Métodos de RMN no estado sólido

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Sumário

- Fundamentos de RMN:
  - Princípios físicos.
    - Propriedades nucleares.
      - Spin nuclear.
      - Momento de dipolo magnético.
      - Modelo de camadas.
      - Tabelas de nuclídeos.
      - Momento de quadrupolo elétrico.

Alguns marcos históricos da RMN

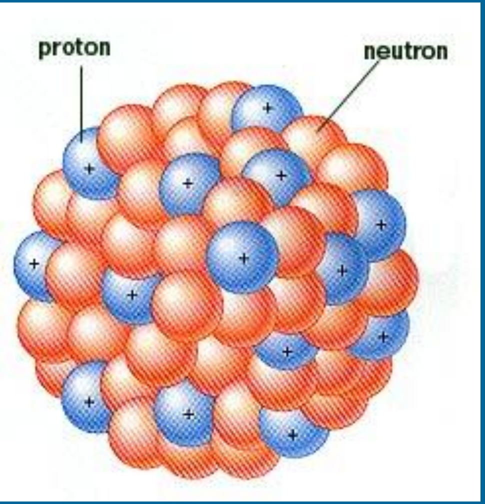
- Rabi (1937): ressonância em feixes de moléculas de H_2.
  - Prêmio Nobel de Física - 1944.
- Bloch (1946): absorção de RF em água.
  - Prêmio Nobel de Física - 1952.
- Purcell (1946): absorção de RF em parafina.
  - Prêmio Nobel de Física - 1952.
- Hahn (1949): ecos de spin.
- Packard (1951): deslocamento químico em etanol.
- Andrew, Lowe (1959): RMN no estado sólido.
- Ernst (1964): RMN com transformada de Fourier.
  - Prêmio Nobel de Química - 1991.
- Wüthrich (1968): RMN aplicada ao estudo de macromoléculas biológicas.
  - Prêmio Nobel de Química - 2002.
- Lauterbur, Mansfeld (1973): imagem por RMN (MRI).
  - Prêmio Nobel de Medicina - 2003.

Spin nuclear e momento de dipolo magnético nuclear

$$\vec{I} = \sum_{k=1}^{A} \left(\vec{l}_k + \vec{s}_k \right)$$

O *spin nuclear*:

- Número quântico *I*.
- Inteiro ou semi-inteiro.



$$\vec{\mu} = (\mu_N / \hbar) \left[\sum_{k=1}^{Z} \vec{l}_k + \sum_{k=1}^{Z} g_{sp} \vec{s}_k + \sum_{k=Z+1}^{A} g_{sn} \vec{s}_k \right]$$

$g_{sp} = 5{,}586$

$g_{sn} = -3{,}826$

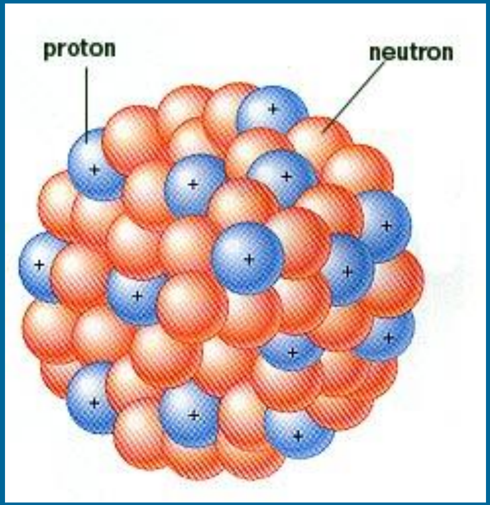
Magnéton nuclear: $$\mu_N = \frac{e\hbar}{2m_p} = 5{,}051 \times 10^{-27} \, J/T$$

Magnéton de Bohr: $$\mu_B = \frac{e\hbar}{2m_e} = 9{,}274 \times 10^{-24} \, J/T$$

