from the angular distributions. The analysis of the histograms into the two components gives the number of protons in each group, and from this the differential cross sections can be calculated.[7] Unfortunately the distribution could not be studied in the most interesting region, at small angles, owing to the overlap of a group of protons from the elastic scattering of deuterons on hydrogen (the target gas was acetylene), but the accuracy with which the cross sections were determined at the larger angles was sufficient to establish the spins and parities of the two states. The observed angular distributions up to angles of about 90° are indicated in Figs. 1(a) and (b) for the 3.7- and 3.9-Mev levels, respectively. The full curves are the distributions calculated on the basis of Butler's theory for various values of the angular momentum transfer. The experimental points are shown together with the statistical errors; these do not include possible errors due to the separation of the groups into two components. It is seen that very good agreement is obtained with $\Delta l=1$ for the 3.7-Mev state and $\Delta l=2$ for the 3.9-Mev state. Since C^{12} has zero spin and even parity in the ground state, it follows that the 3.7-Mev state of C^{13} has a spin of 1/2 or 3/2 and odd parity, while the 3.9-Mev state has spin 3/2 or 5/2 and even parity.

Goldhaber and Williamson[8] have recently investigated the $C^{12}(p, p)$ reaction and found an indication of resonances at 1.68 and 1.73 Mev, pointing to the existence of two levels of N^{13} at an energy around 3.5 Mev; their analysis shows these to be $P_{3/2}$ and $D_{5/2}$ states. This fits in very well with our values found for the 3.7- and 3.9-Mev states of C^{13}. The agreement of the spins and parities of the ground and first excited states of C^{13} and N^{13} has already been established.[9] The present findings of doublets in C^{13} and N^{13}, together with the agreement of their spins and parities, is an excellent confirmation of the correspondence of energy states in mirror nuclei.

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Isotope Shift in the Ce II Spectrum and the Magic Number 82*

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THE isotope shift in the spectrum of Ce II was studied,[1] using an enriched sample of cerium[2] (Ce^{138} 4.4 percent, Ce^{140} 92.0 percent, Ce^{142} 3.5 percent), a hollow-cathode discharge tube,[3] and a Fabry-Perot etalon.

λ4628 ($4f^2 6s\ ^4H_{9/2}-4f^2 6p\ ^4I_{9/2}{}^o$) was studied first, since it is not disturbed by other cerium lines. The Ce^{142}-component was well resolved from the strong Ce^{140}-component. However, the Ce^{138}-component was not resolved, although Ce^{138} is somewhat more abundant than Ce^{142}. The distance 140–142 was found to be 0.055 cm^{-1}, which agrees with the measurement of Brix and Frank[4] within experimental error. The upper limit of the distance 138–140 was found to be about 0.029 cm^{-1}. Figure 1 illustrates some of the spectrograms of λ4628. Here λ4528 ($4f^2 6s\ ^4H_{13/2}-4f^2 6p\ ^4I_{13/2}{}^o$) was also found to have the same structure as λ4628.

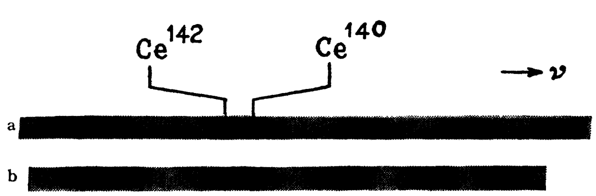

FIG. 1. Fabry-Perot patterns of Ce II λ4628. (a) Natural cerium (Ce^{140} 88.5 percent, Ce^{142} 11.1 percent); 20-mm etalon. (b) Enriched sample (Ce^{138} 4.4 percent, Ce^{140} 92.0 percent, Ce^{142} 3.5 percent); 30-mm etalon.

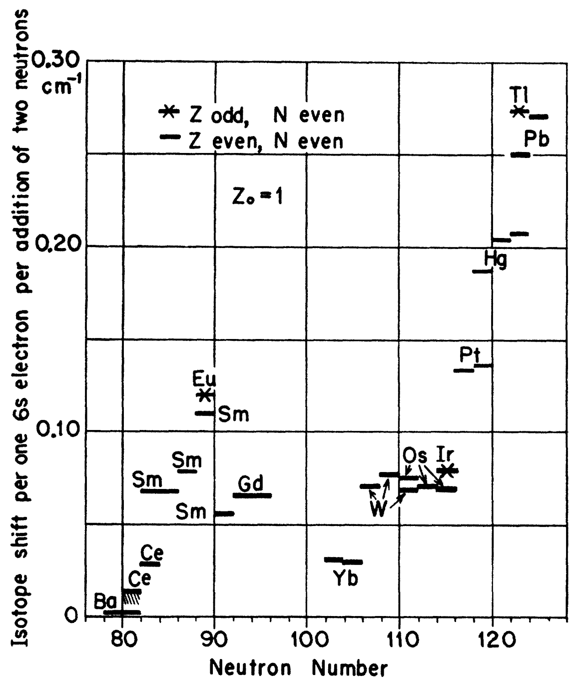

FIG. 2. Plot of the isotope shift per one 6s electron in the neutral atom per addition of two neutrons as a function of the neutron number.

