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Lawrence Radiation Laboratory Berkeley, California

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HYPERFINE STRUCTURES OF Re¹⁸⁶ AND Re¹⁸⁸

Richard G. Schlecht, Matthew B. White, and Douglas W. McColm

October 8, 1964

Hyperfine Structures of Re¹⁸⁶ and Re^{188†} Richard G. Schlecht,[‡] Matthew B. White,[§] and Douglas W. McColm

> Lawrence Radiation Laboratory University of California Berkeley, California

> > October 8, 1964

ABSTRACT

The atomic-beam magnetic-resonance "flop-in" technique has been used to determine the hyperfine-structure separations of the isotopes Re^{186} and Re^{188} . The magnetic-dipole interaction constant a and the electric-quadrupole interaction constant b have been measured for these two radioactive isotopes in the J = 5/2 ground state. Beams were produced by electron bombardment of irradiated rhenium wires. The spins of both isotopes had been determined previously to be 1. For the interaction constants of Re^{186} we obtained

> $a_{186} = \pm 78.3058(24) \text{ Mc/sec}$ $b_{186} = \mp 8.3601(50) \text{ Mc/sec}.$

These give values of the two hyperfine-structure separations of

 $\Delta v_{186}^{(7/2, 5/2)} = \pm 265.292(14) \text{ Mc/sec}$ $\Delta v_{186}^{(5/2, 3/2)} = \pm 208.305(14) \text{ Mc/sec}.$

For the interaction constants of Re¹⁸⁸ we obtained

 $a_{188} = \pm 80.4320(32) \text{ Mc/sec}$ $b_{188} = \pm 7.7455(60) \text{ Mc/sec}$.

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These give values of the two hyperfine-structure separations of

$$\Delta v_{188}(7/2, 5/2) = \pm 273.379(13) \text{ Mc/sec}$$

 $\Delta v_{188}(5/2, 3/2) = \pm 212.698(17) \text{ Mc/sec}.$

The nuclear moments of both isotopes were determined to be positive.

Also obtained was an improved value for the electronic Landé g-factor for rhenium

 $g_{J} = -1.95203(8)$.

I. INTRODUCTION

The atomic-beam magnetic-resonance method of Rabi⁴ and Zacharias² has been used to measure the hyperfine structure separations in the $(5d)^5(6s)^2 \cdot 6s_{5/2}$ ground state of two radioactive isotopes of rhenium, Re¹⁸⁶ and Re¹⁸⁸. The signs of the nuclear moments and an improved value of the rhenium g_J , which was first measured by Meggers, ³ were also obtained. The nuclear spins of Re¹⁸⁶ and Re¹⁸⁸ were determined to be 1 by Doyle and Marrus, ⁴ who also observed evidences of small hyperfinestructure separations. For a pure L-S coupling scheme, a $^{6}S_{5/2}$ state would have zero hyperfine structure. Perturbations to this coupling scheme give rise to the hyperfine structure in rhenium and would therefore be expected to be small. Other examples of this in atomic-beam experiments can be found in the papers of Sandars and Woodgate⁵ and Marrus, Nierenberg, and Winocur.⁶

II. THEORY

The atomic-beam technique is a sensitive method for observing radiofrequency transitions between two energy states of a free atom in an external magnetic field. The Hamiltonian for such an atom is given by

$$3C = a \underline{I} \cdot \underline{J} + b \frac{3(\underline{I} \cdot \underline{J})^2 + 3/2(\underline{I} \cdot \underline{J}) - I(I + 1) J(J + 1)}{2I(2I - 1) J(2J - 1)}$$

$$= g_{I} \left(\frac{\mu_{0}}{h}\right) \underbrace{I}_{m} \cdot \underbrace{H}_{0} - g_{J} \left(\frac{\mu_{0}}{h}\right) \underbrace{J}_{m} \cdot \underbrace{H}_{0}_{m}, \qquad (1)$$

where a and b are the magnetic-dipole and electric-quadrupole hyperfine-structure interaction constants, respectively; I and J are the nuclear and electronic angular momenta in units of \bar{h} ; \underline{H}_{0} is the applied external magnetic field; and g_{I} and g_{J} are the nuclear and electronic g-factors defined by μ_{I}/I and μ_{J}/J , respectively, where the magnetic moments μ_{I} and μ_{J} are in units of the Bohr magneton μ_{0} . Magnetic-octupole and