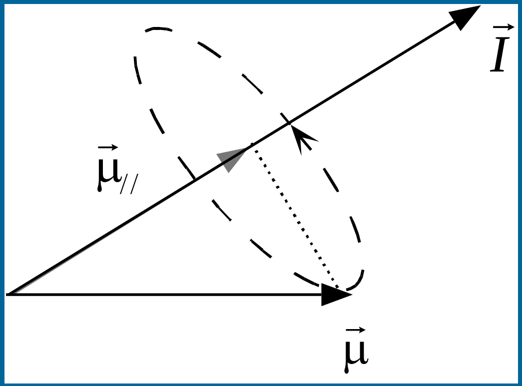
$g_{se} = -2{,}002$

Spin nuclear e momento de dipolo magnético nuclear

$$\vec{\mathbf{I}} = \sum_{k=1}^{A}\left(\vec{l}_k + \vec{s}_k\right)$$



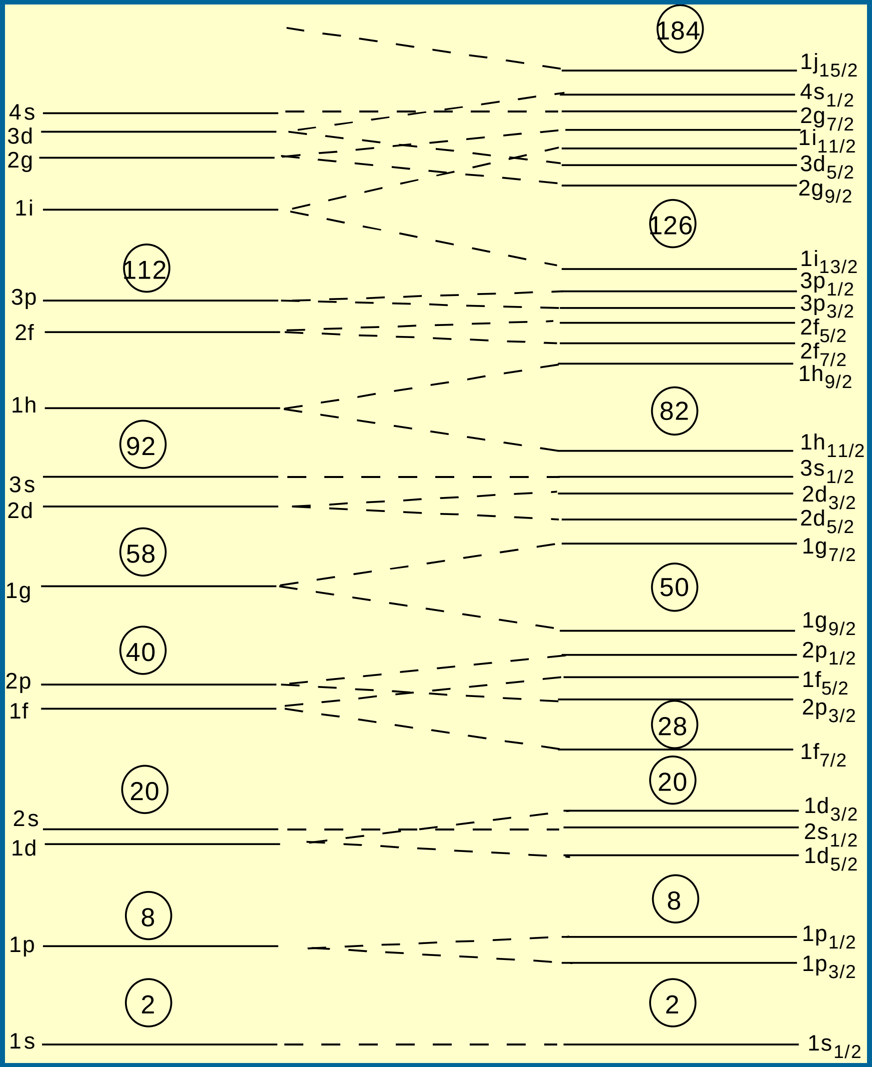
$$\vec{\mu} = (\mu_N/\hbar)\left[\sum_{k=1}^{Z}\vec{l}_k + \sum_{k=1}^{Z} g_{sp}\vec{s}_k + \sum_{k=Z+1}^{A} g_{sn}\vec{s}_k\right]$$



$$\vec{\mu}_{efetivo} = \frac{\left\langle \vec{\mu}\cdot\vec{\mathbf{I}}\right\rangle}{I(I+1)\hbar^2}\vec{\mathbf{I}} = \gamma\vec{\mathbf{I}}$$

Fator giromagnético

Modelo de camadas e spin nuclear



Momento angular de cada núcleon:

$$\vec{j} = \vec{l} + \vec{s}$$

$$j = l \pm 1/2$$

Notação:

$$n\, l_j$$

Capacidade de cada nível:

$$2j + 1$$

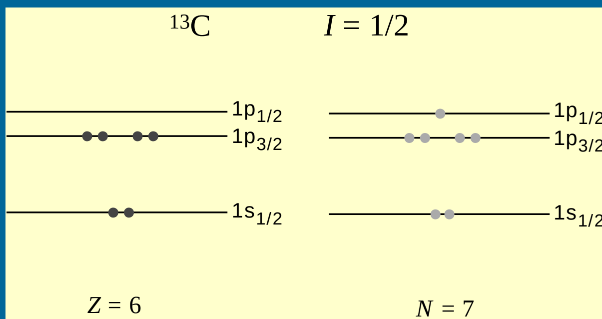
Os núcleos atômicos e a RMN, Freitas & Bonagamba, 1999.

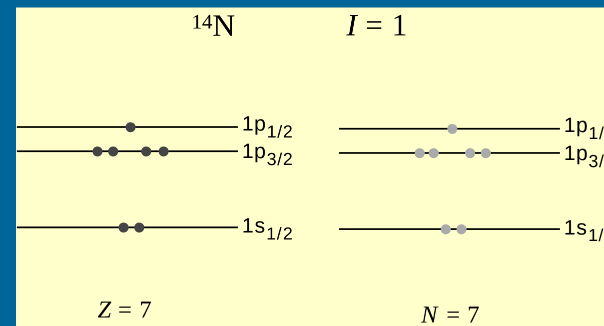
Modelo de camadas e spin nuclear

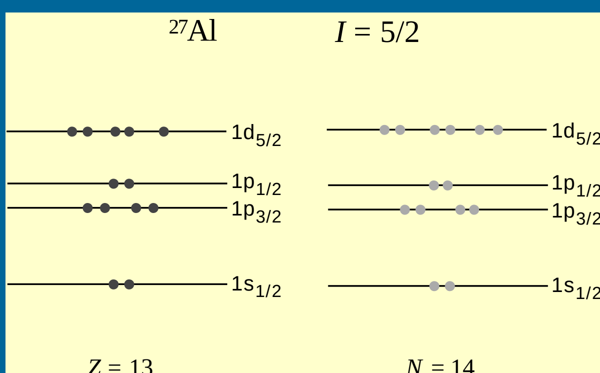
Previsões do modelo de camadas:

