pointed out that a negative quadrupole moment is in agreement with the predictions of all the simple nuclear models that have been proposed for Li^7. However the magnitude and even the sign of Q(Li^7) must still be considered to be in doubt for the following reasons:

(1) The quantity q is the difference between two very nearly equal terms which represent, respectively, nuclear and electronic contributions. The electronic term in q is much more sensitive than the dissociation energy to changes in the wave function. Because of this sensitivity improved wave functions may lead to quite different values of q. One of us (M.A.M.) is repeating the calculations with the more accurate 18-term wave function.

(2) The variational wave function has been determined for only one internuclear distance, $R=2.98$A. The assumption made about the variation of q with R was based on calculations made with a simpler wave function.

(3) The experimental value of eqQ is rather uncertain, since the satellite maxima could not be resolved. There seems to be little doubt, however, about the sign.

(4) No average was made over the vibrational states of the molecule, and no account was taken of rotational distortion. The resulting errors are probably very small.

(5) In both of the wave functions used in these calculations, the $1s$ functions are of the form $e^{-\alpha r}$. No account has been taken of the shielding effect due to the quadrupole moment induced in the $1s$ shell. Sternheimer[9] has calculated a correction factor for this effect in atoms. He finds that for the excited lithium atom the observed nuclear quadrupole moment should be multiplied by the factor 1.148. Although our use of molecular wave functions for the valence electrons precludes a direct application of Sternheimer's result, it seems likely that the correction would be of the same order of magnitude.

It seems unlikely that Q(Li^7) can be calculated with reasonable accuracy from the observed quadrupole interaction energy until a molecular wave function for Li$_2$ is developed which will compare in accuracy with the James-Coolidge function for H$_2$.

We are indebted to Dr. R. J. Finkelstein and Dr. R. D. Present for their valuable suggestions and discussions concerning this work and to Dr. H. M. James who kindly made available his manuscripts on the Li$_2$ molecule.

Note added in proof.—The calculations with the 18-term James function mentioned previously have been completed, and the following results were obtained: dissociation energy $=-0.51$ ev (James originally gave -0.62 ev due to a slight error in his calculations). Using $R=2.98$A: $q'=-0.0030$ atomic unit, $Q(\text{Li}^7)=-4.2\times10^{-26}$ cm^2.

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

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Excited States of Even-Even Nuclei*

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A general survey of excited states of even-even nuclei yields the following results: The nth excited state has usually a spin $I\leq 2n$. For $n=1$, the assignment $I=2+$ (even parity) is compatible with experimental results for 66 out of 68 nuclei investigated. For $n=2$, of 26 nuclei investigated, about one-third have $I=2+$, one-third $I=4+$, and one-third miscellaneous spins of both even and odd parities. The energy of the first excited state plotted against the number of protons or neutrons in the nucleus varies rather smoothly and reaches maxima at closed shells. Wherever the first excited state is very low, e.g., in the rare earths region and for the heavy elements from thorium up, the one-particle model for odd A nuclei is likely to break down except for the ground state. The lack of isomers of odd proton nuclei below magic number 82 may be due to this fact. The average energy of the first excited state of the even-even core in this region is of the order of 0.1 Mev, whereas this energy is of the order of 0.5 Mev for the core of the corresponding odd neutron nuclei ($N<82$). Isomerism in even-even nuclei is discussed. The results are compared with theoretical predictions derived from an extended j-j coupling model and from the liquid drop model of the nucleus.

I. INTRODUCTION

SINCE the strong spin orbit coupling model[1,2] implying a "shell structure" of the nucleus was suggested several years ago, nuclear physics has gravitated toward the study of odd A nuclei. This model, which received its first impetus from a consideration of the pronounced stability of certain nuclear species, soon scored a series of important successes wherever the prediction of spins and parities of nuclear states entered, e.g., in the fields of beta-decay and of isomeric states. However, at the same time a number of features became apparent which seemed to contradict a rigorous single particle picture, such as the large values found for the matrix elements of a number of $E2$ transitions, the sign and size of quadrupole moments, and the scarcity of odd-proton isomers for elements with $50<Z<82$. Also, the model in its present form does not provide a basis for quantitative prediction of energies of nuclear states.

