Hyperfine Structure in the Spectra of Iridium and Osmium

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The hyperfine structure in the spectra of Ir I and Os I was studied and the following results were obtained. (I) Both Ir^{191} and Ir^{193} have nuclear spins $\frac{3}{2}$, and the ratio of their magnetic moments is $\mu^{193}/\mu^{191}=1.04\pm 0.04$, with $\mu^{193}=+0.17\pm 0.03$ nm. Their quadrupole moments are given by $Q^{193}=(+1.0\pm 0.5)\times 10^{-24}$ cm^2 and $Q^{191}/Q^{193}=1.2\pm 0.4$. Lines due to the transition $d^7s^2-d^7sp$ were observed to have an isotope displacement effect of the order of 0.063–0.071 cm^{-1}. (II) Os^{189} has a nuclear spin $\frac{3}{2}$, a nuclear magnetic moment $+0.70\pm 0.09$ nm, and a quadrupole moment $(+2.0\pm 0.8)\times 10^{-24}$ cm^2.

I. IRIDIUM

THE hyperfine structure of the spectra of Ir I and Os I was studied using a water-cooled hollow-cathode discharge tube and a Fabry-Pérot etalon.

The line Ir I λ4198 $(9_{3/2}-d^7sp\ {}^6D_{1/2})$[1] was observed to have the structure: 0 (3), 0.261 (5) cm^{-1}, where numbers in parentheses represent fairly accurate relative intensities. Since the term $9_{3/2}$ was observed to have a very small splitting, this structure is mainly due to the initial term. Iridium is known to consist of two odd isotopes Ir^{193} and Ir^{191} with relative abundances 61.5 and 38.5 percent, respectively.[2] From the above-mentioned structure of λ4198 it can be concluded that both Ir^{193} and Ir^{191} have spins $\frac{3}{2}$, and their magnetic moments are approximately equal.[3] This conclusion is supported by the structures of λ3800 and λ3513 shown in Fig. 1. Sibaiya[4] had previously published the structures of the same lines, but the present results might be considered better owing to an improved technique.

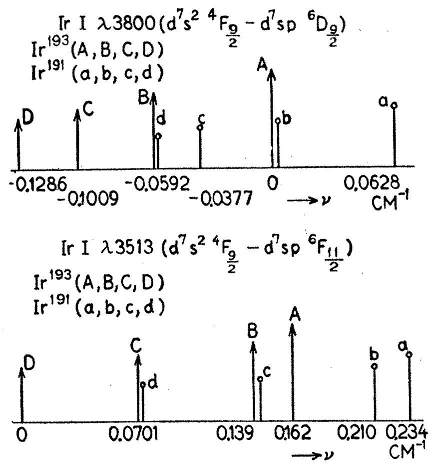

FIG. 1. Hyperfine structures of Ir I λ3800 and λ3513.

[1] W. Albertson, Phys. Rev. **54**, 183 (1938).
[2] M. B. Sampson and W. Bleakney, Phys. Rev. **50**, 732 (1936).
[3] The fact that the spin of Ir^{191} must be $>\frac{1}{2}$ was contained in a private communication by one of the authors (K.M.) quoted by J. E. Mack, Revs. Modern Phys. **22**, 64 (1950). Subsequently, Brix, Kopfermann, and Siemens, Naturwiss. **37**, 397 (1950), concluded that this spin is most probably $\frac{3}{2}$ and that the magnetic moments of Ir^{193} and Ir^{191} are approximately equal.
[4] L. Sibaiya, Phys. Rev. **56**, 768 (1939).

Denoting the interval factor and the quadrupole constant of the initial term and the final term of $\lambda 3800(d^7s^2\,{}^4F_{9/2}-d^7sp\,{}^6D_{9/2})$ by A, B and A', B', respectively, we get from the observed structure of λ3800:

$$A-A'=0.00871,\quad B-B''=0.00004 \text{ cm}^{-1} \text{ for } Ir^{193}.$$

$$A-A'=0.00836,\quad B-B'=0.00006 \text{ cm}^{-1} \text{ for } Ir^{191}.$$

Taking the ratio of the values for $A-A'$, we get

$$\mu^{193}/\mu^{191}=1.04\pm 0.04.$$

Taking the ratio of the values for $B-B'$, we get

$$Q^{191}/Q^{193}=1.5\pm 0.8 \text{ from } \lambda 3800.$$

However, the structure of λ3513 shows that the value of Q^{191}/Q^{193} is nearly equal to 1.0, so that the final value is

$$Q^{191}/Q^{193}=1.2\pm 0.4.$$

We now calculate μ^{193} from the structure of $\lambda 3513\cdot(d^7s^2\,{}^4F_{9/2}-d^7sp\,{}^6F_{11/2})$. Denoting the interval factor and the quadrupole constant of the initial term and the final term by A, B and A', B', respectively, we get

$$6A-5A'=0.0475 \text{ cm}^{-1} \text{ for } Ir^{193}.$$

Assuming a jj-coupling for the initial term and using the Fermi-Segrè-Goudsmit formulas with the correction introduced by Crawford and Schawlow,[5] we get

$$\mu(Ir^{193})=0.17\pm 0.03 \text{ nm}.$$

This shows that $a(6s)=0.0797$ cm^{-1}, $a(6p_{1/2})=0.0076$ cm^{-1} and $a(5d^7\,{}^4F_{9/2})\approx 0.0016$ cm^{-1} for Ir^{193}.