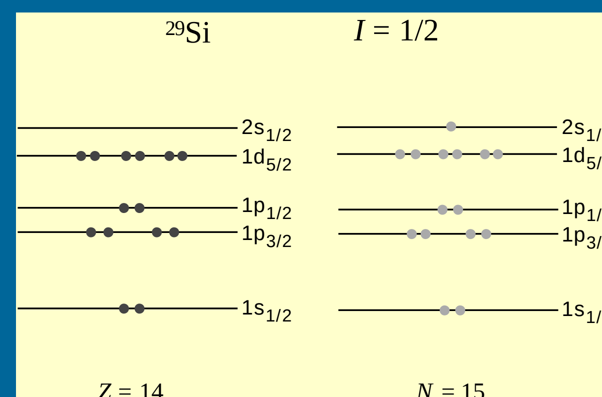
Z	*N*	*A*	*I*	
par	par	par	zero	
par	ímpar	ímpar	semi-inteiro	$I = j_n$
ímpar	par	ímpar	semi-inteiro	$I = j_p$
ímpar	ímpar	par	inteiro	$\left| j_n - j_p \right| \leq I \leq j_n + j_p$

Modelo de camadas e spin nuclear





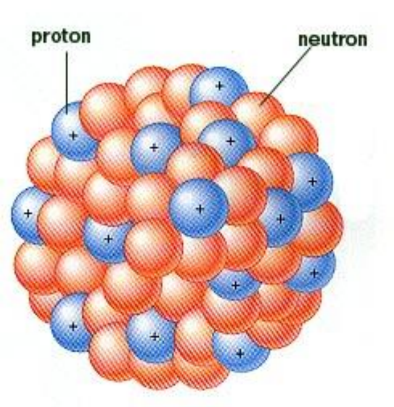




Momento de quadrupolo elétrico nuclear

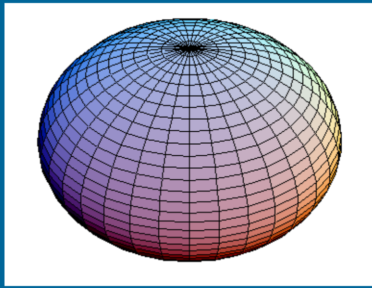
$$Q_{\alpha\beta} = e\sum_{k=1}^{Z}(3x_{\alpha k}x_{\beta k} - \delta_{\alpha\beta}r_k^{\ 2})$$

$$Q_{\alpha\beta} = \frac{eQ}{I(2I-1)\hbar^2}\left[\frac{3}{2}\left(\mathbf{I}_\alpha\mathbf{I}_\beta + \mathbf{I}_\beta\mathbf{I}_\alpha\right) - \delta_{\alpha\beta}\mathbf{I}^2\right]$$

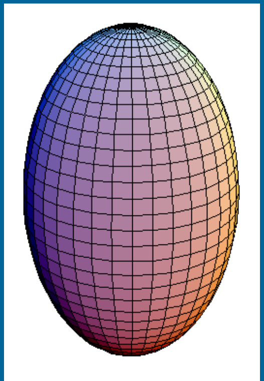


$$eQ = \int(3z'^2 - r'^2)\rho(\vec{r}')d^3r'$$

$$I > 1/2 \Rightarrow Q \neq 0$$



$Q < 0$ (oblata)



$Q > 0$ (prolata)

Alguns núcleos de interesse para RMN

Nuclídeo	*Abundância Natural* (%)	*I*	μ (múltiplos de μ_N)	*Q* (barns)
^{1}H	99,99	1/2	2,7928	0
^{13}C	1,11	1/2	0,7024	0
^{14}N	99,63	1	0,4036	0,01
^{15}N	0,37	1/2	0,2831	0
^{19}F	100	1/2	2,6287	0
^{27}Al	100	5/2	3,6414	0,150
^{29}Si	4,70	1/2	0,5553	0
^{31}P	100	1/2	1,1317	0
^{55}Mn	100	5/2	3,4680	0,400
^{59}Co	100	7/2	4,6490	0,400
^{155}Gd	14,73	3/2	0,2700	1,300
^{157}Gd	15,68	3/2	0,3600	1,500