(5)

higher order multipole-moment terms have been neglected. In the absence of an external magnetic field, the term energies resulting from this Hamiltonian are given by

$$W_{F} = a \frac{C}{2} + \frac{3b}{4} \frac{[C(C+1) - 4/3 I(I+1) J(J+1)]}{2I(2I - 1) J(2J - 1)}$$
(2)

where

$$C = F(F + 1) - J(J + 1) - I(I + 1)$$
(3)

and

by

$$\mathbf{F} = \mathbf{I} + \mathbf{J}.$$
 (4)

The hyperfine-structure separation between two levels F and F' is given

$$\Delta \nu (F, F') = W_F - W_{F'}$$

where a, b, and Δv are in the same units.

The qualitative features of the energy-level diagram for this Hamiltonian when I = 1 and J = 5/2 are given in Fig. 1. Also indicated are the five transitions that can be observed in each isotope with an atomic-beam machine with flop-in magnet geometry. Since a closed-form solution of the secular equation to the above Hamiltonian is, in general, not possible, a complete routine called HYPERFINE-3 (for the IBM 7090) was used to fit the experimental data to theory. The HYPERFINE routine is able to fit any combination of the five variables g_J , g_I , a, b, and c (the magnetic-octupole interaction constant) to the experimental data. Since this routine is discussed elsewhere, ^{7,8,9} it is not reviewed here.

III. EXPERIMENTAL METHOD

Since the atomic-beam machine used in the course of this experiment was fully described elsewhere.¹⁰ we will discuss only the essential features for this experiment. The isotopes Re¹⁸⁶ and Re¹⁸⁸ were produced by bombarding a 20-mil natural rhenium wire with a neutron flux of 10¹⁴ neutrons/cm²/sec. The isotopes Re¹⁸⁶ and Re¹⁸⁸ have half-lives of 90 hours and 17 hours, respectively, and could therefore be distinguished in a decay plot. The Re¹⁸⁶ isotope was produced by bombarding the samples for 72 hours and then allowing them to decay for 5 to 9 days. The amount of Re¹⁸⁸ activity in the beam was less that 5%, as shown by decay plots of samples of the full beam and resonances. The Re¹⁸⁸ isotope was preferentially produced by bombarding the samples for 3 to 4 hours. As determined from decay plots, approximately 20% of the activity in the samples was Re¹⁸⁶. The beams were produced by heating the wires by electron bombardment. The atoms were collected on 1-mil fired-platinum foils which were then placed in a continuous-flow methane beta counter to measure their activity. A full-beam counting rate of from 600 to 1200 counts/min for a 1-minute exposure was determined to be the most convenient. The magnitude of the homogenous magnetic field H was determined by observation of the Zeeman transition frequency in K^{39} .

IV. RESULTS

From Eq. (1) we see that the part of the energy due to the application of an external field H_{μ} in the z direction is given by the Hamiltonian

$$\mathcal{H}_{ext} = -g_{J}(\mu_{0}/h) J_{z} H_{0} - g_{I}(\mu_{0}/h) I_{z} H_{0}.$$
(6)

(7)

In the weak-field case, I and J remain coupled and precess about F.

