(29)
^{51}V	99.76	$^{34}S^{16}O^1H^+$, $^{35}Cl^{16}O^+$, $^{38}Ar^{13}C^+$, $^{36}Ar^{15}N^+$, $^{36}Ar^{14}N^1H^+$, $^{37}Cl^{14}N^+$, $^{36}S^{15}N^+$, $^{33}S^{18}O^+$, $^{34}S^{17}O^+$	(2)(3)(14)(15)(19)(22) (29)(35)
^{182}W	26.41	$^{166}Er^{16}O^+$	(27)
^{172}Yb	21.9	$^{156}Gd^{16}O^+$	(38)
^{173}Yb	16.13	$^{157}Gd^{16}O^+$	(27)
^{64}Zn	48.89	$^{32}S^{16}O_2^+$, $^{48}Ti^{16}O^+$, $^{31}P^{16}O_2^1H^+$, $^{48}Ca^{16}O^+$, $^{32}S_2^+$, $^{31}P^{16}O^{17}O^+$ $^{34}S^{16}O_2^+$, $^{36}Ar^{14}N_2^+$	(2)(9)(11)(15)(19)(22)(34) (35)
^{66}Zn	27.81	$^{50}Ti^{16}O^+$, $^{34}S^{16}O_2^+$, $^{33}S^{16}O_2^1H^+$, $^{32}S^{16}O^{18}O^+$, $^{32}S^{17}O_2^+$, $^{33}S^{16}O^{17}O^+$, $^{32}S^{34}S^+$, $^{33}S_2^+$	(9)(11)(15)(22)
^{67}Zn	4.11	$^{35}Cl^{16}O_2^+$, $^{33}S^{34}S^+$, $^{34}S^{16}O_2^1H^+$, $^{32}S^{16}O^{18}O^1H^+$, $^{33}S^{34}S^+$, $^{34}S^{16}O^{17}O^+$, $^{33}S^{16}O^{18}O^+$, $^{32}S^{17}O^{18}O^+$, $^{33}S^{17}O_2^+$, $^{35}Cl^{16}O_2^+$	(1)(9)(11)(15)(22) (35)
^{68}Zn	18.57	$^{36}S^{16}O_2^+$, $^{34}S^{16}O^{18}O^+$, $^{40}Ar^{14}N_2^+$, $^{35}Cl^{16}O^{17}O^+$, $^{34}S_2^+$, $^{36}Ar^{32}S^+$, $^{34}S^{17}O_2^+$, $^{33}S^{17}O^{18}O^+$, $^{32}S^{18}O_2^+$, $^{32}S^{36}S^+$	(11)(15)(22) (35)
^{70}Zn	0.62	$^{35}Cl^{35}Cl^+$, $^{40}Ar^{14}N^{16}O^+$, $^{35}Cl^{17}O^{18}O^+$, $^{37}Cl^{16}O^{17}O^+$, $^{34}S^{18}O_2^+$, $^{36}S^{16}O^{18}O^+$, $^{36}S^{17}O_2^+$, $^{34}S^{36}S^+$, $^{36}Ar^{34}S^+$, $^{38}Ar^{32}S^+$	(9)(22)

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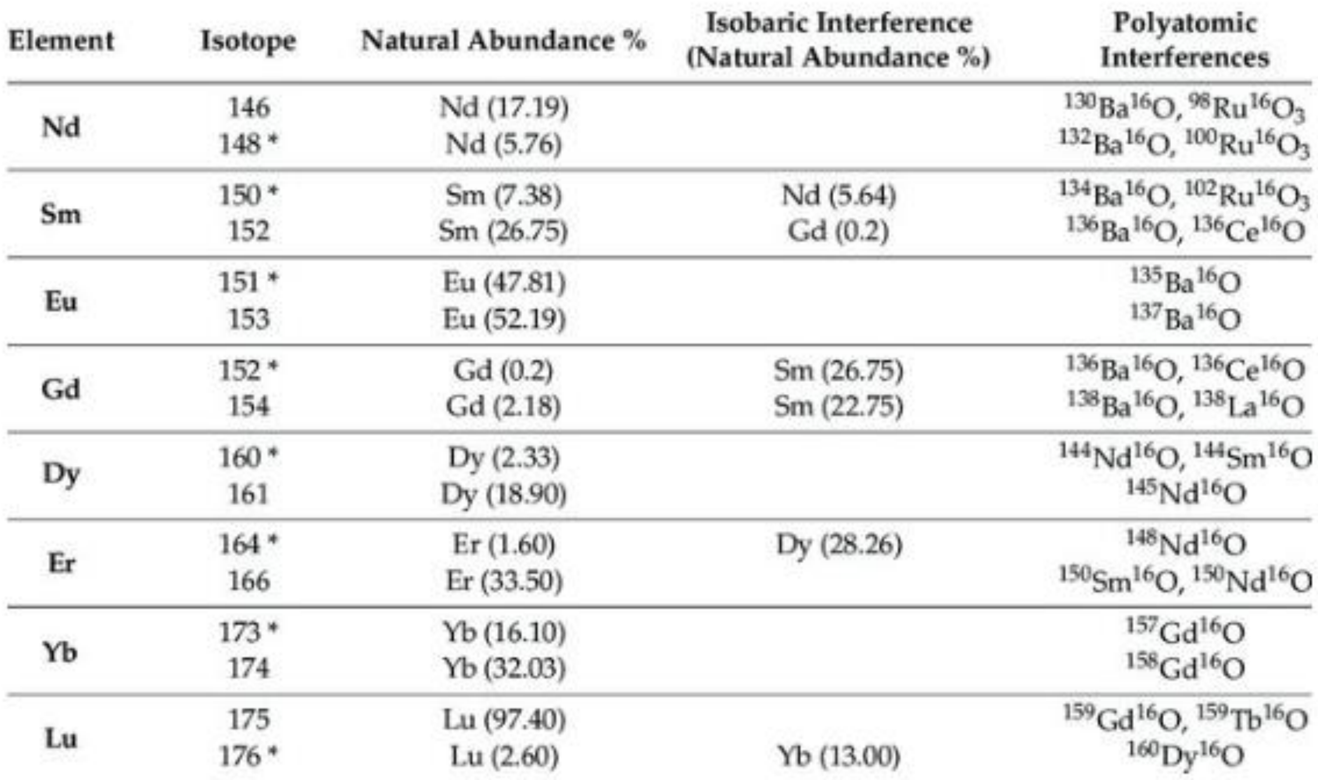
Spectral interferences