This result shows that the upper limit of the distance 138–140 is about half of the distance 140–142. Since the neutron number (N) of the isotope 140 is 82, the above-mentioned anomaly can be very probably ascribed to the stable nuclear structure connected with the magic number 82.[5]

The isotope shift in the spectra of heavy elements was treated theoretically by Rosenthal and Breit[6] and by Crawford and Shawflow.[7] It is characteristic of similar theories that the isotope shift is proportional to $\psi^2(0)$, the square of the nonrelativistic wave function at the position of the nucleus. It is expressed by

$$\psi^2(0)=Z_i Z_0^2(dn^*/dn)/[\pi a_H^3 n^{*3}],$$

where the symbols have their usual meaning.

Using the same considerations as those of Crawford and Shawlow[7] and the above-mentioned formula, we can calculate from experimental data, for most heavy elements, the isotope shift per one 6s electron in the neutral atom ($Z_0=1$), per addition of two neutrons, the accuracy being 10–15 percent. Figure 2 represents the above-mentioned quantity[8] as a function of the neutron number. The isotope Sm^{146} does not exist, so the value for the isotope $Sm^{144}-Sm^{148}$ is divided by 2 and plotted. Since no gross multiplet analysis of Nd I is available, no value for the Nd isotopes is plotted. However, a rough estimate, obtained by using the data of Klinkenberg,[9] shows that the plots for Nd fall fairly close to those of Sm, and the irregularity for the pair N88–90 is especially conspicuous for Nd also.

Figure 2 shows that there is a distinct rise in the diagram when we pass from $N=80$ to $N=82$, and the above-mentioned anomaly in the isotope shift for $N=88$–90 is especially large, an idea which was expressed by Klinkenberg. Investigation of the physical meaning of the neutron number 88 or 90 will be important.

The idea that the neutron number is more important than the proton number in considering the isotope shift in the spectra of heavy elements is not altogether new, but we believe that the diagram given in Fig. 2 will be useful in arranging isotope shift data.

We are looking forward to the availability of the enriched cerium isotope 136.

* Supported by the ONR.

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β-Ray Spectrum and the *ft* Value in the Second Forbidden Transition

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RECENTLY, a new type of forbidden β-ray spectrum of Cl^{36} was explained by Wu and Feldman[1] by means of a linear combination of A_{ij} and T_{ij} terms in the second forbidden tensor interaction C_{2T}. This provides a valuable basis for further interpretation and also for the eventual discovery of forbidden spectra. We have tried to reinterpret the forbidden spectra of

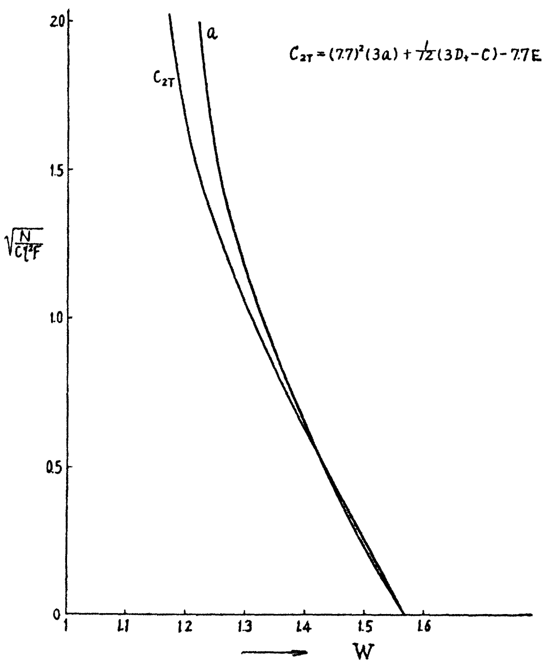


FIG. 1. Corrected Fermi plot of Tc^{99} for $k=7.7$. If we adopt the value $k\geqq 7.8$ instead of $k=7.7$, the curve will deviate downward from the straight line about the point $W=1.32$. And for $k\leqq 7.6$, the curve tends to bend upward for W less than 1.37. The curve might be a straight line up to $W<1.35$, if we take for k a value a little smaller than 7.7.

