is high and the deuteron energy rather low. We might therefore expect to find spin-flip stripping showing up most strongly for the lower lying states in reactions of large Q value.

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Note added in proof.—Professor Parkinson has kindly informed me that the idea of spin flip by the departing nucleus in a stripping reaction is due not to him but to Professor A. P. French of the Cavendish Laboratory, Cambridge, and now of the University of South Carolina who conceived of it in about 1952 in terms of an exchange process of intrinsic spins. Professor Parkinson also informs me that the possibility of spin flip in the particular case of interest here is discussed by Dr. N. T. S. Evans in his Ph.D. thesis (1956) at the Cavendish Laboratory.

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Quadrupole Moments of Os^{189}, Ta^{181}, Lu^{175}, and La^{139}

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The quadrupole moment of Os^{189} was determined from the hyperfine structure of the level $5d^66s^2\ {}^5D_4$ of Os I and was found to be $Q(Os^{189})=(+0.8\pm0.2)\times10^{-24}$ cm^2 without shielding correction. The quadrupole moments (without shielding correction) of Ta^{181}, Lu^{175}, and La^{139} that were determined previously from the configurations $5d^36s^2$, $5d6s^2$, and $5d^26s$ respectively are, in units of 10^{-24} cm^2, $+3.9\pm0.4$, $+5.1\pm0.3$, and $+0.5\pm0.2$ respectively. If one assumes a shielding correction of -0.3 for the $5d$ electron, these values become $Q(Os^{189})=+0.6\pm0.14$, $Q(Ta^{181})=+2.7\pm0.3$, $Q(Lu^{175})=+3.6\pm0.2$, and $Q(La^{139})=+0.3\pm0.1$ in units of 10^{-24} cm^2, where the probable error does not include the uncertainty of the shielding correction.

I. INTRODUCTION

ACCORDING to the calculations of Sternheimer,[1] the atomic core shields or antishields the nuclear quadrupole coupling, so that the quadrupole moment (Q) deduced from the hyperfine structure (hfs) of atomic spectra must be multiplied by the factor $1+\Delta$, in order to get the true quadrupole moment. Δ is the shielding correction, which we called the "polarization correction" in previous work. Sternheimer has recently published a more accurate calculation concerning the shielding correction.[2]

In our previous work[3,4] on $Q(La^{139})$, $Q(Lu^{175})$, and $Q(Ta^{181})$, the values of Δ for the $5d$ electron were taken from the tabulation in reference 1. The more accurate calculation[2] shows that these values must be revised. Sternheimer[2] calculated the values of Δ for the configurations Cu I $3d^94s^2$ and W I $5d^4$; the other values are concerned with p electrons only. According to Sternheimer,[5] concerning the shielding correction for the states Ta I $5d^36s^2$ and Os I $5d^6s^2$, it is likely from his calculations for W I $5d^4$ that for these states the antishielding will predominate, leading to $\Delta<0$; however, such a conclusion cannot be drawn with certainty, but could be verified only by specific calculations for these elements with the appropriate wave functions. In the present work, therefore, we shall leave the accurate calculation of the shielding correction of the $5d$ electron of La, Os, Lu, and Ta for future work and tentatively assume that it is the same as in the case of W I $5d^4$, namely $\Delta=-0.3$, and examine whether it leads to reasonable values of Q.

II. QUADRUPOLE MOMENT OF Os^{189}

In previous work,[3,6] the hfs of Os I $\lambda4260(5d^66s^2\ {}^5D_4-5d^66s6p\ {}^7D_5)$[7] was studied, but the splitting of the final level for the isotope $Os^{189}(I=\frac{3}{2})$ could not be deduced from the observed hfs by a purely empirical method, and this introduced uncertainty in deducing the value of $Q(Os^{189})$ (footnote 22 of reference 3). In the present work the hfs of Os I $\lambda4420(5d^66s^2\ {}^5D_4-5d^66s6p\ {}^7D_4)$ was studied, and the result of the measurement is shown schematically in Fig. 1. From Fig. 1 of the present work and Fig. 3 of reference 3, we get the interval factor $A=0.008$ cm^{-1}, and the quadrupole coupling constant $B=0.10_4\times10^{-3}$ cm^{-1} for the common final level $5d^66s^2\ {}^5D_4$ for the isotope Os^{189}.

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[1] R. M. Sternheimer, Phys. Rev. **80**, 102 (1950); **84**, 244 (1951); **86**, 316 (1952).

[2] R. M. Sternheimer, Phys. Rev. **95**, 736 (1954). Sternheimer's $1/(1-R)$ is our $1+\Delta$.

[3] K. Murakawa, Phys. Rev. **98**, 1285 (1955). Erratum: Eq. (5) should read $(d^4s\ {}^6D_{\frac{3}{2}}{}^{\frac{3}{2}}|\omega|d^4s\ {}^6D_{\frac{3}{2}}{}^{\frac{3}{2}})=-(2/4375)(584R_2'-91R_2''+132S_2)$.

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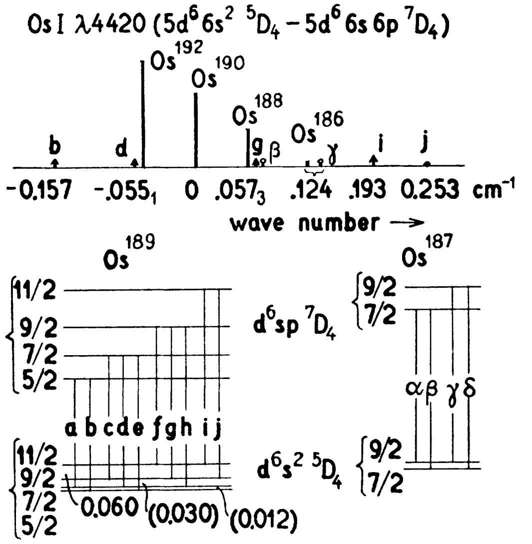

FIG. 1. hfs of Os I λ4420.