The interaction energy due to the external field is then given by

$$W_{ext} = -g_F(\mu_0/h)m_F H_0$$

where

$$g_{F} = g_{J} \frac{F(F+1) + J(J+1) - I(I+1)}{2F(F+1)} + g_{I} \frac{F(F+1) - J(J+1) + I(I+1)}{2F(F+1)}.$$
 (8)

Therefore in the low-field approximation the transition frequencies for the a, β , and γ transitions indicated in Fig. 1 ($\Delta F = 0$, $\Delta m_F = \pm 1$) are given by

$$v = -g_{\rm F}(\mu_0/h) H_0$$
 (9)

Neglecting the nuclear terms, we have the so-called Zeeman transition frequency

$$f = -\frac{(g_{J}\mu_{0}H_{0})}{h} \frac{F(F+1) + J(J+1) - I(I+1)}{2F(F+1)}.$$
 (10)

Then the magnetic field was increased until these frequencies began to deviate from the Zeeman transition frequencies. Deviations were first seen at about 10 gauss. A third-order perturbation procedure was then used to predict the transition frequencies at higher fields. When enough points has been observed, the HYPERFINE-3 program was used to determine initial values of a and b. An IBM 650 computer program called JO-9 was then used to predict the transition frequencies at even higher fields, using the a and b values calculated by HYPERFINE-3. This procedure was continued until the values of a and b were known with sufficient accuracy that we could begin searching for the direct transitions $(F=7/2, m_F = -1/2) \leftrightarrow (F=5/2, m_F = -1/2)$ and $(F=5/2, m_F = 1/2) \leftrightarrow (F=3/2, m_F = 1/2)$.

Note that both direct transitions are σ transitions ($\Delta m_F = 0$), whereas the a, β , and γ transitions are π transitions ($\Delta m_F = \pm 1$). The π -hairpin that was used to produce the a, β , and γ transitions was also used to produce the direct transitions. The part of this hairpin that carried the rf current consisted of a strip of metal whose plane was perpendicular to the external magnetic field. Therefore the only places where the radio-frequency magnetic field was parallel to the external magnetic field were at the edges of the strip. In this way separated oscillating fields, necessary for one to observe a Ramsey pattern, were produced. This type of hairpin construction was described by Schlecht and McColm.¹¹ Ramsey patterns were observed for both direct transitions in both isotopes. It was determined that the transition (F = 5/2, $m_F = 1/2$) \leftrightarrow (F = 3/2, $m_F = 1/2$) attained a minimum transition frequency at approximately 12 gauss. Both direct transitions were observed for each isotope at this field in order to reduce the effect of the field error in the above transition.

Resonance curves representative of those obtained are shown in Figs. 2 and 3. A π -transition is shown in Fig. 2 and a σ -transition in Fig. 3. Since the oscillating fields are 180° out of phase, the Ramsey pattern in Fig. 3 shows a dip at the transition frequency rather than a peak.

Tables I and II give the final HYPERFINE-3 output for the isotopes Re¹⁸⁶ and Re¹⁸⁸, respectively. A measure of how well the experimental points fit theoretical predictions based on the a and b values already obtained is the value of the goodness-of-fit parameter χ^2 . Since χ^2 should have the value N - N', where N is the number of observations and N' is the number of variables, therefore for the Re¹⁸⁸ data χ^2 should be 6 and for the Re¹⁸⁶ χ^2 shold be 5. The values of 0.4 and 1.3, which were obtained by HYPERFINE-3 for Re¹⁸⁸ and Re¹⁸⁶, respectively, indicate that pessimistic values of the frequency errors were used. Thus the frequency errors as given by the HYPERFINE-3 program are also pessimistic. However, for security, twice these values have been used as the experimental errors. Therefore we obtain for Re¹⁸⁶ the values

 $a = \pm 78.3058(24)$ Mc/sec $b = \mp 8.3601(50)$ Mc/sec

and $g_1 > 0$.

For Re¹⁸⁸ we obtain the values

 $a = \pm 80.4320(32) \text{ Mc/sec}$ $b = \mp 7.7455(60) \text{ Mc/sec}$

and $g_T > 0$.