From the structure of λ3513, we get

$$55B-36B'=-0.0031 \text{ cm}^{-1} \text{ for } Ir^{193}.$$

The numbers 55 and 36 are the values of $J(2J-1)$ for the initial and the final term of λ3513, respectively. Using the usual procedure, we get

$$Q(Ir^{193})=(+1.0\pm 0.5)\times 10^{-24} \text{ cm}^2.$$

Figure 1 shows that Ir^{193} is displaced towards lower frequency side against Ir^{191} by 0.063 cm^{-1} and 0.071 cm^{-1} in the lines λ3800 and λ3513, respectively.

[5] M. F. Crawford and A. L. Schawlow, Phys. Rev. **76**, 1310 (1949).

II. OSMIUM

Kawada[6] found an isotope effect in some lines of Os I, and Suwa[7] measured the isotope effect more accurately in a larger number of lines. These authors deduced $\frac{1}{2}$ as the most probable value of the nuclear spin of Os^{189}. However, a critical review shows that a spin of $\frac{3}{2}$ with a large quadrupole moment for Os^{189} is not yet excluded. The present investigation was undertaken to test this assumption, using a much improved technique.

The structure of $\lambda 4260(d^6s^2\ ^5D_4 - d^6sp\ ^7D_5)$[8] is shown in Fig. 2. The isotope Os^{189} possesses a flag pattern consisting of four components, from which we conclude that the spin of Os^{189} is $\frac{3}{2}$. It was found that the structure of other osmium lines supports this conclusion.

Denoting the interval factor and the quadrupole constant of the initial term and the final term of λ4260 by A, B and A', B', respectively, we get

$$11A - 9A' = 0.359\ \text{cm}^{-1},\quad 45B - 28B' = -0.0087\ \text{cm}^{-1},$$

for Os^{189}. The former relation gives (as in the case of iridium)

$$\mu(Os^{189}) = 0.70 \pm 0.09\ \text{nm},$$

with $a(6s) = 0.305\ \text{cm}^{-1}$, $a(6p_{1/2}) = 0.019\ \text{cm}^{-1}$, and $a(5d^6\ ^5D_4) \approx 0.0096\ \text{cm}^{-1}$; and the latter relation gives

$$Q(Os^{189}) = (+2.0 \pm 0.8) \times 10^{-24}\ \text{cm}^2.$$

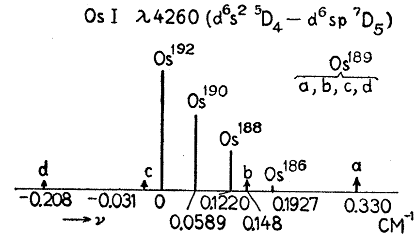

FIG. 2. Hyperfine structure of Os I λ4260.

[6] T. Kawada, Proc. Phys.-Math. Soc. Japan 20, 653 (1938).
[7] S. Suwa, Phys. Rev. 83, 1258 (1951).
[8] W. Albertson, Phys. Rev. 45, 304 (1934).

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Distributions-in-Energy for Alpha-Particles and Protons from U^{235} Fission*

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The Ranger has been applied to obtain the distributions-in-range for the alpha-particles and protons emitted from a thin film of U^{235} irradiated by thermal neutrons. For the alpha-particles the corresponding distribution-in-energy was obtained from 5.2 Mev to 50 Mev, showing appreciable intensity above 35 Mev and being well approximated in the high intensity region by a Gaussian curve centered at 15.2 Mev and with a 4.3 Mev rms half-width. The total intensity observed in this energy region corresponds to one alpha-particle in 220 fissions.

The proton intensity was found to be low above 2.1 Mev but to rise sharply as the energy was diminished to the limit of observation at 1.4 Mev, indicating about one proton with an energy in excess of 1.4 Mev emitted per 5000 fissions.

IN April, 1944, L. W. Alvarez observed light charged particles of about 21-cm range to be emitted from U^{235} bombarded by thermal neutrons. He used coincidence counting between two thin-walled ionization chambers irradiated in the thermal column of the Argonne Graphite Reactor. Since that time a number of observers[1] have studied this phenomenon, establishing that the bulk of the particles are helium nuclei emitted in a rare mode of U^{235} fission. Similar emission has been observed also in the fission of U^{233} and Pu^{239}.

The efforts of the author to establish the distribution-in-energy of these particles led to the development of the Ranger,[2] whose application to the study of neutron spectra has been described.[3] A number of measurements on the long-range particles from U^{235} and Pu^{239} made in the course of this development have been described.[2] The present note serves to record in the open literature the final measurements, made in February, 1946, on the long-range particles from U^{235}.

Figure 1 shows the arrangement by which a U^{235} foil one mg/cm² thick was irradiated in a beam of neutrons from the thermal column of the Argonne Heavy Water

* The work described in this article was done under the auspices of the Atomic Energy Project, and the information contained herein will also be included in the *National Nuclear Energy Series* (Manhattan Project Technical Section).
† Now at Vanderbilt University, Nashville, Tennessee.
[1] K. W. Allen and J. T. Dewan, Phys. Rev. 80, 181 (1950); L. L. Green and D. L. Livesy, Trans. Roy. Soc. (London) A241, 323 (1949); Tsien, Ho, Chastel, and Vigneron, J. phys. radium 8, 165, 200 (1947). See these papers for further references to the extensive literature on this subject.

[2] D. L. Hill, Rev. Sci. Instr. (to be published); see also unpublished Atomic Energy Commission Declassified Report No. 1945 (Rev.), which gives a detailed account of the Ranger and of the work done with it up to the summer of 1946.
[3] D. L. Hill, Rev. Sci. Instr. (to be published); D. L. Hill, Phys. Rev. 87, 1034 (1952).