Obviously, some interaction of the single particle with the even-even core has to be taken into account. Whether the whole core has to be considered[3,4] or, in first approximation, only the "loose" particles with the

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* Work was supported by the U. S. Atomic Energy Commission.

[1] M. G. Mayer, Phys. Rev. **75**, 1894 (1949); **78**, 16 and 22 (1950).

[2] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949).

[3] J. Rainwater, Phys. Rev. **79**, 432 (1950).

[4] A. Bohr, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **26**, 14 (1952).

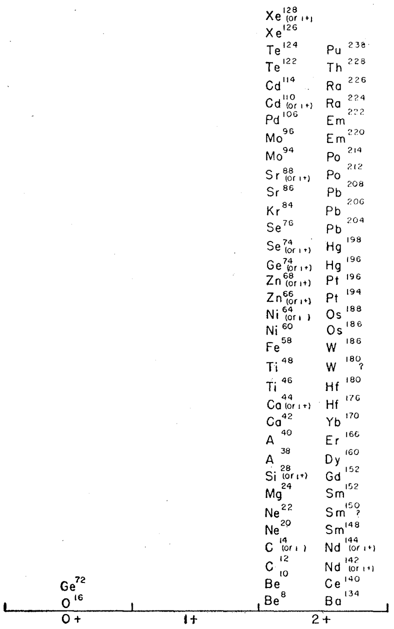

FIG. 1. Distribution of known spins and parities of first excited state of even-even nuclei. For methods of determination and references see Table I, columns 6 and 7. For 66 nuclei, a spin assignment of 2 and even parity is compatible with experimental results. In 53 of these cases a spin 2 and even parity can be assigned with certainty. For eleven more nuclei a spin of 2, even, seems probable, but the possibility that their first excited state has a spin 1, even, cannot be excluded. For two other cases, it can only be said that $I \leq 2$ for the first excited state. See Secs. II, 1 and III, 1 of text.

same quantum numbers (l, j) as those of the odd particle,[5, 6] is not yet clear.

At this point, it seems of great interest to survey our empirical knowledge of even-even nuclei, for its own sake as well as to promote a better understanding of odd A nuclei.[7]

We restrict ourselves here to a survey of the spins and parities of the first 3 excited states of even-even nuclei and of the energy spacings between the ground state and these 3 excited states.

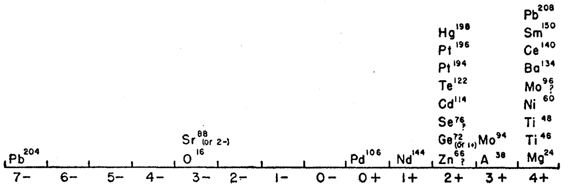

FIG. 2. Distribution of known spins and parities for the second excited state of even-even nuclei. The light nuclei show a preference of spin 4 and even parity for their second excited state. This is in agreement with theoretical expectations for nucleon pairs with low j. States with odd parity can be described as the result of "splitting up" of a pair of nucleons. See Secs. II, 2 and III, 2 of text. According to a private communication by F. Metzger, Os^{186} has also 2+ for its second excited state.

For the ground state of a nucleus, it is generally assumed that an even number of equivalent nucleons couple to zero angular momentum and, of course, even parity. Only a small number of nuclear spins of even-even nuclei have actually been measured,[8] but many experimental facts indicate that this assumption is correct. We therefore base our conclusions on spins and parities of excited states on the assumption that the ground state of an even-even nucleus has a total angular momentum (hereafter called spin) $I=0$ and even parity.

II. RESULTS OF THE SURVEY

1. Goldhaber and Sunyar[9] pointed out in 1951 that the first excited states of even-even nuclei have predominantly spin $I=2$ and even parity.[10] The summary of the first excited states with spin and parity known at that time yielded nineteen examples supporting this "2+ rule" and seven contradicting it. These seven cases consisted of two cases with spin 0, even, and five with spins 1 and 3, some of them with odd parity.

Meanwhile a great number of new spin assignments have been made, often with more accurate methods.

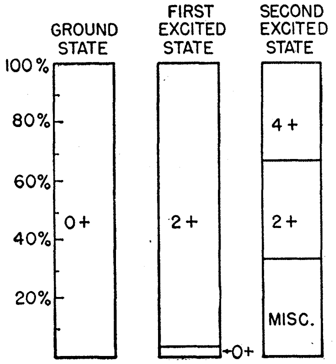

FIG. 3. Percentage distribution of spins and parities of ground state and first two excited states of even-even nuclei. See Secs. II, 3 and III, 3 of text.

