Nuclear Gyromagnetic Ratios. IV*

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The super-regenerative oscillator techniques described in earlier reports have been employed to observe nuclear magnetic resonance absorption by B^{10}, N^{14}, Cl^{35}, Cl^{37}, As^{75}, In^{113}, In^{115}, and Bi^{209}. Nuclear g factors and magnetic moments of these nuclei are tabulated for comparison with corresponding values obtained by other techniques.

EARLIER reports from this laboratory[1–3] have described super-regenerative oscillator techniques for observing nuclear magnetic resonance phenomena. The present paper gives a resume of results obtained on nuclear species not treated in the earlier papers.

The apparatus employed in the present study was essentially the same as that reported earlier[3] except for certain improvements in electronic circuitry. These improvements include the use of a cascode preamplifier[4] between the radiofrequency circuit and the narrow-band amplifier and the use of a phase-sensitive detector between the narrow-band amplifier and the chart recorder. The introduction of these new amplifier units has resulted in the improvement of signal to noise ratios by a factor of at least 4.

In Table I are listed the observed ratios of resonance frequencies of various nuclei in the same applied magnetic field. Each value listed in the table is the mean of at least ten independent determinations. The uncertainties given are the systematic errors involved in the instrumentation and in the matching of resonance line centers in the somewhat complicated line patterns given by the super-regenerative techniques.[5] Although the side bands may be well resolved in the chart displays for the unknown and the "standard" nuclei, it is necessary that the operating conditions of the oscillator be the same for the two nuclei. In the case of each resonance listed in the table, the statistically most probable error is smaller than the indicated systematic error.

In three of the samples listed in Table I small amounts of magnetic catalysts have been used. Although the use of catalysts may produce slight shifts in resonance frequency,[6] it was found necessary to employ catalysts in those three cases in order to obtain similar line shapes for comparison purposes in the standard and the unknown. In all cases catalyst concentration was very low, and on the basis of Dickinson's studies it can be assumed that any shifts in resonance frequency result in uncertainties smaller than those listed in Table I.

The "standard" nuclei used in the present study are D^2, Sc^{45}, and Rb^{85}. The ratios of the resonance frequencies of these secondary standards to the proton frequency are given in Table II.[7–10]

In order to compare the present experimental results with those of other workers, it is desirable to express all results as ratios of resonance frequencies to the resonance frequency of the proton in the same applied magnetic field. This has been done, and these ratios are shown in Table III.[2,11–14]

Brief comments on the results obtained for the various nuclear species are given below:

The agreement between the present results for B^{10} and the early results of Bitter[11] is excellent. Of the two values of the ratio obtained in the present work, the value based on Rb^{85} is believed to be more accurate, since the Rb^{85} frequency is closer to the B^{10} frequency and since the Rb^{85} line shape is somewhat better than the line shape obtained for D^2.

The values for N^{14} and Cl^{35} are in excellent agreement with values obtained by Proctor and Yu[12]; the Cl^{37} ratio obtained in the present study is slightly higher,

TABLE I. Resonance frequency ratios.

Nuclei compared	Resonance frequency ratio	Samples (aqueous solutions)
B^{10} to D^2	0.700065±0.00007	$Na_2B_2O_4$, D_2O+$NiCl_2$
B^{10} to Rb^{85}	1.11282 ±0.00005	$Na_2B_2O_4$, RbCl
N^{14} to Rb^{85}	0.74837 ±0.00004	HNO_3, RbCl
Cl^{35} to Rb^{85}	1.01481 ±0.00005	LiCl, RbCl
Cl^{37} to Rb^{85}	0.84477 ±0.00005	LiCl, RbCl
Cl^{35} to Cl^{37}	1.20128 ±0.00006	LiCl
As^{75} to D^2	1.11569 ±0.00005	Na_2HAsO_4+NaOH, D_2O+$NiCl_2$
In^{115} to In^{113}	1.00213 ±0.00004	$In(NO_3)_3$
In^{115} to Sc^{45}	0.901877±0.00005	$In(NO_3)_3$+$Mn(NO_3)_2$, $ScCl_3$
Bi^{209} to D^2	1.04684 ±0.00005	$Bi(NO_3)_3$, D_2O

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TABLE II. Resonances used as standards.

Ratio[a]	Resonance frequency ratio used as standard
D^2 to H^1	0.153506
Sc^{45} to H^1	0.242939±0.000003
Rb^{85} to H^1	0.0965521

[a] The value for the D^2/H^1 ratio is taken from Lindstrom (see reference 7) and Smaller, *et al.* (see reference 8); Hunten's Sc^{45}/H^1 ratio (see reference 9) is assumed; the Rb^{85}/H^1 ratio is based on the work of Yasaitis and Smaller. (See reference 10.)

but agrees with the Proctor-Yu measurement within experimental errors.