polyatomic

REE in geological samples



Element	Isotope	Natural Abundance %	Isobaric Interference (Natural Abundance %)	Polyatomic Interferences
Nd	146	Nd (17.19)		$^{130}\mathrm{Ba}^{16}\mathrm{O}$, $^{98}\mathrm{Ru}^{16}\mathrm{O}_3$
	148 *	Nd (5.76)		$^{132}\mathrm{Ba}^{16}\mathrm{O}$, $^{100}\mathrm{Ru}^{16}\mathrm{O}_3$
Sm	150 *	Sm (7.38)	Nd (5.64)	$^{134}\mathrm{Ba}^{16}\mathrm{O}$, $^{102}\mathrm{Ru}^{16}\mathrm{O}_3$
	152	Sm (26.75)	Gd (0.2)	$^{136}\mathrm{Ba}^{16}\mathrm{O}$, $^{136}\mathrm{Ce}^{16}\mathrm{O}$
Eu	151 *	Eu (47.81)		$^{135}\mathrm{Ba}^{16}\mathrm{O}$
	153	Eu (52.19)		$^{137}\mathrm{Ba}^{16}\mathrm{O}$
Gd	152 *	Gd (0.2)	Sm (26.75)	$^{136}\mathrm{Ba}^{16}\mathrm{O}$, $^{136}\mathrm{Ce}^{16}\mathrm{O}$
	154	Gd (2.18)	Sm (22.75)	$^{138}\mathrm{Ba}^{16}\mathrm{O}$, $^{138}\mathrm{La}^{16}\mathrm{O}$
Dy	160 *	Dy (2.33)		$^{144}\mathrm{Nd}^{16}\mathrm{O}$, $^{144}\mathrm{Sm}^{16}\mathrm{O}$
	161	Dy (18.90)		$^{145}\mathrm{Nd}^{16}\mathrm{O}$
Er	164 *	Er (1.60)	Dy (28.26)	$^{148}\mathrm{Nd}^{16}\mathrm{O}$
	166	Er (33.50)		$^{150}\mathrm{Sm}^{16}\mathrm{O}$, $^{150}\mathrm{Nd}^{16}\mathrm{O}$
Yb	173 *	Yb (16.10)		$^{157}\mathrm{Gd}^{16}\mathrm{O}$
	174	Yb (32.03)		$^{158}\mathrm{Gd}^{16}\mathrm{O}$
Lu	175	Lu (97.40)		$^{159}\mathrm{Gd}^{16}\mathrm{O}$, $^{159}\mathrm{Tb}^{16}\mathrm{O}$
	176 *	Lu (2.60)	Yb (13.00)	$^{160}\mathrm{Dy}^{16}\mathrm{O}$

Relative Isotopic Abundance Table

(unit: %)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
H	99.99	0.01															H
He				100													He
Li						7.59	**92.41**										Li
Be									**100**								Be
B										19.9	**80.1**						B
C												98.93	1.07				C
N														99.64	0.36		N
O																99.76	O

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
O	0.04	0.2															O
F			100														F
Ne				90.48	0.27	9.25											Ne
Na							**100**										Na
Mg								**78.99**	10.00	11.01							Mg
Al											**100**						Al
Si												**92.22**	4.69	3.09			Si
P															**100**		P
S																94.99	S

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	
S	0.75	**4.25**		0.01													S
Cl			**75.76**		24.24												Cl
Ar				0.34		0.06		99.60									Ar
K							**93.26**	0.01	6.73								K
Ca								96.941		0.647	**0.135**	**2.086**		0.004		0.187	Ca
Sc													**100**				Sc
Ti														8.25	**7.44**	73.72	Ti

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
Ti	5.41	5.18															Ti
V		0.25	**99.75**														V
Cr		4.345		**83.79**	9.50	2.365											Cr
Mn							**100**										Mn
Fe						5.85		**91.75**	2.12	0.28							Fe
Co											**100**						Co
Ni										68.08		**26.22**	1.14	3.63		0.93	Ni
Cu															**69.15**		Cu
Zn																49.17	Zn

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	
Cu	30.85																Cu
Zn		**27.73**	4.04	18.45		0.61											Zn
Ga					60.11		**39.89**										Ga
Ge						20.57		**27.45**	7.75	36.50		7.73					Ge
As											**100**						As
Se										0.89		9.37	7.63	**23.77**		49.61	Se
Br															**50.69**		Br
Kr														0.35		2.29	Kr

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	
Se		8.73															Se
Br	49.31																Br
Kr		11.59	11.50	56.99		17.28											Kr
Rb					**72.17**		27.83										Rb
Sr				0.56		9.86	7.00	**82.58**									Sr
Y									**100**								Y
Zr										**51.45**	11.22	17.15		17.38		2.80	Zr
Nb													**100**				Nb
Mo												14.53		9.15	**15.84**	16.67	Mo
Ru																5.54	Ru

🟨 : recommended mass number (He mode)

	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	
Mo	9.60	24.39		9.82													Mo
Ru		1.87	12.76	12.60	**17.06**	31.55		18.62									Ru
Rh							**100**										Rh
Pd						1.02		11.14	**22.33**	27.33		26.46		11.72			Pd
Ag											**51.84**		48.16				Ag
Cd										1.25		0.89		12.49	**12.80**	24.13	Cd
Sn																0.97	Sn

	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	
Cd	12.22	28.73		7.49													Cd
In	4.29		**95.71**														In
Sn		0.66	0.34	14.54	7.68	**24.22**	8.59	32.58		4.63		5.79					Sn
Sb									**57.21**		42.79						Sb
Te								0.09		2.55	0.89	4.74	**7.07**	18.84		31.74	Te
I															**100**		I
Xe												0.09		0.09		1.91	Xe

	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	
Te		34.08															Te
Xe	26.40	4.07	21.23	26.91		10.44		8.86									Xe
Cs					**100**												Cs
Ba		0.11		0.10		2.42	6.59	7.85	**11.23**	71.70							Ba
La										0.09	**99.91**						La
Ce								0.19		0.25		**88.45**		11.11			Ce
Pr													**100**				Pr
Nd														27.2	12.2	23.8	Nd
Sm																3.07	Sm

	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	
Nd	8.3	**17.2**		5.7		5.6											Nd
Sm			**14.99**	11.24	13.82	7.38		26.75		22.75							Sm
Eu							47.81		**52.19**								Eu
Gd								0.20		2.18	14.80	20.47	**15.65**	24.84		21.86	Gd
Tb															**100**		Tb
Dy												0.06		0.09		2.33	Dy

