Aage Bohr, Professor T. Lauritsen, Dr. B. Mottelson, and Mr. Aage Winther to whom I want to express my sincere gratitude.

[1] Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949); R. Sherr and J. B. Gerhart, Phys. Rev. **91**, 909 (1953).
[2] W. Arber and P. Stähelin, Helv. Phys. Acta. **26**, 433 (1953).
[3] E. Wigner and E. Feenberg, Repts. Progr. Phys. **8**, 274 (1941).
[4] A. Winther and O. Kofoed-Hansen, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 14 (1953); O. Kofoed-Hansen and A. Winther, Phys. Rev. **86**, 428 (1952).
[5] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).
[6] Swann, Mandeville, and Whitehead, Phys. Rev. **79**, 598 (1950).
[7] Van Patter, Sperduto, Endt, Buechner, and Enge, Phys. Rev. **85**, 142 (1952).
[8] W. M. Martin and S. W. Breckon, Can. J. Phys. **30**, 643 (1952).

The β Spectrum of RaD†

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(Received June 8, 1953; revised manuscript received September 28, 1953)

In negative β decay the binding energy of the orbital electrons of the daughter atom exceeds that of the parent atom. The question of how this energy excess, $\Delta E_z = E(Z+1) - E(Z)$, is disposed of has been discussed theoretically since 1937. Goldstein[1] and Hebb[2] came to the conclusion that ΔE_z is carried away by the β particle, the result being a cutoff at the low-energy end of the β spectrum at 16 kev for $Z=82$, according to the Fermi-Thomas model of the atom. This looked plausible because there is no appreciable coupling of the neutrino with the atomic electrons.

Some β emitters having an upper energy limit E_0 of the same order of magnitude as E_z should thus have a spectrum with a line shape about the endpoint. Among these elements, RaD seemed best suited for examination because it can be introduced into a proportional counter in the form of gaseous lead tetramethyl, the measurement thus avoiding difficulties by self-absorption and backscattering. β decay of RaD is followed by a strongly converted γ ray of 46.5 kev. In most disintegrations the proportional counter will therefore measure the sum of the energies of the β particle and the secondary radiations caused by the conversion, i.e., the sum of the energies of the β particle and the γ ray. Thus the measured distribution should give immediately the shape of the β spectrum shifted towards higher energies by 46.5 kev. But the counter gives finite line-width for a monoenergetic line and thus flattens the steep beginning of the spectrum. The correction for this is the only important one. In the case of solid sources corrections are more complicated.[3]

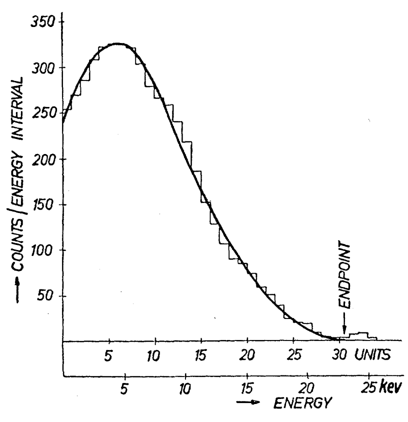

Fig. 1. β spectrum of RaD, uncorrected. (Corrections are needed from 0 to 4 kev).

The pulse output of the counter was analyzed by the method of Curran *et al.*[4] Figure 1 shows the result. The smooth curve corresponds to a straight Kurie-plot from the endpoint down to 7.5 kev, below which it is fitted to the measured distribution (without corrections).

There is no cutoff at 16 kev; i.e., ΔE_z is shared between electron and neutrino. This agrees with recent theoretical considerations.[5]

After the experiments described here had been finished, Jaffe and Cohen[6] published their results on the disintegration of RaD. They used almost the same experimental methods, and arrived at the same result as to the disposal of ΔE_z. However, they found $E_0 = 15.2 \pm 1$ kev, while the Kurie-plot corresponding to Fig. 1 gives $E_0 = 23.0$ kev with an estimated accuracy of ± 2.5 kev. An error of more than -3.0 kev seems not to be compatible with the experimental results. Energy calibrations were made by superimposing the K rays of Ag and the γ ray of RaD from external sources. Jaffe and Cohen calibrated in a similar manner, taking the widths of the calibration lines as a check of the proportionality of the counter. Proportionality of the whole apparatus near the endpoint ($E_0 + 46.5$ kev) could not be directly measured. Perhaps this may cause the discrepancy in the values of E_0.