Propriedades de alguns núcleos de interesse para RMN

TABLE 1
The Spin Properties of Spin-1/2 Nuclei

Isotope	Natural abundance (x/%)	Magnetic moment (μ/μ_N)	Magnetogyric ratio ($\gamma/10^7$ rad s^{-1} T^{-1})	Frequency ratio (Ξ/%)	Reference compound	Sample conditions	Relative receptivity D^P	Relative receptivity D^C
^{1}H	99.9885	4.837 353 570	26.752 2128	100.000 000	Me_4Si	$CDCl_3$, $\varphi = 1\%$	1.000	5.87×10^{3}
^{3}H	—	5.159 714 367	28.534 9779	106.663 974	Me_4Si-t_1	See lit.	—	—
^{3}He	1.37×10^{-4}	−3.685 154 336	−20.380 1587	76.179 437	He	Gas	6.06×10^{-7}	3.56×10^{-3}
^{13}C	1.07	1.216 613	6.728 284	25.145 020	Me_4Si	$CDCl_3$, $\varphi = 1\%$	1.70×10^{-4}	1.00
^{15}N	0.368	−0.490 497 46	−2.712 618 04	10.136 767	$MeNO_2$	Neat/$CDCl_3$	3.84×10^{-6}	2.25×10^{-2}
^{19}F	100	4.553 333	25.181 48	94.094 011	CCl_3F	See lit.	0.834	4.90×10^{3}
^{29}Si	4.6832	−0.961 79	−5.3190	19.867 187	Me_4Si	$CDCl_3$, $\varphi = 1\%$	3.68×10^{-4}	2.16
^{31}P	100	1.959 99	10.8394	40.480 742	H_3PO_4	See lit.	6.65×10^{-2}	3.91×10^{2}
^{57}Fe	2.119	0.156 9636	0.868 0624	3.237 778	$Fe(CO)_5$	C_6D_6	7.24×10^{-7}	4.25×10^{-3}
^{77}Se	7.63	0.926 775 77	5.125 3857	19.071 513	Me_2Se	Neat/C_6D_6	5.37×10^{-4}	3.15
^{89}Y	100	−0.238 010 49	−1.316 2791	4.900 198	$Y(NO_3)_3$	H_2O/D_2O	1.19×10^{-4}	0.700
^{103}Rh	100	−0.1531	−0.8468	3.186 447	$Rh(acac)_3$	$CDCl_3$, sat.	3.17×10^{-5}	0.186
(^{107}Ag)	51.839	−0.196 898 93	−1.088 9181	4.047 819	$AgNO_3$	D_2O, sat.	3.50×10^{-5}	0.205
^{109}Ag	48.161	−0.226 362 79	−1.251 8634	4.653 533	$AgNO_3$	D_2O, sat.	4.94×10^{-5}	0.290
(^{111}Cd)	12.80	−1.030 3729	−5.698 3131	21.215 480	Me_2Cd	Neat	1.24×10^{-3}	7.27
^{113}Cd	12.22	−1.077 8568	−5.960 9155	22.193 175	Me_2Cd	Neat	1.35×10^{-3}	7.94
(^{115}Sn)	0.34	−1.5915	−8.8013	32.718 749	Me_4Sn	Neat/C_6D_6	1.21×10^{-4}	0.711
(^{117}Sn)	7.68	−1.733 85	−9.588 79	35.632 259	Me_4Sn	Neat/C_6D_6	3.54×10^{-3}	20.8
^{119}Sn	8.59	−1.813 94	−10.0317	37.290 632	Me_4Sn	Neat/C_6D_6	4.53×10^{-3}	26.6
(^{123}Te)	0.89	−1.276 431	−7.059 098	26.169 742	Me_2Te	Neat/C_6D_6	1.64×10^{-4}	0.961
^{125}Te	7.07	−1.538 9360	−8.510 8404	31.549 769	Me_2Te	Neat/C_6D_6	2.28×10^{-3}	13.4
^{129}Xe	26.44	−1.347 494	−7.452 103	27.810 186	$XeOF_4$	Neat	5.72×10^{-3}	33.6
^{183}W	14.31	0.204 009 19	1.128 2403	4.166 387	Na_2WO_4	D_2O, 1 M	1.07×10^{-5}	6.31×10^{-2}
^{187}Os	1.96	0.111 9804	0.619 2895	2.282 331	OsO_4	CCl_4, 0.98 M	2.43×10^{-7}	1.43×10^{-3}
^{195}Pt	33.832	1.0557	5.8385	21.496 784	Na_2PtCl_6	D_2O, 1.2 M	3.51×10^{-3}	20.7
^{199}Hg	16.87	0.876 219 37	4.845 7916	17.910 822	Me_2Hg^{a}	Neat	1.00×10^{-3}	5.89
(^{203}Tl)	29.524	2.809 833 05	15.539 3338	57.123 200	$Tl(NO_3)_3$	See lit.	5.79×10^{-2}	3.40×10^{2}
^{205}Tl	70.476	2.837 470 94	15.692 1808	57.683 838	$Tl(NO_3)_3$	See lit.	0.142	8.36×10^{2}
^{207}Pb	22.1	1.009 06	5.580 46	20.920 599	Me_4Pb	Neat/C_6D_6	2.01×10^{-3}	11.8

Note. Taken from *Pure Appl. Chem.* **73**, 1795 (2001). © IUPAC 2001 Full text at http://www.iupac.org/publications/pac/2001/7311/7311x1795.html.
[a] Highly toxic. Do not handle directly. Some other reference compounds are toxic. The unified scale should always be used in these cases.

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Propriedades de alguns núcleos de interesse para RMN