	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	
Dy	18.89	25.47	**24.90**	28.26													Dy
Ho					**100**												Ho
Er		0.14		1.60		**33.50**	22.87	26.98		14.91							Er
Tm									**100**								Tm
Yb								0.12		2.98	14.09	**21.68**	16.10	32.03		13.00	Yb
Lu															**97.40**	2.60	Lu
Hf														0.16		5.26	Hf

	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	
Hf	18.60	**27.28**	13.62	35.08													Hf
Ta				0.01	**99.99**												Ta
W				0.12		**26.50**	14.31	30.64		28.43							W
Re									**37.40**		62.60						Re
Os								0.02		1.59	1.96	13.24	**16.15**	26.26		40.78	Os
Ir															37.3		Ir
Pt														0.012		0.782	Pt

	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	
Ir	**62.7**																Ir
Pt		32.86	**33.78**	25.21		7.356											Pt
Au					**100**												Au
Hg				0.15		9.97	16.87	23.10	**13.18**	**29.86**		6.87					Hg
Tl											29.52		**70.48**				Tl
Pb												1.4		24.1	22.1	**52.4**	Pb

	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	
Bi	**100**																Bi

	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	
Th								**100**									Th
U										0.005	0.720			99.274			U

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Spectral interferences

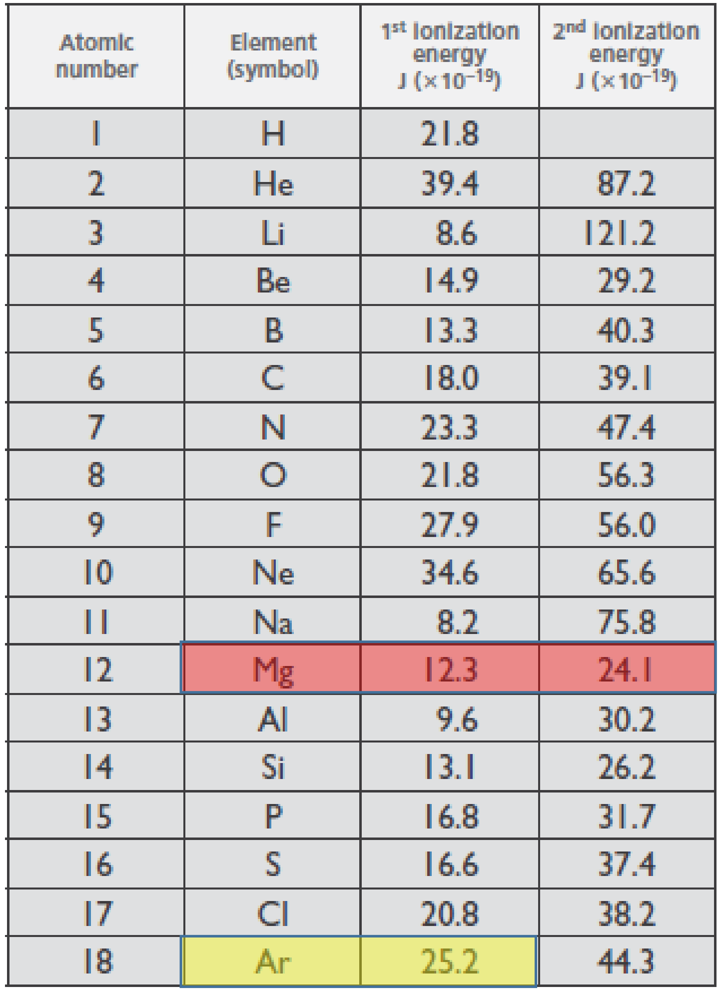
multiply charged ions

- Are due to relatively rare doubly-charged matrix or sample ions with twice the mass of the analyte and hence the same m/z. exaple $^{90}Zr^{++}$ on $^{45}Sc^{+}$
- The formation of doubly-charged species can be minimized by optimizing instrument operating conditions.
- For most elements is second ionisation potential higher than first ionization potential of Ar

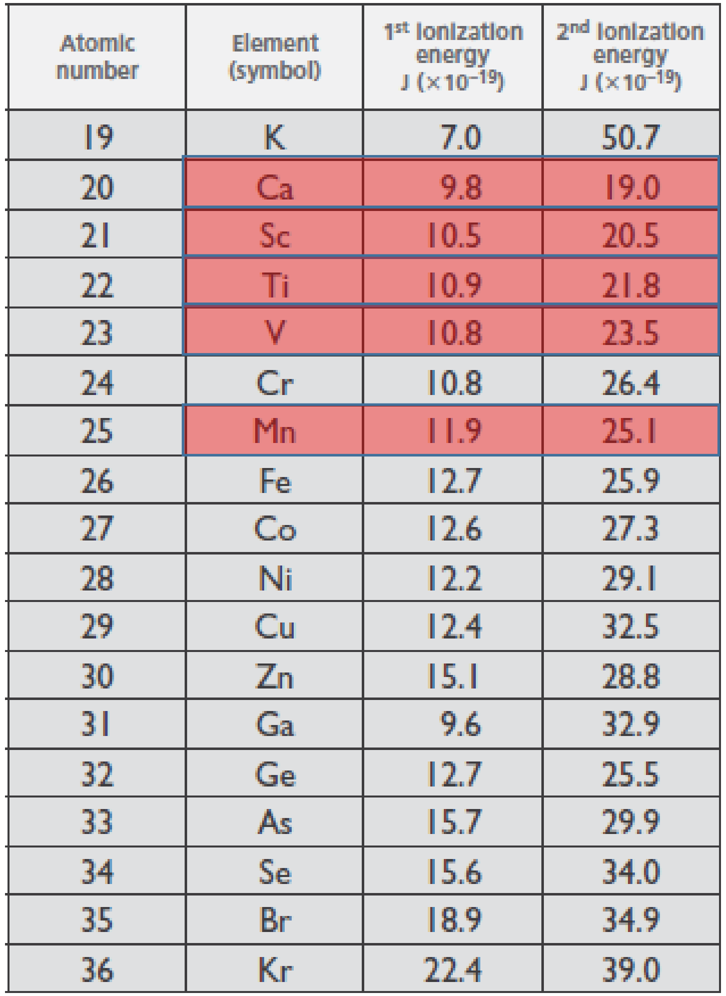
Spectral interferences

doubly charged ions

The formation of a doubly charged ion is significant in the case of **Sr**, **Ba**, (Pb).