Taking the weighted average of the two values for g_J , we obtain the value

$$g_{J} = -1.95203(8)$$
.

For pure Russell-Saunders coupling, the g_T factor is given by ¹²

$$g_{J} = 1 + (g_{S} - 1) \frac{J(J + 1) + S(S + 1) - L(L + 1)}{2J(J + 1)}$$

where g_S is the g-factor of the electron. Therefore, the g_J value for rhenium should be

$$g_{T} = g_{S} = -2.00229$$
.

The major part of the discrepancy between this value and the experimental value should come from the breakdown of Russell-Saunders coupling due to

the spin-orbit and configuration interactions.

From equations (2) and (5) we obtain, for the two hyperfine-structure

separations in rhenium,

$$\Delta v(7/2, 5/2) = 7/2 a + 21/20 b$$

 $\Delta v(5/2, 3/2) = 5/2 a - 3/2 b$.

From this we obtain for the hyperfine-structure separations of Re¹⁸⁶ the

values

$$\Delta v_{186} (7/2, 5/2) = \pm 265.292(14) \text{ Mc/sec}$$

 $\Delta v_{186} (5/2, 3/2) = \pm 208.305(14) \text{ Mc/sec}$

For Re¹⁸⁸ we obtain the values

$$\Delta v_{188} (7/2, 5/2) = \pm 273.379(13)$$
 Mc/sec
 $\Delta v_{188} (5/2, 3/2) = \pm 212.698(17)$ Mc/sec.