Figure 1 shows a maximum in the energy distribution at about 4.5 ± 2.5 kev (Jaffe and Cohen: 2.7 kev). (The uncertainty in its position is caused by deficiencies in the calibration: neither Jaffe and Cohen nor the present author disposed of γ sources strong enough in comparison with the gaseous source.) At the moment it cannot be said whether the maximum is real or not. The correction for finite line-width is somewhat difficult, and that made by Jaffe and Cohen leads to a rather broad uncertainty in the shape of the spectrum below 3 kev. It can, however, be shown that the real shape below 4 kev can be calculated with an accuracy of 5 percent. Calculation shows that a maximum below 2.5 kev may be caused by finite line-width; if it lies at higher energies it must be real.

In all cases the calculation exhibits a marked deficit of β particles at low energies compared with the Fermi theory neglecting screening of the nucleus by the orbital electrons. (This is confirmed by the quite simple calculation of the shape the counter gives to a theoretically allowed spectrum with $E_0 = 23$ or 15 kev, shifted by 46.5 kev towards higher energies.) Screening diminishes the probability of emission at low energies. Computations are not yet available in the case of RaD, but are now in progress at the University of Marburg. However, there are doubts that the effect of screening is sufficiently high to explain a pronounced maximum, if it should exist.

A full account of the experimental work and the necessary corrections will soon be published elsewhere.

† Communicated at the Deutscher Physikertag, Berlin, September 1952. Physik. Verhandl. 3, 187 (1952).
[1] L. Goldstein, J. phys. et radium **8**, 235, 316 (1937).
[2] M. H. Hebb, Physica **5**, 701 (1938).
[3] Insch, Balfour, and Curran, Phys. Rev. **85**, 805 (1952).
[4] Curran, Angus, and Cockroft, Phil. Mag. **11**, 36 (1949).
[5] R. Serber and H. S. Snyder, Phys. Rev. **87**, 152 (1952); H. M. Schwartz, Phys. Rev. **86**, 195 (1952).
[6] A. A. Jaffe and S. G. Cohen, Phys. Rev. **89**, 454 (1953).

The 0^+ States of the Light Odd-Odd Nuclei

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(Received September 23, 1953)

Nuclear states with zero spin and even parity have been found in ${}_{19}K^{38}$, ${}_{17}Cl^{34}$, and ${}_{13}Al^{26}$.[1] Their half-lives are (0.95 ± 0.03) sec, (1.58 ± 0.05) sec, and 6.3 sec, respectively. They decay by positron emission directly into the ground state of the neighboring even-even isobars A^{38}, S^{34}, and Mg^{26}. The disintegration energies correspond closely to the decrease of Coulomb energy.

Assuming a uniform distribution of the nuclear charge in a spherical volume and using the empirical mass differences, we can calculate a nuclear radius R.[2] In Fig. 1 the resulting values of $r_0 = RA^{-\frac{1}{3}}$ are plotted against the number of protons. The black points refer to the well-known mirror transitions. They show that at least for $A > 20$ a useful approximation of the Coulomb energy results from the value $r_0 = 1.43 \times 10^{-13}$ cm. The open circles, representing K^{38}, Cl^{34}, and Al^{26}, fit well to this value of r_0. That means that the Coulomb energy (together with the neutron-proton mass difference) accounts for the whole energy difference between the 0^+ states of the neighboring isobars with $A=38$, with $A=34$, and with $A=26$.[3]

This result confirms not only the assumption of charge symmetry but even of charge-independence of the nuclear forces. Furthermore it allows us to assign isotopic spin $T=1$ to the 0^+ states of Al^{26}, Cl^{34}, and K^{38}. This assignment is confirmed by the constancy of the $\log ft$ values: K^{38} (3.35 ± 0.07), Cl^{34} (3.47 ± 0.06), and Al^{26}, (3.52 ± 0.10). These values also may be compared with the corresponding values of O^{14} (3.52 ± 0.10) and C^{14} (3.31 ± 0.15).[4] From the mean value (3.44 ± 0.05) we deduce a Fermi coupling constant $(1.51\pm0.08)\times10^{-49}$ erg cm^3. This result agrees with the value $(1.55\pm0.10)\times10^{-49}$ erg cm^3 which Kofoed-Hansen and Winther[5] derived from the ft values of odd-A nuclei.