Atomic number	Element (symbol)	1st ionization energy J (×10^{-19})	2nd ionization energy J (×10^{-19})
1	H	21.8	
2	He	39.4	87.2
3	Li	8.6	121.2
4	Be	14.9	29.2
5	B	13.3	40.3
6	C	18.0	39.1
7	N	23.3	47.4
8	O	21.8	56.3
9	F	27.9	56.0
10	Ne	34.6	65.6
11	Na	8.2	75.8
12	Mg	12.3	24.1
13	Al	9.6	30.2
14	Si	13.1	26.2
15	P	16.8	31.7
16	S	16.6	37.4
17	Cl	20.8	38.2
18	Ar	25.2	44.3

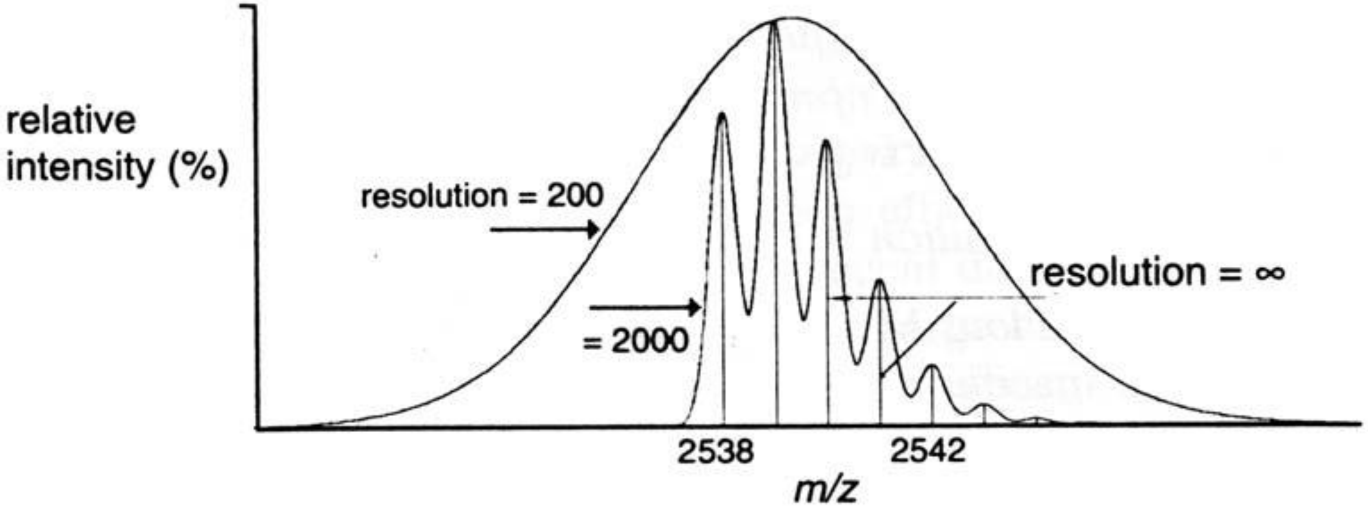


Atomic number	Element (symbol)	1st ionization energy J (×10^{-19})	2nd ionization energy J (×10^{-19})
19	K	7.0	50.7
20	Ca	9.8	19.0
21	Sc	10.5	20.5
22	Ti	10.9	21.8
23	V	10.8	23.5
24	Cr	10.8	26.4
25	Mn	11.9	25.1
26	Fe	12.7	25.9
27	Co	12.6	27.3
28	Ni	12.2	29.1
29	Cu	12.4	32.5
30	Zn	15.1	28.8
31	Ga	9.6	32.9
32	Ge	12.7	25.5
33	As	15.7	29.9
34	Se	15.6	34.0
35	Br	18.9	34.9
36	Kr	22.4	39.0

Resolving power

of mass spectrometer

Resolving power is the ability of a mass spectrometer to distinguish between ions of different mass mass-to-charge ratios. Therefore, greater resolving power corresponds directly to the increased ability to differentiate ions.