TABLE 2
The Spin Properties of Quadrupolar Nuclei

Isotope	Spin	Natural abundance (x/%)	Magnetic moment (μ/μ_N)	Magnetogyric ratio ($\gamma/10^7$ rad s^{-1} T^{-1})	Quadrupole moment (Q/fm^2)	Frequency ratio (Ξ/%)	Reference sample	Sample conditions	Line-width factor (ℓ/fm^4)	Relative receptivity D^P	Relative receptivity D^C
^{2}H	1	0.0115	1.212 600 77	4.106 627 91	0.2860	15.350 609	$(CD_3)_4Si$	$CDCl_3$ $\varphi = 1\%$	0.41	1.11×10^{-6}	6.52×10^{-3}
^{6}Li	1	7.59	1.162 5637	3.937 1709	−0.0808	14.716 086	LiCl	D_2O, 9.7 m	0.033	6.45×10^{-4}	3.79
^{7}Li	3/2	92.41	4.204 075 05	10.397 7013	−4.01	38.863 797	LiCl	D_2O, 9.7 m	21	0.271	1.59×10^{3}
^{9}Be	3/2	100	−1.520 136	−3.759 666	5.288	14.051 813	$BeSO_4$	D_2O, 0.43 m	37	1.39×10^{-2}	81.5
^{10}B	3	19.9	2.079 2055	2.874 6786	8.459	10.743 658	$BF_3{\cdot}Et_2O$	$CDCl_3$	14	3.95×10^{-3}	23.2
^{11}B	3/2	80.1	3.471 0308	8.584 7044	4.059	32.083 974	$BF_3{\cdot}Et_2O$	$CDCl_3$	22	0.132	7.77×10^{2}
^{14}N	1	99.632	0.571 004 28	1.933 7792	2.044	7.226 317	CH_3NO_2	Neat/$CDCl_3$	21	1.00×10^{-3}	5.90
^{17}O	5/2	0.038	−2.240 77	−3.628 08	−2.558	13.556 457	D_2O	Neat	2.1	1.11×10^{-5}	6.50×10^{-2}
^{21}Ne	3/2	0.27	−0.854 376	−2.113 08	10.155	7.894 296	Ne	Gas, 1.1 MPa	140	6.65×10^{-6}	3.91×10^{-2}
^{23}Na	3/2	100	2.862 9811	7.080 8493	10.4	26.451 900	NaCl	D_2O, 0.1 M	140	9.27×10^{-2}	5.45×10^{2}
^{25}Mg	5/2	10.00	−1.012 20	−1.638 87	19.94	6.121 635	$MgCl_2$	D_2O, 11 M	130	2.68×10^{-4}	1.58
^{27}Al	5/2	100	4.308 6865	6.976 2715	14.66	26.056 859	$Al(NO_3)_3$	D_2O, 1.1 m	69	0.207	1.22×10^{3}
^{33}S	3/2	0.76	0.831 1696	2.055 685	−6.78	7.676 000	$(NH_4)_2SO_4$	D_2O, sat.	61	1.72×10^{-5}	0.101
^{35}Cl	3/2	75.78	1.061 035	2.624 198	−8.165	9.797 909	NaCl	D_2O, 0.1 M	89	3.58×10^{-3}	21.0
^{37}Cl	3/2	24.22	0.883 1998	2.184 368	−6.435	8.155 725	NaCl	D_2O, 0.1 M	55	6.59×10^{-4}	3.87
^{39}K	3/2	93.2581	0.505 433 76	1.250 0608	5.85	4.666 373	KCl	D_2O, 0.1 M	46	4.76×10^{-4}	2.79
(^{40}K)	4	0.0117	−1.451 3203	−1.554 2854	−7.3	5.802 018	KCl	D_2O, 0.1 M	5.2	6.12×10^{-7}	3.59×10^{-3}
(^{41}K)	3/2	6.7302	0.277 396 09	0.686 068 08	7.11	2.561 305	KCl	D_2O, 0.1 M	67	5.68×10^{-6}	3.33×10^{-2}
^{43}Ca	7/2	0.135	−1.494 067	−1.803 069	−4.08	6.730 029	$CaCl_2$	D_2O, 0.1 M	2.3	8.68×10^{-6}	5.10×10^{-2}
^{45}Sc	7/2	100	5.393 3489	6.508 7973	−22.0	24.291 747	$Sc(NO_3)_3$	D_2O, 0.06 M	66	0.302	1.78×10^{3}
^{47}Ti	5/2	7.44	−0.932 94	−1.5105	30.2	5.637 534	$TiCl_4$	Neat	290	1.56×10^{-4}	0.918
^{49}Ti	7/2	5.41	−1.252 01	−1.510 95	24.7	5.639 037	$TiCl_4$	Neat	83	2.05×10^{-4}	1.20
(^{50}V)	6	0.250	3.613 7570	2.670 6490	21.0	9.970 309	$VOCl_3$	Neat/C_6D_6	17	1.39×10^{-4}	0.818
^{51}V	7/2	99.750	5.838 0835	7.045 5117	−5.2	26.302 948	$VOCl_3$	Neat/C_6D_6	3.7	0.383	2.25×10^{3}
^{53}Cr	3/2	9.501	−0.612 63	−1.5152	−15.0	5.652 496	K_2CrO_4	D_2O, sat.	300	8.63×10^{-5}	0.507
^{55}Mn	5/2	100	4.104 2437	6.645 2546	33.0	24.789 218	$KMnO_4$	D_2O, 0.82 m	350	0.179	1.05×10^{3}
^{59}Co	7/2	100	5.247	6.332	42.0	23.727 074	$K_3[Co(CN)_6]$	D_2O, 0.56 m	240	0.278	1.64×10^{3}
^{61}Ni	3/2	1.1399	−0.968 27	−2.3948	16.2	8.936 051	$Ni(CO)_4$	Neat/C_6D_6	350	4.09×10^{-5}	0.240
^{63}Cu	3/2	69.17	2.875 4908	7.111 7890	−22.0	26.515 473	$[Cu(CH_3CN)_4][ClO_4]$	CH_3CN, sat.	650	6.50×10^{-2}	3.82×10^{2}
^{65}Cu	3/2	30.83	3.074 65	7.604 35	−20.4	28.403 693	$[Cu(CH_3CN)_4][ClO_4]$	CH_3CN, sat.	550	3.54×10^{-2}	2.08×10^{2}
^{67}Zn	5/2	4.10	1.035 556	1.676 688	15.0	6.256 803	$Zn(NO_3)_2$	D_2O, sat.	72	1.18×10^{-4}	0.692
(^{69}Ga)	3/2	60.108	2.603 405	6.438 855	17.1	24.001 354	$Ga(NO_3)_3$	D_2O, 1.1 m	390	4.19×10^{-2}	2.46×10^{2}
^{71}Ga	3/2	39.892	3.307 871	8.181 171	10.7	30.496 704	$Ga(NO_3)_3$	D_2O, 1.1 m	150	5.71×10^{-2}	3.35×10^{2}
^{73}Ge	9/2	7.73	−0.972 2881	−0.936 0303	−19.6	3.488 315	$(CH_3)_4Ge$	Neat	28	1.09×10^{-4}	0.642
^{75}As	3/2	100	1.858 354	4.596 163	31.4	17.122 614	$NaAsF_6$	CD_3CN, 0.5 M	1300	2.54×10^{-2}	1.49×10^{2}