Figure 1 shows the distribution of spins and parities of first excited states of even-even nuclei: *Apart from 2 nuclei, no sure exception from the 2+ rule for the first excited state exists.* The nuclei listed range from very light (Be^{8}) to very heavy (Pu^{238}). There are now altogether at least 66 nuclei for which a 2+ assignment is compatible with experimental results. Of these, 53 nuclei have 2+, 11 have either 2+ or 1+, and 2 have either 2+ or 1±.

The two exceptions, O^{16} and Ge^{72}, have spin zero and even parity in their first excited state. No γ-radiations are observed in these cases. The transition from the much investigated 6.05-Mev state of O^{16} takes place by pair emission with a half-life of 7×10^{-11} sec,[11] whereas the 0.68-Mev state[12] of Ge^{72} decays by means of internal

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[5] D. Kurath, Phys. Rev. **87**, 218 (1952).

[6] B. H. Flowers, Phys. Rev. **86**, 254 (1952); Proc. Roy. Soc. (London) **215**, 398 (1952); and previous publications.

[7] Preliminary notes: G. Scharff-Goldhaber, Phys. Rev. **87**, 218 (1952); Physica **18**, 1105 (1952).

[8] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).

[9] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

[10] Independently, Horie, Umezawa, Yamaguchi, and Yoshida [Prog. Theoret. Phys. **6**, 254 (1951)] discussed the spins and parities of first and second excited states of some even-even nuclei.

[11] Devons, Hereward, and Lindsey, Nature **164**, 586 (1949).

[12] Bowe, Goldhaber, Hill, Meyerhof, and Sala, Phys. Rev. **73**, 1219 (1948).