Using the formula given in reference 3, we get $Q(\mathrm{Os}^{189}) = (+0.8\pm0.2)\times10^{-24}$ cm^2 without shielding correction. If we assume a shielding correction $\Delta=-0.3$, this becomes $Q(\mathrm{Os}^{189}) = (+0.6\pm0.14)\times10^{-24}$ cm^2.

III. QUADRUPOLE MOMENT OF Ta^{181}

Analysis[4] of the hfs of Ta I $5d^36s^2$ yielded the result that $Q(\mathrm{Ta}^{181}) = (+4.3\pm0.4)\times10^{-24}$ cm^2, if we assume that $\Delta=0.103$; this shows that $Q(\mathrm{Ta}^{181}) = (+3.9\pm0.4)\times10^{-24}$ cm^2 without shielding correction. If we assume $\Delta=-0.3$, this becomes $Q(\mathrm{Ta}^{181}) = (+2.7\pm0.3)\times10^{-24}$ cm^2. If we assume a strong coupling between the unbalanced nucleon and the nuclear surface, our spectroscopic quadrupole moment yields (according to the formula given by Bohr[8]) the intrinsic quadrupole moment $Q_0(\mathrm{Ta}^{181})=6\times10^{-24}$ cm^2. On the other hand, the Coulomb excitation experiment of Huus *et al.*[9] yielded the result that $Q_0(\mathrm{Ta}^{181})=7\times10^{-24}$ cm^2, and Goodman's investigation[10] gave $Q_0(\mathrm{Ta}^{181})=6.7\times10^{-24}$ cm^2. The spectroscopic value of Q_0 is now in good agreement with these values, and this shows that the abovementioned value of Δ is correct at least qualitatively.

IV. QUADRUPOLE MOMENT OF Lu^{175}

Using the data published by Gollnow,[11] Kamei[4] got $Q(\mathrm{Lu}^{175})=+5.7\times10^{-24}$ cm^2 from the hfs of the level Lu I $5d6s^2\,{}^2D_{\frac{5}{2}}$ assuming that $\Delta=0.107$. This shows that $Q(\mathrm{Lu}^{175})=+5.5\times10^{-24}$ cm^2 without shielding correction. If we assume $\Delta=-0.3$, this becomes $Q(\mathrm{Lu}^{175}) =+3.9\times10^{-24}$ cm^2; $Q_0(\mathrm{Lu}^{175})=8\times10^{-24}$ cm^2. On the other hand, Huus *et al.*[9] gave $Q_0(\mathrm{Lu}^{175})=9\times10^{-24}$ cm^2, and Goodman[10] obtained $Q_0(\mathrm{Lu}^{175})=7.8\times10^{-24}$ cm^2. The spectroscopic Q_0 is again in good agreement with Q_0 obtained from the Coulomb excitation experiment.

V. QUADRUPOLE MOMENT OF La^{139}

Under the assumption $\Delta_d=0.164$, it was concluded[3] that $Q(\mathrm{La}^{139})=(0.6\pm0.2)\times10^{-24}$ cm^2 from the hfs of the level $5d^26s\,{}^4F_{\frac{3}{2}}$. This means that $Q(\mathrm{La}^{139})=(+0.5\pm0.2)\times10^{-24}$ cm^2 without shielding correction. If we assume that $\Delta_d=-0.3$, we get $Q(\mathrm{La}^{139})=(+0.3_5\pm0.1)\times10^{-24}$ cm^2. On the other hand,[12] the value $+0.3\times10^{-24}$ cm^2 without shielding correction was obtained from the hfs of the level $5d6s\,{}^3D_1$ of La II. This small discrepancy can apparently be understood by assuming that the shielding correction for the configuration $5d^26s$ of La I is somewhat larger than that for $5d6s$ of La II in absolute magnitude.[13]

In summary, we may conclude that the data shown in Secs. III and IV indicate the validity of Sternheimer's idea of shielding or antishielding of the nuclear quadrupole coupling by the atomic core. However, owing to the rather small accuracy of the calculations, only one-digit discussions seem to be possible at the present time.

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[10] C. Goodman, quoted by C. H. Townes, Symposium on Quadrupole Moment held at the University of Kyoto (Japan) in June, 1956 (unpublished).

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[12] Full details of the deduction of $Q(\mathrm{La}^{139})$ were published by K. Murakawa, J. Phys. Soc. (Japan) **10**, 927 (1955).

[13] In a recent work G. Lührs [Z. Physik **141**, 486 (1955)] has come to the conclusion that the level $5d^26s\,{}^4F_{\frac{3}{2}}$ of La I is appreciably perturbed by the level $5d6s^2\,{}^2D_{\frac{3}{2}}$, and therefore he proposes to abandon the value of Q deduced from the level $5d^26s\,{}^4F_{\frac{3}{2}}$. This conclusion is not in agreement with that of M. F. Crawford [Phys. Rev. **47**, 768 (1935)], who showed that the perturbation is negligibly small. Lührs' conclusion is also in conflict with the theory of G. Racah [Phys. Rev. **63**, 367 (1943), Table II and Eq. (81)], and is therefore extremely difficult to accept.