The As^{75} ratio obtained in the present work is slightly higher than the value obtained by Dharmatti and Weaver[13] and slightly lower than the ratio obtained by Jeffries, Loeliger, and Staub.[14] However, the three ratios agree within the limits of experimental error.

The ratios of the In^{113} and In^{115} to the proton frequency as obtained in the present study are slightly lower than the Proctor-Yu[12] values but agree within the limits of error.

The Bi^{209} ratio is in excellent agreement with the value obtained by Proctor and Yu.[12] It might be remarked that several determinations of the Cl^{35}/Cl^{37} and In^{115}/In^{113} frequency ratios were made in the present investigation. The present value of 1.20128 ±0.00006 for the Cl^{35}/Cl^{37} ratio is in agreement with the Proctor-Yu value[12] of 1.2014±0.0001, and with the recent value 1.2013±0.0001 obtained by Watkins and Pound.[15] The In^{115}/In^{113} frequency ratio of 1.00213 ±0.00004 checks closely with the ratio 1.0021±0.001 obtained by Proctor and Yu.[12] It might be noted that, since $I=\frac{3}{2}$ for both Cl^{35} and Cl^{37} and $I=9/2$ for both In^{113} and In^{115}, the above frequency ratios are also the ratios of the magnetic moments for the pairs of isotopes.

The values of nuclear g factor cannot be determined directly from the observed frequency ratios since, owing to the diamagnetic effects of atomic electrons, the local fields at the nuclei being compared may be slightly different even though the applied fields may be the same.

TABLE III. Ratios of nuclear resonance frequency to the proton frequency in the same magnetic field.

Nucleus	Sample	Ratio	Uncertainty (percent)	Intermediate standard	Reference
B^{10}	$Na_2B_2O_4$	0.107464	±0.010	D^2	Present study
	$Na_2B_2O_4$	0.107445	0.005	Rb^{85}	
		0.10745	0.04	B^{11}	11
N^{14}	HNO_3	0.072257	0.005	Rb^{85}	Present study
	HNO_3	0.072255	0.010	D^2	12
Cl^{35}	LiCl	0.097982	0.005	Rb^{85}	Present study
	HCl	0.097978	0.010	D^2	12
	LiCl	0.09799	0.07		2
Cl^{37}	LiCl	0.081564	0.007	Rb^{85}	Present study
	HCl	0.081553	0.014	Cl^{35}	12
As^{75}	Na_2HAsO_4 +NaOH	0.171265	0.005	D^2	Present study
	Na_2HAsO_4 +NaOH	0.17125	0.030	Na^{23}	13
	Na_3AsO_4 +NaOH	0.17129	0.018		14
also	Na_3AsS_4				
In^{113}	$In(NO_3)_3$	0.21863	0.010	In^{115}	Present study
	$In(NO_3)_3$	0.21865	0.014	Na^{23}	12
In^{115}	$In(NO_3)_3$ +cat	0.219101	0.006	Sc^{45}	Present study
	$In(NO_3)_3$	0.21911	0.014	Na^{23}	12
Bi^{209}	$Bi(NO_3)_3$	0.160696	0.006	D^2	Present study
	$Bi(NO_3)_3$	0.16069	0.010	D^2	12

TABLE IV. Nuclear g values and nuclear magnetic moments.

Nucleus	Diamagnetic correction	Nuclear g value	Spin (I)	Nuclear magnetic moment
B^{10}	1.00017	0.60033±0.00006[a]	3	1.80099±0.00018[a]
		0.60022±0.00005	3	1.80066±0.00015
N^{14}	1.00028	0.40369±0.00003	1	0.40369±0.00003
Cl^{35}	1.00110	0.54786±0.00003	3/2	0.82180±0.00005
Cl^{37}	1.00110	0.45606±0.00003	3/2	0.68410±0.00005
As^{75}	1.00284	0.95929±0.00005	3/2	1.43893±0.00008
In^{113}	1.00490	1.2272 ±0.0001	9/2	5.5222 ±0.0005
In^{115}	1.00490	1.22976±0.00008	9/2	5.5339 ±0.0004
Bi^{209}	1.0104	0.90689±0.00008	9/2	4.0810 ±0.0004

[a] Uncertainties in diamagnetic corrections are not included.

However, by applying the Lamb diamagnetic correction,[16] one can obtain g factors in terms of the proton g factor. In Table IV are listed the g factors and nuclear magnetic moments obtained from the present experimental measurements after application of the indicated diamagnetic correction on the basis of the proton moment $\mu=2.79268\pm0.00006$ nm obtained by Sommers, Thomas, and Hipple[17] and the values of nuclear spin I given in Mack's recent survey paper.[18]

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