Resolving power

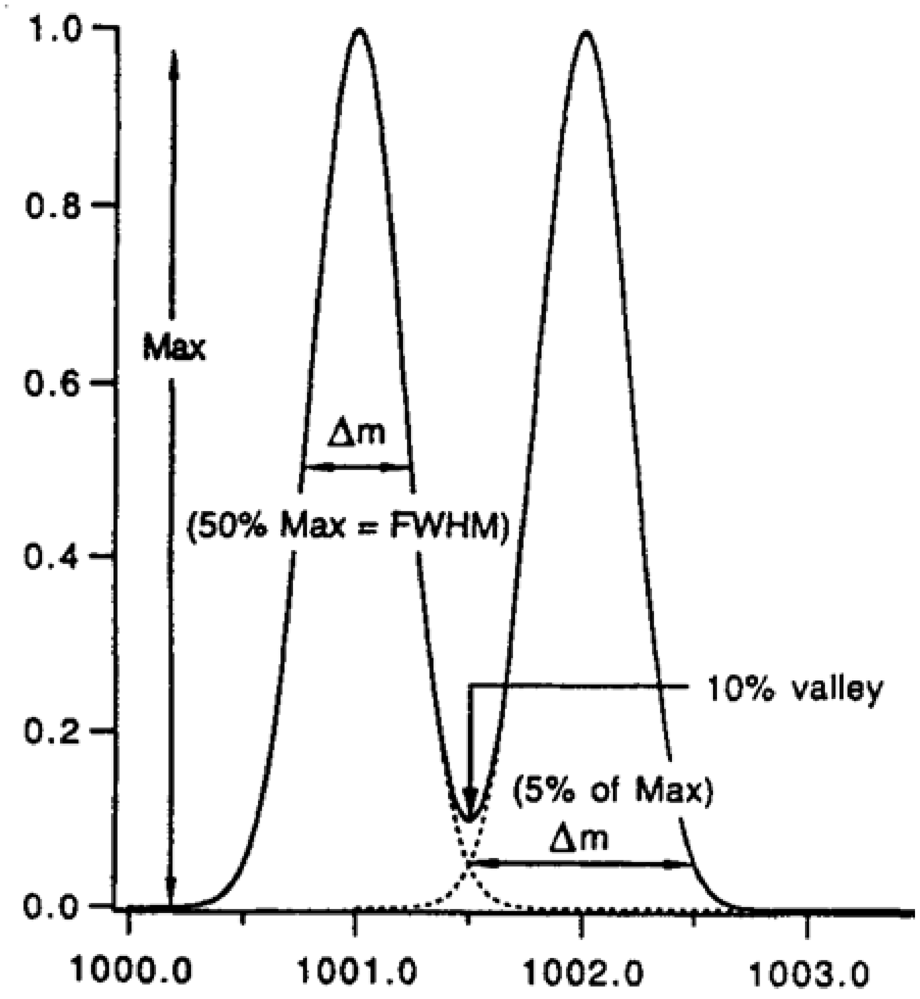
of mass spectrometer

- Width of one peak

  $RP = m / \Delta m$

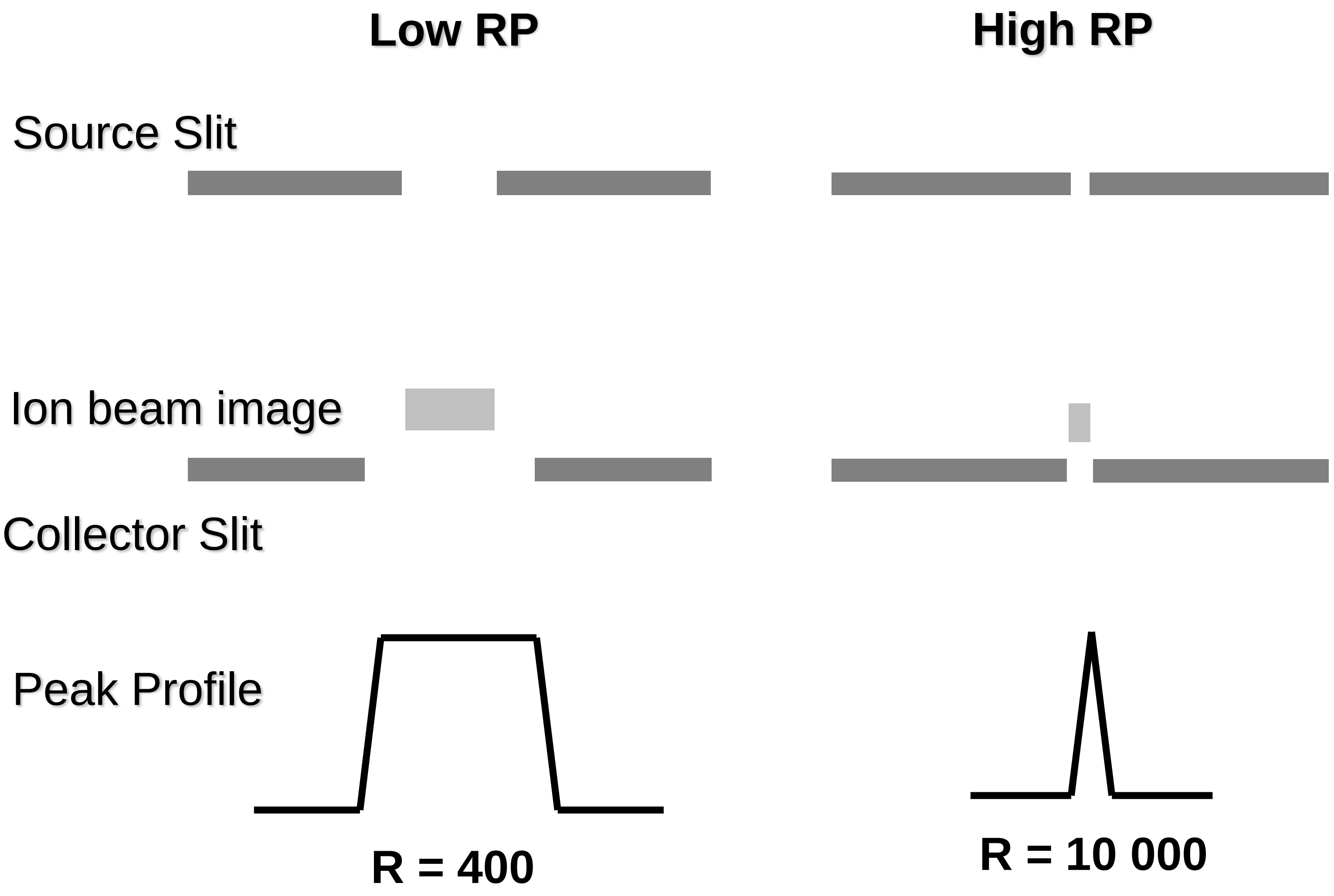
- Overlay of two peaks

  $RP = m_1 / (m_2 - m_1)$



Resolving power

of mass spectrometer



Low RP

High RP

Source Slit

Ion beam image

Collector Slit

Peak Profile

R = 400

R = 10 000

Resolution *vs* resolving power

of mass spectrometer

Sometimes used for low resolution analyzers (quadrupoles, ion traps) „Resolution“ instead of „Resolving Power“