FOOTNOTES AND REFERENCES

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a	Ъ	gJ	$g_{I} \times 10^{4}$	Er ir	ror na	Error in b	E1 ir	ror E ^{1 g} j g	Crror in I × 10 ⁴	x²
78.305	8 -8.3601	-1.951997	11.444159	0.0	0012	0.0025	0.00	0044 6	.939246	1.3444083
			Energy	levels	and re	siduals				
			b	/a =	-0. 10	58				
			۴. بروند کرد	/h =	1.399	9677				
			M _p /N	$M_e = 1$	836.12					
				μ[=	2.10	1285			ان و المرابق مرابق المرابق المرابق المرابق المرابق المرابق المرابق مرابق المرابق المرابق المرابق المرابق المرابق المرابق	
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Run No.	Frequency (Mc/sec)	Residual (Mc/sec)	Freq. error (Mc/sec)	F ₁	M	F ₂	M ₂	H (G)	ΔН (G)	Weight factor
Run No.	Frequency (Mc/sec) 129.9300	Residual (Mc/sec) 0.0152	Freq. error (Mc/sec) 0.0150	F1 5/2	M ₁ 1/2	F ₂ 5/2	M ₂ -1/2	H (G) 50.0003	ΔH (G) 3 0.0092	Weight factor 1122.8
Run No. 1 2	Frequency (Mc/sec) 129.9300 480.1450	Residual (Mc/sec) 0.0152 -0.0108	Freq. error (Mc/sec) 0.0150 0.0150	F ₁ 5/2 7/2	M ₁ 1/2 -1/2	F ₂ 5/2 7/2	M ₂ -1/2 -3/2	H (G) 50.0003 200.0000	ΔH (G) 3 0.0092 0 0.0044	Weight factor 1122.8 2783.9
Run No. 1 2 3	Frequency (Mc/sec) 129.9300 480.1450 103.8550	Residual (Mc/sec) 0.0152 -0.0108 0.0147	Freq. error (Mc/sec) 0.0150 0.0150 0.0150	F ₁ 5/2 7/2 7/2	M ₁ 1/2 -1/2 -1/2	F ₂ 5/2 7/2 7/2	M ₂ -1/2 -3/2 -3/2	H (G) 50.0003 200.0000 50.0003	ΔH (G) 3 0.0092 0 0.0044 3 0.0092	Weight factor 1122.8 2783.9 1562.9
Run No. 1 2 3 4	Frequency (Mc/sec) 129.9300 480.1450 103.8550 190.8450	Residual (Mc/sec) 0.0152 -0.0108 0.0147 0.0109	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150	F ₁ 5/2 7/2 7/2 3/2	M ₁ 1/2 -1/2 -1/2 3/2	F ₂ 5/2 7/2 7/2 3/2	M ₂ -1/2 -3/2 -3/2 1/2	H (G) 50.0003 200.0003 50.0003	ΔH (G) 3 0.0092 0 0.0044 3 0.0092 3 0.0092	Weight factor 1122.8 2783.9 1562.9 810.8
Run No. 1 2 3 4 5	Frequency (Mc/sec) 129.9300 480.1450 103.8550 190.8450 78.3350	Residual (Mc/sec) 0.0152 -0.0108 0.0147 0.0109 0.0045	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 5/2 7/2 7/2 3/2 3/2	M ₁ 1/2 -1/2 -1/2 3/2 3/2	F ₂ 5/2 7/2 7/2 3/2 3/2	M ₂ -1/2 -3/2 -3/2 1/2 1/2	H (G) 50.0003 200.0000 50.0003 50.0003 20.0000	ΔH (G) 3 0.0092 0 0.0044 3 0.0092 3 0.0092 0 0.0119	Weight factor 1122.8 2783.9 1562.9 810.8 410.2
Run No. 1 2 3 4 5 6	Frequency (Mc/sec) 129.9300 480.1450 103.8550 190.8450 78.3350 273.0000	Residual (Mc/sec) 0.0152 -0.0108 0.0147 0.0109 0.0045 0.0093	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 5/2 7/2 7/2 3/2 3/2 5/2	M ₁ 1/2 -1/2 -1/2 3/2 3/2 1/2	F ₂ 5/2 7/2 7/2 3/2 3/2 5/2	M ₂ -1/2 -3/2 -3/2 1/2 1/2 -1/2	H (G) 50.0003 200.0003 50.0003 20.0003 99.9995	ΔH (G) 3 0.0092 0 0.0044 3 0.0092 3 0.0092 0 0.0119 5 0.0064	Weight factor 1122.1 2783.9 1562.9 810.1 410.1 1807.1
Run No. 1 2 3 4 5 6 7	Frequency (Mc/sec) 129.9300 480.1450 103.8550 190.8450 78.3350 273.0000 221.4800	Residual (Mc/sec) 0.0152 -0.0108 0.0147 0.0109 0.0045 0.0093 0.0087	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 5/2 7/2 7/2 3/2 3/2 5/2 7/2	M ₁ 1/2 -1/2 -1/2 3/2 3/2 1/2 -1/2	F ₂ 5/2 7/2 7/2 3/2 3/2 5/2 7/2	M ₂ -1/2 -3/2 -3/2 1/2 1/2 -1/2 -3/2	H (G) 50.0003 200.0003 50.0003 20.0003 99.9995 99.9499	ΔH (G) 3 0.0092 0 0.0044 3 0.0092 3 0.0092 0 0.0119 5 0.0064 9 0.0064	Weight factor 1122.8 2783.9 1562.9 810.8 410.3 1807.8 2119.9
Run No. 1 2 3 4 5 6 7	Frequency (Mc/sec) 129.9300 480.1450 103.8550 190.8450 78.3350 273.0000 221.4800 204.1675	Residual (Mc/sec) 0.0152 -0.0108 0.0147 0.0109 0.0045 0.0093 0.0087 0.0000	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F1 5/2 7/2 7/2 3/2 3/2 5/2 7/2 5/2	M ₁ 1/2 -1/2 -1/2 3/2 3/2 1/2 -1/2 1/2	F ₂ 5/2 7/2 7/2 3/2 3/2 5/2 7/2 3/2	M ₂ -1/2 -3/2 -3/2 1/2 1/2 -1/2 -3/2 -1/2 -1/2	H (G) 50.0003 200.0003 50.0003 20.0003 99.9995 99.9495 11.9995	ΔH (G) 0.0092 0.0044 0.0092 0.0092 0.0092 0.0119 0.0064 0.0064 0.0128	Weight factor 1122.1 2783.9 1562.9 810.1 410.2 1807.1 2119.9 39862.4