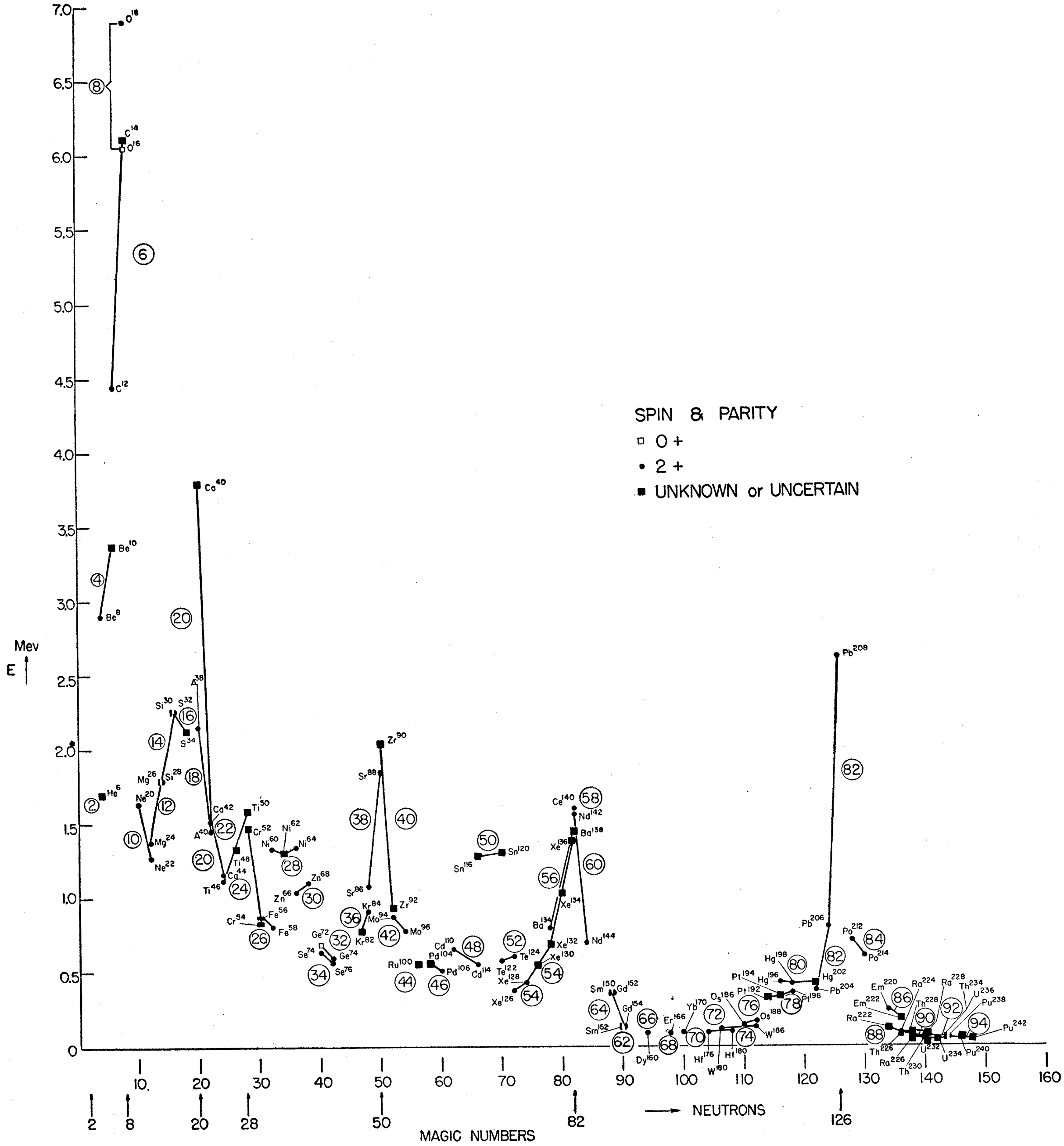

FIG. 4. Energies of first excited states of even-even nuclei plotted against number of neutrons. Points for isotopes of the same element are connected with straight lines. The corresponding proton number, encircled, appears next to the connecting lines. (See Secs. II, 4 and III, 4 of text.)

conversion with a half-life of 0.3 μsec. These lifetimes are in agreement with theoretical expectations.[13] Possible interpretations of these 0+ states will be given in Sec. III, 1.

2. *The distribution of spins and parities for the second excited state of even-even nuclei*, as represented in Fig. 2, *indicates that spin 2 or 4 and even parity is preferred.* Among the light nuclei spin 4 predominates. For medium heavy and heavy nuclei both possibilities appear. In addition, spins of 1 or 3 occur, and some second excited states have odd parity. Outstanding is again O^{16} with a spin of 3−, and Pb^{204}, with 7−.

It must be borne in mind that the identification of a state as a second excited state is not always certain, since a second excited state, e.g., of low spin 0 or 1, situated between a 2+ and a 4+ state may be poorly