R. K. HARRIS *et al.*

Propriedades de alguns núcleos de interesse para RMN

TABLE 2
The Spin Properties of Quadrupolar Nuclei

Isotope	Spin	Natural abundance (x/%)	Magnetic moment (μ/μ_N)	Magnetogyric ratio ($\gamma/10^7$ rad s^{-1} T^{-1})	Quadrupole moment (Q/fm^2)	Frequency ratio (Ξ/%)	Reference sample	Sample conditions	Line-width factor(ℓ/fm^4)	Relative receptivity	
										D^p	D^C
(^{79}Br)	3/2	50.69	2.719 351	6.725 616	31.3	25.053 980	NaBr	D_2O, 0.01 M	1300	4.03×10^{-2}	2.37×10^2
^{81}Br	3/2	49.31	2.931 283	7.249 776	26.2	27.006 518	NaBr	D_2O, 0.01 M	920	4.91×10^{-2}	2.88×10^2
^{83}Kr	9/2	11.49	−1.073 11	−1.033 10	25.9	3.847 600	Kr	Gas	50	2.18×10^{-4}	1.28
(^{85}Rb)	5/2	72.17	1.601 3071	2.592 7050	27.6	9.654 943	RbCl	D_2O, 0.01 M	240	7.67×10^{-3}	45.0
^{87}Rb	3/2	27.83	3.552 582	8.786 400	13.35	32.720 454	RbCl	D_2O, 0.01 M	240	4.93×10^{-2}	2.90×10^2
^{87}Sr	9/2	7.00	−1.209 0236	−1.163 9376	33.5	4.333 822	$SrCl_2$	D_2O, 0.5 M	83	1.90×10^{-4}	1.12
^{91}Zr	5/2	11.22	−1.542 46	−2.497 43	−17.6	9.296 298	$Zr(C_5H_5)_2Cl_2$	CH_2Cl_2, sat.	99	1.07×10^{-3}	6.26
^{93}Nb	9/2	100	6.8217	6.5674	−32.0	24.476 170	$K[NbCl_6]$	CH_3CN, sat.	76	0.488	2.87×10^3
^{95}Mo	5/2	15.92	−1.082	−1.751	−2.2	6.516 926	Na_2MoO_4	D_2O, 2 M	1.5	5.21×10^{-4}	3.06
(^{97}Mo)	5/2	9.55	−1.105	−1.788	25.5	6.653 695	Na_2MoO_4	D_2O, 2 M	210	3.33×10^{-4}	1.95
^{99}Tc	9/2	—	6.281	6.046	−12.9	22.508 326	NH_4TcO_4	D_2O	12	—	—
^{99}Ru	5/2	12.76	−0.7588	−1.229	7.9	4.605 151	$K_4[Ru(CN)_6]$	D_2O, 0.3 M	20	1.44×10^{-4}	0.848
^{101}Ru	5/2	17.06	−0.8505	−1.377	45.7	5.161 369	$K_4[Ru(CN)_6]$	D_2O, 0.3 M	670	2.71×10^{-4}	1.59
^{105}Pd	5/2	22.33	−0.760	−1.23	66.0	4.576 100	K_2PdCl_6	D_2O, sat.	1400	2.53×10^{-4}	1.49
(^{113}In)	9/2	4.29	6.1124	5.8845	79.9	21.865 755	$In(NO_3)_3$	D_2O, 0.1 M	470	1.51×10^{-2}	88.5
^{115}In	9/2	95.71	6.1256	5.8972	81.0	21.912 629	$In(NO_3)_3$	D_2O, 0.1 M	490	0.338	1.98×10^3
^{121}Sb	5/2	57.21	3.9796	6.4435	−36.0	23.930 577	$KSbCl_6$	CH_3CN, sat.	410	9.33×10^{-2}	5.48×10^2
(^{123}Sb)	7/2	42.79	2.8912	3.4892	−49.0	12.959 217	$KSbCl_6$	CH_3CN, sat.	330	1.99×10^{-2}	1.17×10^2
^{127}I	5/2	100	3.328 710	5.389 573	−71.0	20.007 486	KI	D_2O, 0.01 M	1600	9.54×10^{-2}	5.60×10^2
^{131}Xe	3/2	21.18	0.893 1899	2.209 076	−11.4	8.243 921	$XeOF_4$	Neat	170	5.96×10^{-4}	3.50
^{133}Cs	7/2	100	2.927 7407	3.533 2539	−0.343	13.116 142	$CsNO_3$	D_2O, 0.1 M	0.016	4.84×10^{-2}	2.84×10^2
(^{135}Ba)	3/2	6.592	1.081 78	2.675 50	16.0	9.934 457	$BaCl_2$	D_2O, 0.5 M	340	3.30×10^{-4}	1.93
^{137}Ba	3/2	11.232	1.210 13	2.992 95	24.5	11.112 928	$BaCl_2$	D_2O, 0.5 M	800	7.87×10^{-4}	4.62
^{138}La	5	0.090	4.068 095	3.557 239	45.0	13.194 300	$LaCl_3$	D_2O/H_2O	120	8.46×10^{-5}	0.497
^{139}La	7/2	99.910	3.155 6770	3.808 3318	20.0	14.125 641	$LaCl_3$	D_2O, 0.01 M	54	6.05×10^{-2}	3.56×10^2
^{177}Hf	7/2	18.60	0.8997	1.086	336.5	(4.007)	—	—	1.5×10^4	2.61×10^{-4}	1.54
^{179}Hf	9/2	13.62	−0.7085	−0.6821	379.3	(2.517)	—	—	1.1×10^4	7.45×10^{-5}	0.438
^{181}Ta	7/2	99.988	2.6879	3.2438	317.0	11.989 600	$KTaCl_6$	CH_3CN, sat.	1.4×10^4	3.74×10^{-2}	2.20×10^2
(^{185}Re)	5/2	37.40	3.7710	6.1057	218.0	22.524 600	$KReO_4$	D_2O, 0.1 M	1.5×10^4	5.19×10^{-2}	3.05×10^2
^{187}Re	5/2	62.60	3.8096	6.1682	207.0	22.751 600	$KReO_4$	D_2O, 0.1 M	1.4×10^4	8.95×10^{-2}	5.26×10^2
^{189}Os	3/2	16.15	0.851 970	2.107 13	85.6	7.765 400	OsO_4	CCl_4, 0.98 M	9800	3.95×10^{-4}	2.32
(^{191}Ir)	3/2	37.3	0.1946	0.4812	81.6	(1.718)	—	—	8900	1.09×10^{-5}	6.38×10^{-2}
^{193}Ir	3/2	62.7	0.2113	0.5227	75.1	(1.871)	—	—	7500	2.34×10^{-5}	0.137
^{197}Au	3/2	100	0.191 271	0.473 060	54.7	(1.729)	—	—	4000	2.77×10^{-5}	0.162
^{201}Hg	3/2	13.18	−0.723 2483	−1.788 769	38.6	6.611 583	$(CH_3)_2Hg$[a]	Neat	2000	1.97×10^{-4}	1.16
^{209}Bi	9/2	100	4.5444	4.3750	−51.6	16.069 288	$Bi(NO_3)_3$	$HNO_3/D_2O/H_2O$	200	0.144	8.48×10^2