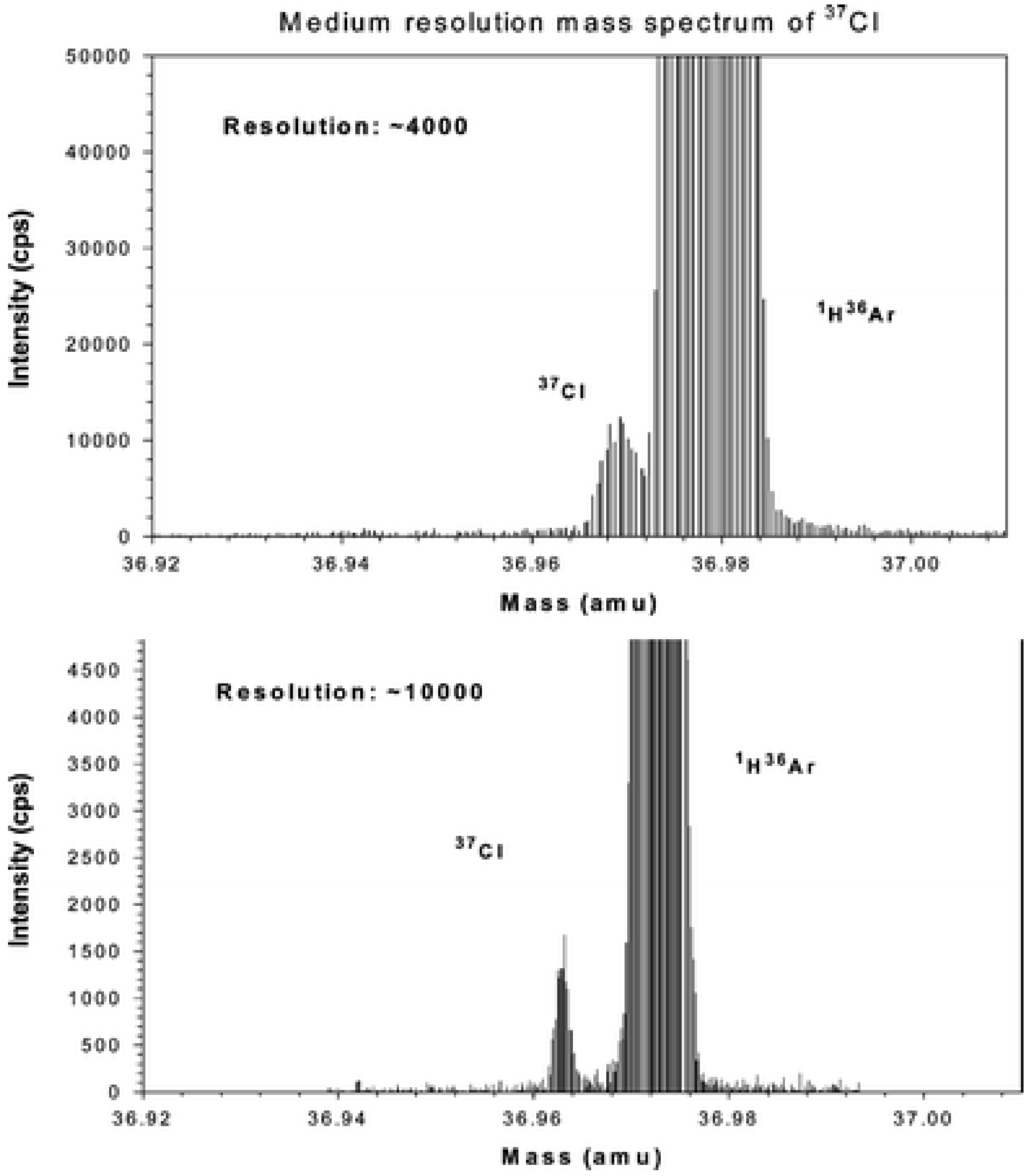
The resolution is expressed e.g. as a unit resolution (typical for quadrupoles).

RP must be related to a certain m/z value or m/z range, manufacturers often define a resolution valid for the whole mass range of the analyzer, (e.g. 2 000 – 4 000).

Resolving power

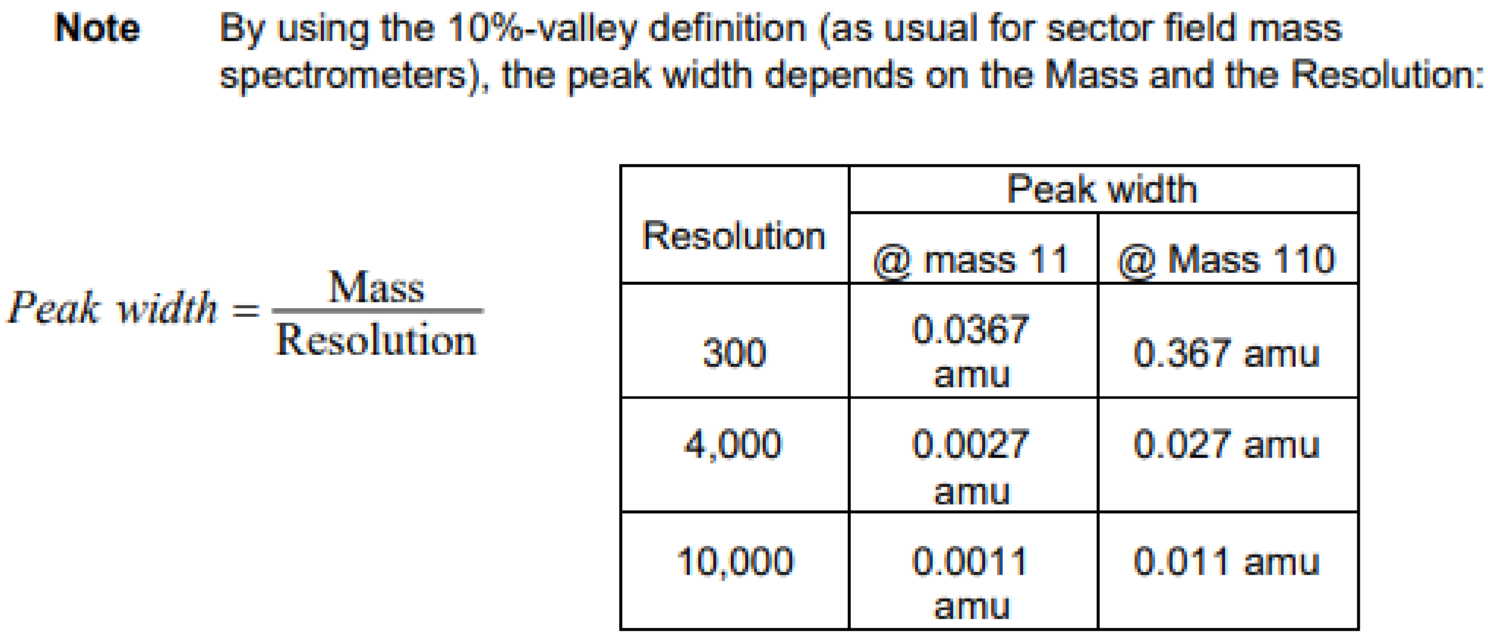
of ICP mass spectrometer

- Low: 300-400 (quadrupole)
- Medium: 2000-4000 (TOF)
- High: 8 000 – 10 000 (SF)