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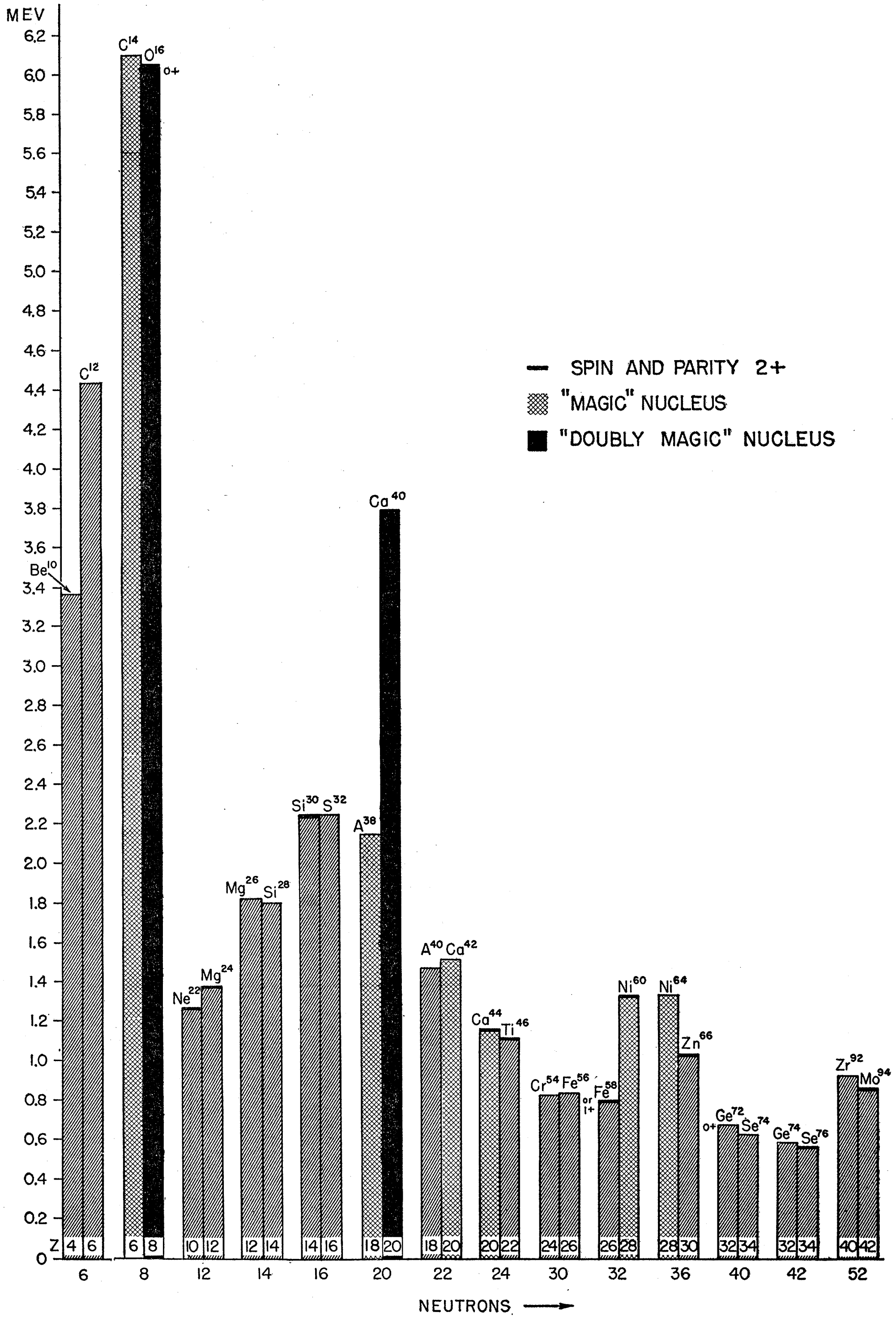
[13] S. D. Drell, Oak Ridge National Laboratory Report ORNL-792 (unpublished).



(a)

populated and hence be missed, if the 4+ state is mainly excited. It is much less likely that a first excited state is missed, unless it should turn out to have a very high spin. In that case it would be a metastable state. There is at present no evidence for the occurrence of low-lying, long-lived metastable states in even-even nuclei.

The spins of the second excited state will be further discussed in Sec. III, 2.