The assignment of isotopic spin one to the 0^+ states does not imply that the isotopic spin is a good quantum number. The high purity of isotopic spin in these particular cases probably arises from the fact that the next admissible states with the same spin and the same parity, but with different isotopic spin, occur only at much higher excitation energies.

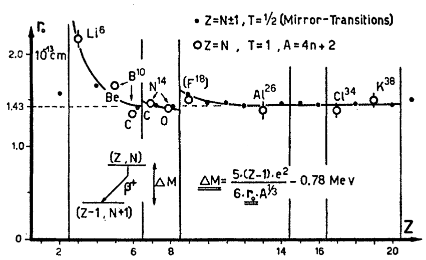

FIG. 1. Reduced nuclear radii $r_0=RA^{-1/3}$, calculated from the empirical disintegration energies.

The smooth dependence of r_0 on the atomic number (Fig. 1) enables us to predict the position of the 0^+ levels in P^{30}, Na^{22} and F^{18}. The analogous states of N^{14}, B^{10}, and Li^6 have been found empirically.[4] In every odd-odd nucleus with an equal number of protons and neutrons we therefore know the relative positions of the lowest $(T=1)$ and $(T=0)$ levels. Figure 2 shows the corresponding level schemes. The spin assignments are taken from reference 1.[6]

From the new spin assignments there also follow some small modifications of the diagram given by King and Peaslee[7] for the ground-state spins of odd-odd nuclei with neutrons and protons filling equivalent shells. In the new diagram, Fig. 3, the low-lying isomers of the $f_{7/2}$ shell have been plotted as additional points. The most puzzling feature of this diagram, the steady

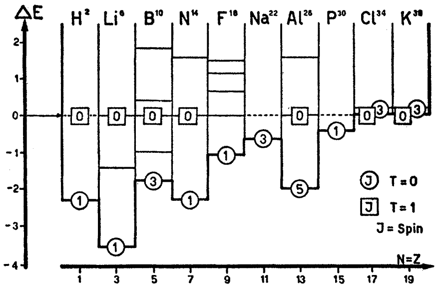

FIG. 2. Level schemes of the odd-odd nuclei containing an equal number of protons and neutrons. As a basis of reference the 0^+ states ($T=1$) are arbitrarily put to the same level.

growth of the spin with every added pair of nucleons in the lower half of the $1p$ shell and in the lower half of the $1d$ shell, is still unchanged, and the prediction of spin five for Al^{26} by King and Peaslee[7] is verified. It looks as if all the orbits were paired, while all the spins are aligned. In the $1d_{3/2}$ shell and in the $1f_{7/2}$ shell, however, holes and particles seem to be nearly equivalent, which indicates prevalence of $j-j$ coupling.

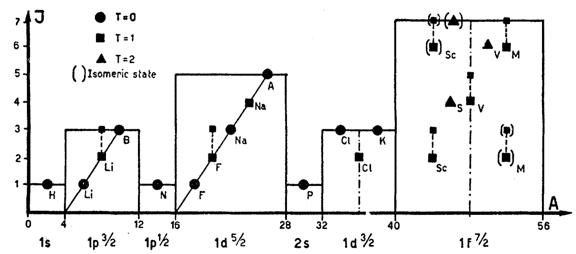

FIG. 3. Spins of the light odd-odd nuclei.

A detailed report will appear in *Helvetica Physica Acta*. I am grateful to Dr. P. Preiswerk for many helpful discussions.

[1] W. Arber and P. Stähelin, Helv. Phys. Acta **26**, 433 (1953) and Helv. Phys. Acta (to be published); P. Stähelin and P. Preiswerk, Nuovo cimento **10**, 1219 (1953) and Helv. Phys. Acta (to be published).
[2] H. A. Bethe, Phys. Rev. **54**, 436 (1938).
[3] It seems very likely that this statement also holds for $A=14$, for $A=10$, and for $A=6$. The deviations from a smooth curve in Fig. 1 are probably due to the insufficient approximation of the Coulomb term (compare reference 4).
[4] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).
[5] O. Kofoed-Hansen and A. Winther, Phys. Rev. **86**, 428 (1952).
[6] The isomerism of Al^{26} proposed in reference 1 has found a recent confirmation in the fact that $\sigma[Al^{27}(\gamma,n)]$ seems to be three times as high if the neutrons are counted instead of the electrons which are emitted from the 6.3-sec isomeric state [Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953)].
[7] R. W. King and D. C. Peaslee, Phys. Rev. **90**, 1001 (1953).