Resolving power

of ICP mass spectrometer



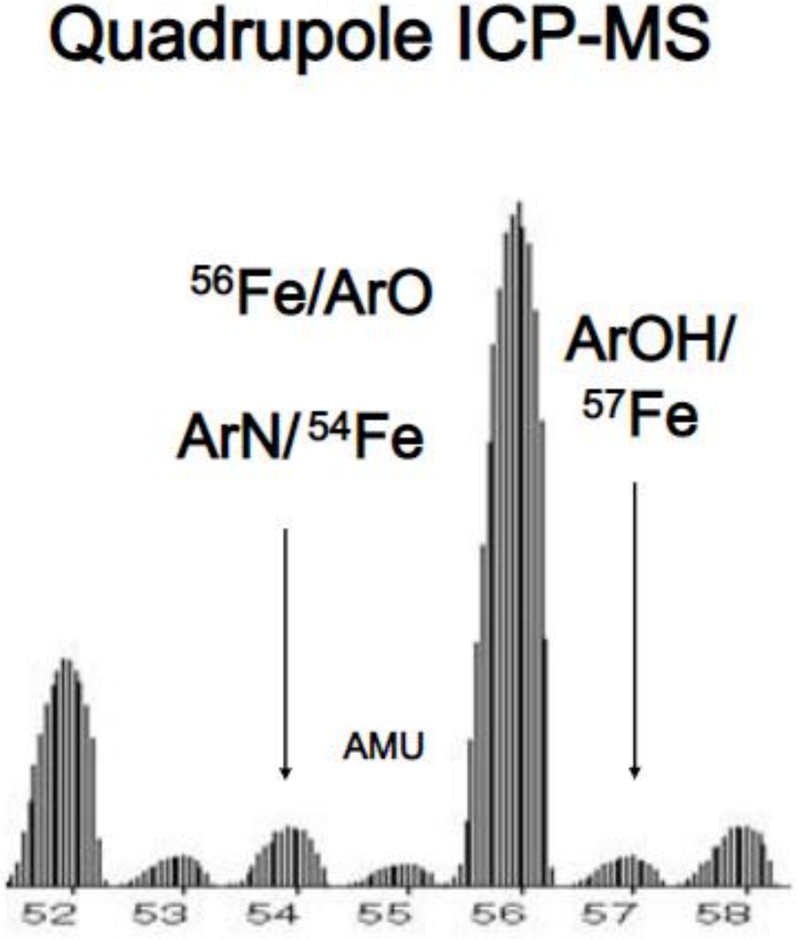
Note By using the 10%-valley definition (as usual for sector field mass spectrometers), the peak width depends on the Mass and the Resolution:

$$\text{Peak width} = \frac{\text{Mass}}{\text{Resolution}}$$

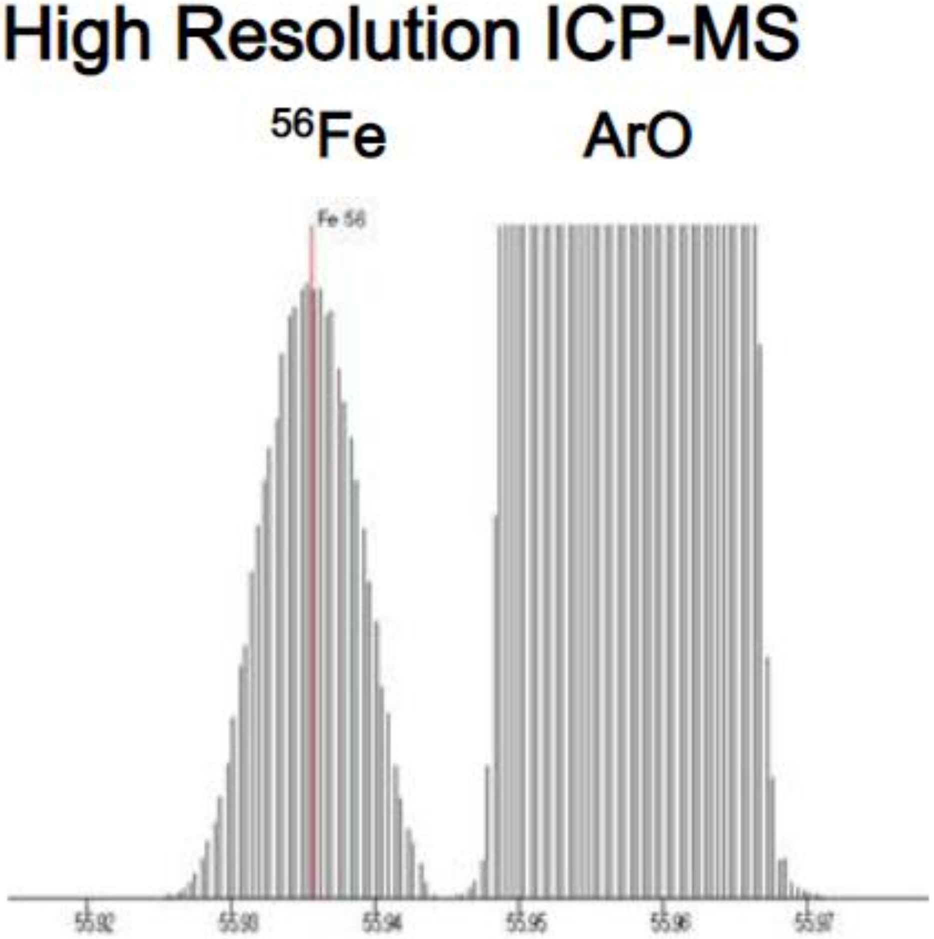
Resolution	Peak width	
	@ mass 11	@ Mass 110
300	0.0367 amu	0.367 amu
4,000	0.0027 amu	0.027 amu
10,000	0.0011 amu	0.011 amu

Resolving power

of ICP mass spectrometer



Quadrupole ICP-MS



High Resolution ICP-MS

Resolving power

calculations

Calculate the resolution power necessary to distinguish ions with amu:

$^{28}Si^+$	27.9769284	*vs.*	$^{14}N_2^+$	28.006148
$^{40}Ca^+$	39.9625907	*vs.*	$^{40}Ar^+$	39.962383
$^{56}Fe^+$	55.9349393	*vs.*	$^{40}Ar\,^{16}O^+$	59.957298