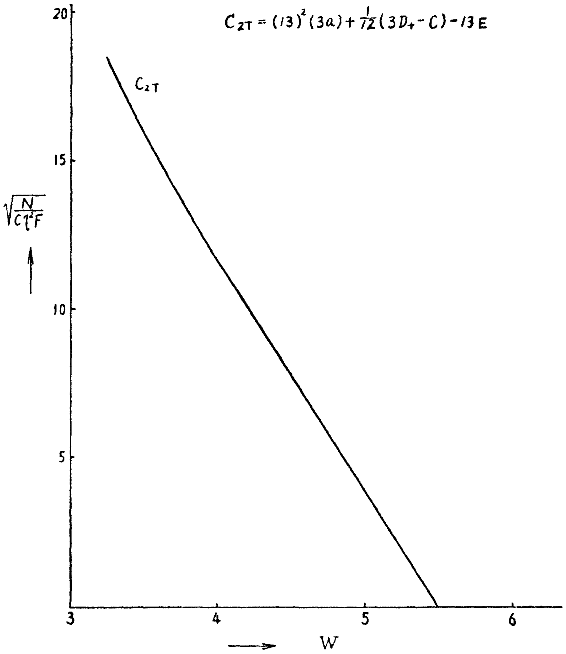


FIG. 2. Corrected Fermi plot of Sb^{124} for $k=13$. If we adopt the value $k<13$, the curve is nearly straight up to $W\sim 3.5$, but the curve deviates slightly from a straight line about $W=4.5$. This deviation, however, can be removed by a small modification of the lines joining the empirical data in Langer's graph.

Tc^{99} and Sb^{124} following this principle, i.e., using a correction factor

$$C_{2T}\sim k^2(3a)+(1/12)(3D_+-c)-kE,$$

where a, $3D_+-c$, and E are as defined in Konopinski's[2] paper, and

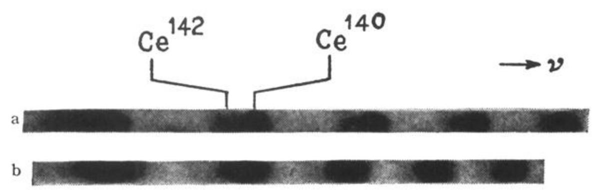
$$k^2=\Sigma|A_{ij}|^2/\Sigma|T_{ij}|^2. \tag{1}$$

The quantity k will be determined so that a straight-line Fermi plot may result by using the correction factor C_{2T}.

${}_{43}Tc_{56}{}^{99}$:—If we take $k=7.7$, the forbidden Fermi plot becomes a straight line up to $W=1.35\ mc^2$ from the maximum energy, as is seen in Fig. 1. The experimental material used here was given in Taimuty's[3] paper. The spin of the ground state of ${}_{43}Tc_{56}{}^{99}$ has been determined[4] to be 9/2. On the basis of the nuclear shell model, we can expect the ground state of ${}_{43}Tc_{56}{}^{99}$ to arise from the combination of a $g_{9/2}$ proton with an even state neutron; the resultant state should then have even parity. The ground state of ${}_{44}Ru_{55}{}^{99}$ presumably may be constructed by the $d_{5/2}$ (or $g_{7/2}$) neutron with an even state proton. If the ground state of Ru^{99} is $d_{5/2}$, the required selection rule, $\Delta J=\pm 2$, no parity change, will be satisfied.

Sb^{124}:—We found that $k=13$ results in a straight line forbidden Curie plot down to $W=4\ mc^2$ for the highest energy β-ray of Sb^{124} (see Fig. 2). The data were presented by Langer, Moffat, and Price,[5] who showed that the "a"-type interaction C_{1T} provides a good explanation for it. In the light of their analysis concerning $Sb^{124}\rightarrow Te^{124}$ decay schemes, we can take the alternative explanation: i.e., if a C_{2T} transition ($\Delta J=\pm 2$, no) is valid, the odd parity and spin 3 ground state ($g_{7/2}$, $h_{11/2}$) of Sb^{124} goes to the odd parity excited state (presumably spin 1) of Te^{124}, which is accompanied by the electric dipole ratiation, 0.607-Mev γ-ray, reaching the even parity and spin 0 ground state of Te^{124}. On Mayer's nuclear shell model, however, it seems more reasonable to assume a ($g_{7/2}$ proton, $s_{1/2}$ neutron)-state, thus even parity for the ground state of Sb^{124}, and also to assign even parity for the excited state of Te^{124}.

Once the ratio k is determined, one can evaluate the *ft* values of β-decay in these cases. By using the forbidden *f*-functions,[6]



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