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8	·b	٤J	$g_{I} \times 10^{4}$	Erro in a	or E a	rror in b	Erro in g	or Err J ^g l >	or in (10 ⁴	x ²
80,432	20 -7:.7455	-1.952082	13,190500	0,00	16 O	.0030	0.000	075 6.59	7555	0.38542005
			Energy	levels	and rea	siduals				
			b	/a =	-0.096	3 '				
			μ.	/h =	1. 399	677				
			M _p /N	$M_{e} = 18$	36. 12					
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Run No.	Frequency (Mc/sec)	Residual (Mc/sec)	Freq. error (Mc/sec)	F ₁	M ₁	F ₂	M ₂	H (G)	ΔH (G)	Weight
Run No.	Frequency (Mc/sec) 39.8850	Residual (Mc/sec) 0.0110	Freq. error (Mc/sec) 0.0150	F ₁ 7/2.	^M 1 -1/2	F ₂ 7/2	M ₂ -3/2	H (G) 20.0000	ΔH (G) 0.0119	Weight factor 1224.4
Run No. 1 2	Frequency (Mc/sec) 39.8850 51.1350	Residual (Mc/sec) 0.0110 0.0087	Freq. error (Mc/sec) 0.0150 0.0150	F ₁ 7/2· 5/2	M ₁ -1/2 1/2	F ₂ 7/2 5/2	M ₂ -3/2 -1/2	H (G) 20.0000 20.7547	ΔH (G) 0.0119 0.0118	Weight factor 1224.4 884.6
Run No. 1 2 3	Frequency (Mc/sec) 39.8850 51.1350 129.7250	Residual (Mc/sec) 0.0110 0.0087 -0.0041	Freq. error (Mc/sec) 0.0150 0.0150 0.0150	F ₁ 7/2, 5/2 5/2	M ₁ -1/2 1/2 1/2	F ₂ 7/2 5/2 5/2	M ₂ -3/2 -1/2 -1/2	H (G) 20.0000 20.7547 50.0003	ΔH (G) 0.0119 0.0118 0.0092	Weight factor 1224.4 884.6 1125.2
Run No. 1 2 3 4	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2. 5/2 5/2 3/2	M ₁ -1/2 1/2 1/2 3/2	F ₂ 7/2 5/2 5/2 3/2	M ₂ -3/2 -1/2 -1/2 1/2	H (G) 20.0000 20.7547 50.0003 20.0000	ΔH (G) 0.0119 0.0118 0.0092 0.0119	Weight factor 1224.4 884.6 1125.2 409.8
Run No. 1 2 3 4 5	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300 191.2100	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081 -0.0072	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2. 5/2 5/2 3/2 3/2	M ₁ -1/2 1/2 1/2 3/2 3/2	F ₂ 7/2 5/2 5/2 3/2 3/2	M ₂ -3/2 -1/2 -1/2 1/2 1/2 1/2	H (G) 20.0000 20.7547 50.0003 20.0000 50.0003	ΔH (G) 0.0119 0.0118 0.0092 0.0119 0.0092	Weight factor 1224.4 884.6 1125.2 409.8 802.2
Run No. 1 2 3 4 5 6	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300 191.2100 272.9000	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081 -0.0072 0.0037	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2. 5/2 5/2 3/2 3/2 3/2 5/2	M ₁ -1/2 1/2 1/2 3/2 3/2 1/2	F ₂ 7/2 5/2 5/2 3/2 3/2 5/2	M ₂ -3/2 -1/2 -1/2 1/2 1/2 1/2 -1/2	H (G) 20.0000 20.7547 50.0003 20.0000 50.0003 99.9995	ΔH (G) 0.0119 0.0118 0.0092 0.0119 0.0092 0.0064	Weight factor 1224.4 884.6 1125.2 409.8 802.2 1803.4