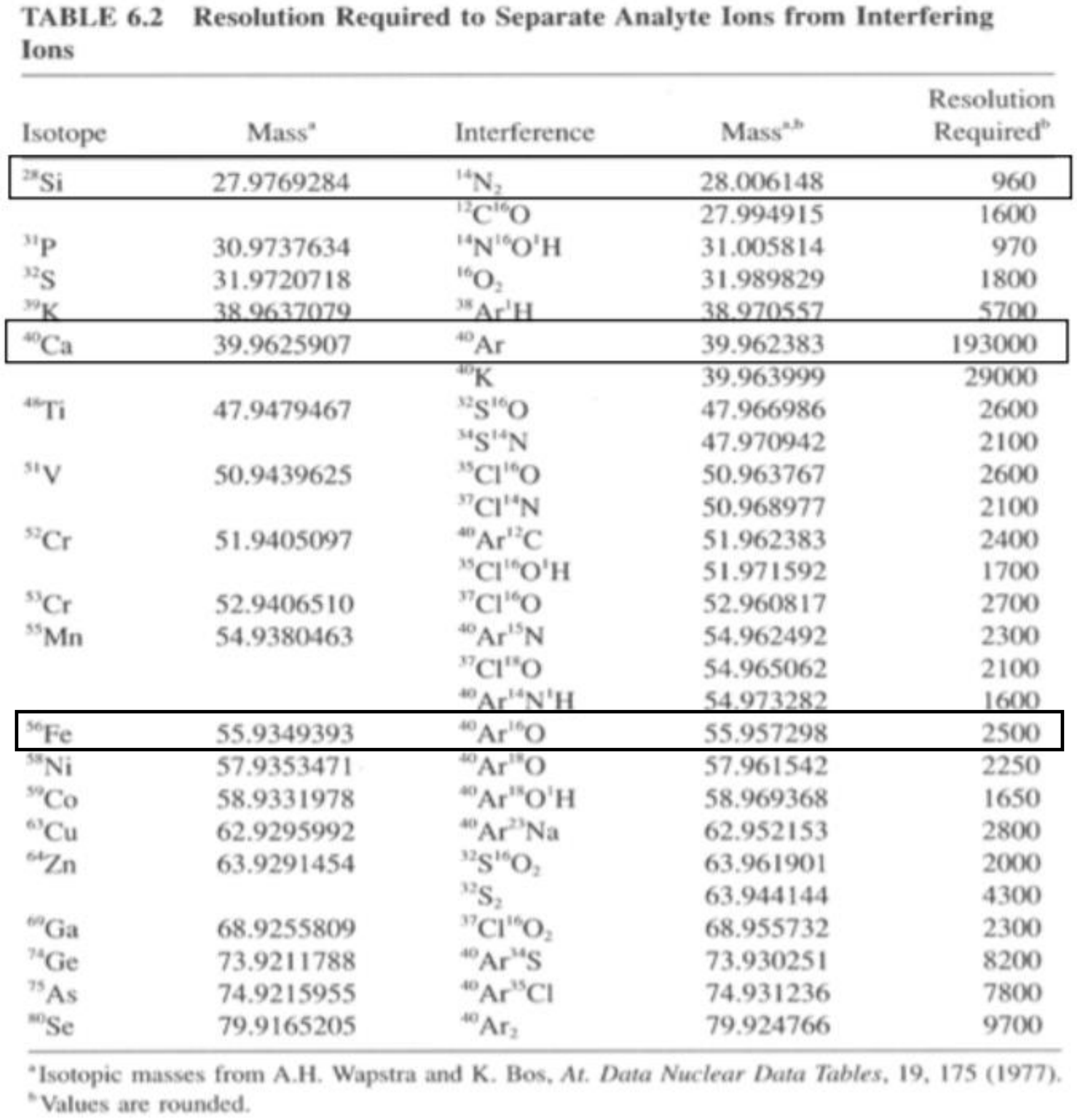


TABLE 6.2 Resolution Required to Separate Analyte Ions from Interfering Ions

Isotope	Mass[a]	Interference	Mass[a,b]	Resolution Required[b]
$^{28}\mathrm{Si}$	27.9769284	$^{14}\mathrm{N}_2$	28.006148	960
		$^{12}\mathrm{C}^{16}\mathrm{O}$	27.994915	1600
$^{31}\mathrm{P}$	30.9737634	$^{14}\mathrm{N}^{16}\mathrm{O}^{1}\mathrm{H}$	31.005814	970
$^{32}\mathrm{S}$	31.9720718	$^{16}\mathrm{O}_2$	31.989829	1800
$^{39}\mathrm{K}$	38.9637079	$^{38}\mathrm{Ar}^{1}\mathrm{H}$	38.970557	5700
$^{40}\mathrm{Ca}$	39.9625907	$^{40}\mathrm{Ar}$	39.962383	193000
		$^{40}\mathrm{K}$	39.963999	29000
$^{48}\mathrm{Ti}$	47.9479467	$^{32}\mathrm{S}^{16}\mathrm{O}$	47.966986	2600
		$^{34}\mathrm{S}^{14}\mathrm{N}$	47.970942	2100
$^{51}\mathrm{V}$	50.9439625	$^{35}\mathrm{Cl}^{16}\mathrm{O}$	50.963767	2600
		$^{37}\mathrm{Cl}^{14}\mathrm{N}$	50.968977	2100
$^{52}\mathrm{Cr}$	51.9405097	$^{40}\mathrm{Ar}^{12}\mathrm{C}$	51.962383	2400
		$^{35}\mathrm{Cl}^{16}\mathrm{O}^{1}\mathrm{H}$	51.971592	1700
$^{53}\mathrm{Cr}$	52.9406510	$^{37}\mathrm{Cl}^{16}\mathrm{O}$	52.960817	2700
$^{55}\mathrm{Mn}$	54.9380463	$^{40}\mathrm{Ar}^{15}\mathrm{N}$	54.962492	2300
		$^{37}\mathrm{Cl}^{18}\mathrm{O}$	54.965062	2100
		$^{40}\mathrm{Ar}^{14}\mathrm{N}^{1}\mathrm{H}$	54.973282	1600
$^{56}\mathrm{Fe}$	55.9349393	$^{40}\mathrm{Ar}^{16}\mathrm{O}$	55.957298	2500
$^{58}\mathrm{Ni}$	57.9353471	$^{40}\mathrm{Ar}^{18}\mathrm{O}$	57.961542	2250
$^{59}\mathrm{Co}$	58.9331978	$^{40}\mathrm{Ar}^{18}\mathrm{O}^{1}\mathrm{H}$	58.969368	1650
$^{63}\mathrm{Cu}$	62.9295992	$^{40}\mathrm{Ar}^{23}\mathrm{Na}$	62.952153	2800
$^{64}\mathrm{Zn}$	63.9291454	$^{32}\mathrm{S}^{16}\mathrm{O}_2$	63.961901	2000
		$^{32}\mathrm{S}_2$	63.944144	4300
$^{69}\mathrm{Ga}$	68.9255809	$^{37}\mathrm{Cl}^{16}\mathrm{O}_2$	68.955732	2300
$^{74}\mathrm{Ge}$	73.9211788	$^{40}\mathrm{Ar}^{34}\mathrm{S}$	73.930251	8200
$^{75}\mathrm{As}$	74.9215955	$^{40}\mathrm{Ar}^{35}\mathrm{Cl}$	74.931236	7800
$^{80}\mathrm{Se}$	79.9165205	$^{40}\mathrm{Ar}_2$	79.924766	9700

[a] Isotopic masses from A.H. Wapstra and K. Bos, *At. Data Nuclear Data Tables*, 19, 175 (1977).
[b] Values are rounded.