Note. Taken from *Pure Appl. Chem.* **73**, 1795 (2001). © IUPAC 2001. Full text at http://www.iupac.org/publications/pac/7311/7311x1795.html.
[a] Highly toxic. Do not handle directly. Some other reference compounds are toxic. The unified scale should always be used in these cases.

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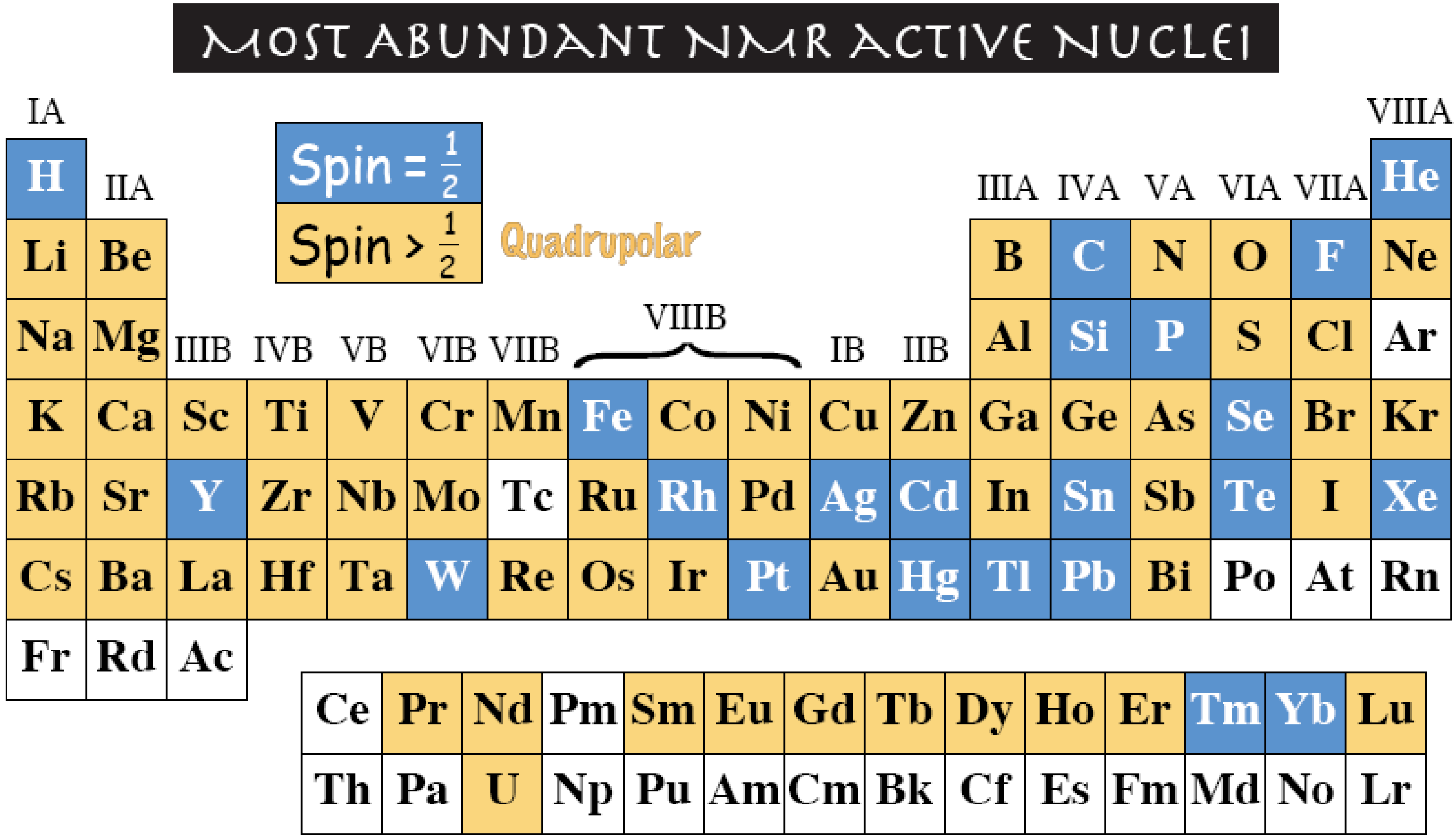
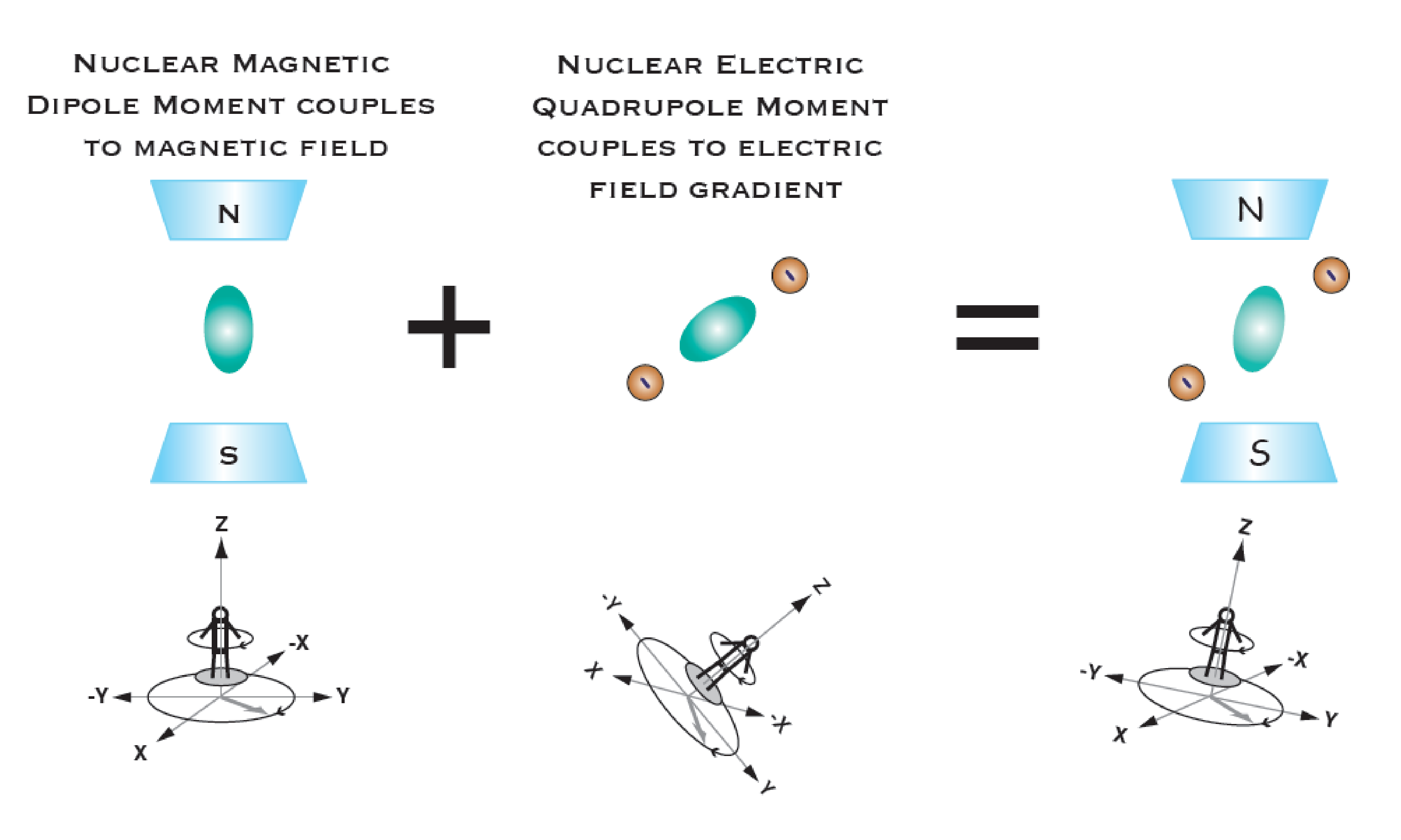
Alguns núcleos de interesse para RMN



http://www.grandinetti.org/Research/NMR

Interação nuclear combinada: magnética e elétrica



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