Run No. 1 2 3 4 5 5 6 7	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300 191.2100 272.9000 220.8750	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081 -0.0072 0.0037 -0.0008	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2. 5/2 5/2 3/2 3/2 3/2 5/2 7/2	M ₁ -1/2 1/2 1/2 3/2 3/2 1/2 -1/2	F ₂ 7/2 5/2 5/2 3/2 3/2 5/2 5/2 7/2	M ₂ -3/2 -1/2 -1/2 1/2 1/2 -1/2 -1/2 -3/2	H (G) 20.0000 20.7547 50.0003 20.0000 50.0003 99.9995 99.9995	ΔH (G) 0.0119 0.0118 0.0092 0.0119 0.0092 0.0064 0.0064	Weight factor 1224.4 884.6 1125.2 409.8 802.2 1803.1 2129.8
Run No. 1 2 3 4 5 6 7 8	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300 191.2100 272.9000 220.8750 103.6270	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081 -0.0072 0.0037 -0.0008 -0.0060	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2. 5/2 5/2 3/2 3/2 3/2 5/2 7/2 7/2	M ₁ -1/2 1/2 1/2 3/2 3/2 1/2 -1/2 -1/2	F ₂ 7/2 5/2 5/2 3/2 3/2 5/2 7/2 7/2	M ₂ -3/2 -1/2 -1/2 1/2 1/2 -1/2 -1/2 -3/2 -3/2	H (G) 20.0000 20.7547 50.0003 20.0000 50.0003 99.9995 99.9995 \$50.0003	ΔH (G) 0.0119 0.0118 0.0092 0.0119 0.0092 0.0064 0.0064 0.0092	Weight factor 1224.4 884.6 1125.2 409.8 802.2 1803.4 2129.8 1570.5
Run No. 1 2 3 4 5 6 7 8 9	Frequency (Mc/sec) 39.8850 51.1350 129.7250 78.3300 191.2100 272.9000 220.8750 103.6270 276.6650	Residual (Mc/sec) 0.0110 0.0087 -0.0041 0.0081 -0.0072 0.0037 -0.0008 -0.0060 -0.0001	Freq. error (Mc/sec) 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150 0.0150	F ₁ 7/2, 5/2 5/2 3/2 3/2 3/2 5/2 7/2 7/2 7/2	M ₁ -1/2 1/2 1/2 3/2 3/2 1/2 -1/2 -1/2 -1/2	F ₂ 7/2 5/2 5/2 3/2 3/2 5/2 7/2 7/2 5/2	M ₂ -3/2 -1/2 -1/2 1/2 1/2 -1/2 -3/2 -3/2 -3/2 -1/2	H (G) 20.0000 20.7547 50.0003 20.0000 50.0003 99.9995 99.9995 •50.0003 11.9999	ΔH (G) 0.0119 0.0118 0.0092 0.0119 0.0092 0.0064 0.0064 0.0092 0.0128	Weight factor 1224.4 884.6 1125.2 409.8 802.2 1803.4 2129.8 1570.5 8548.5

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FIGURE CAPTIONS

Fig. 1. Breit-Rabi diagram for Re¹⁸⁶ and Re¹⁸⁸.

Fig. 2. Alpha transition in Re¹⁸⁶ at 99.950 G.

Fig. 3. $(5/2, 1/2) \leftrightarrow (3/2, 1/2)$ direct transition in Re¹⁸⁶

at 12.000 G.



I = I , J = 5/2

Q

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MU-29246

Fig. l



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MU-31481

Fig. 3

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