3. The percentage distribution of spin and parity of

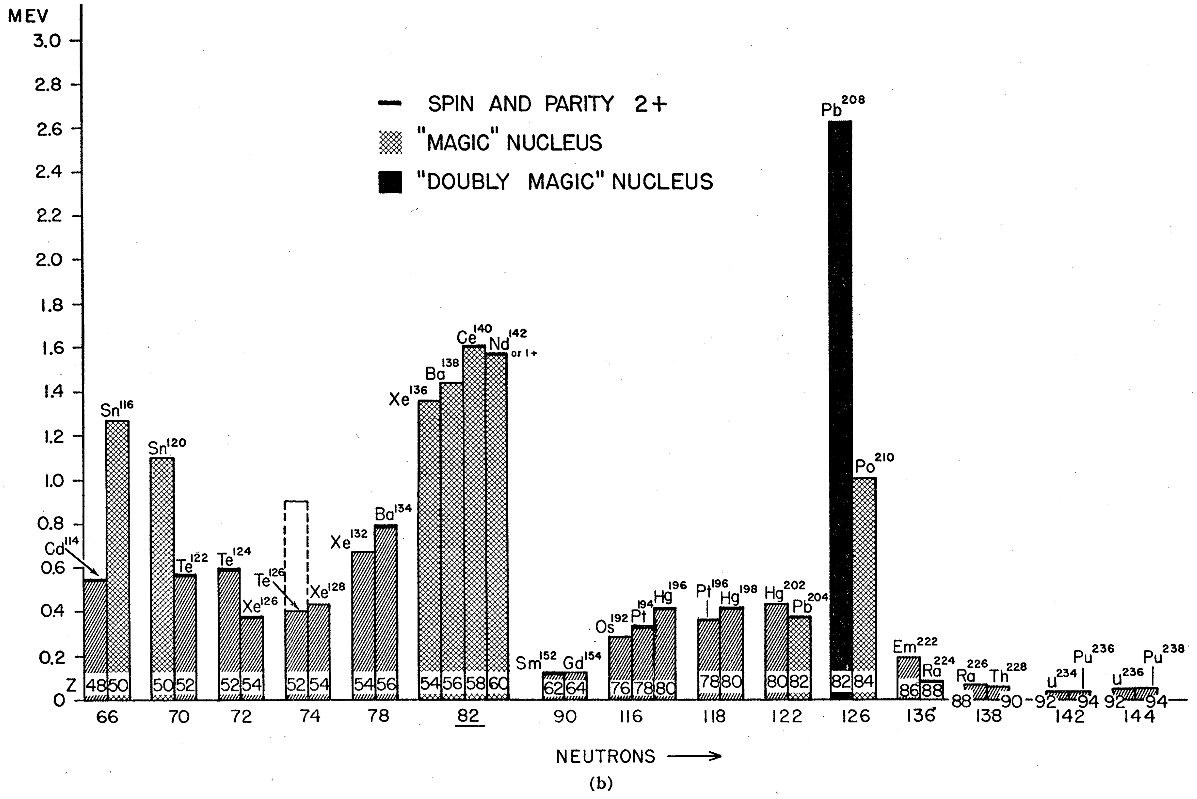


FIG. 5. Energies of first excited states of even-even nuclei are plotted against number of neutrons. (a) $N \leq 60$. (b) $N > 60$. Energies for nuclei differing by 2, 4, or 6, protons are compared, where possible. "Energy columns" for nuclei with either a magic neutron or proton number are cross hatched; energies of double magic nuclei are shown by black columns (see Sec. II, 4 of text).—For Te^{126} a value of 0.64 Mev should probably replace the 2 alternative energy values shown in the figure.

the ground state and the first two excited states is shown in Fig. 3. From this distribution and from the fact that very few long-lived even-even isomers exist, one can deduce that, as a rule, *$I \leq 2n$ for the nth excited state of an even-even nucleus.* Occurrence of an isomer would imply a spin change $\Delta I \geq 3$ between two successive states.

The only long-lived even-even isomers known at present are Pb^{204m} (68 min), Hf^{180m} (5.5 hr), and Pb^{202m} (5.6 sec). Pb^{204m} decays by means of a two step ($E5$–$E2$) isomeric transition.[14] Its isomeric state is the 7-state mentioned under II, 2. For Hf^{180m} and Pb^{202m},[15] spin and parity of the isomeric state are not known. Hf^{180m} emits a very complex γ-ray spectrum, suggesting that the isomeric state is probably the fourth excited state and that its spin $I \geq 7$.[14]

4. We come next to a consideration of the energy of the first excited state. Goldhaber and Sunyar[9] have already pointed out an interesting regularity: In the rare earth region first excited states of very low energy, of the order of 100 kev or less, occur, from which transitions to the ground state with matrix elements >1 (some with $|M|^2 \sim 150$) take place.

Meanwhile, a systematic survey of the energies of all reasonably well-assigned first excited states of even-even nuclei has been carried out.[7, 16–18] The result is shown in Fig. 4. Here, the excitation energy is plotted against the number of neutrons in the nucleus. From this graph, the following conclusions may be drawn:

A. *The energy of the first excited state of even-even nuclei varies smoothly and decreases—in general—with increasing mass number. However, the curve has strong maxima for the "double magic" nuclei,* O^{16}, Ca^{40}, *and* Pb^{208}, *i.e., nuclei with a magic number of neutrons and a magic number of protons. Smaller maxima occur for nuclei with a magic number of neutrons and still less pronounced maxima for nuclei with a magic number of protons.* As mentioned above, a deep and smooth trough appears in the rare earth region between the neutron numbers 82 and 126 and the proton numbers 50 and 82. After having reached a maximum for Pb^{208}, the curve descends again in the heavy element region to an energy as low

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[14] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

[15] N. J. Hopkins, Phys. Rev. **88**, 680 (1952).

[16] Independently, a similar survey was made by P. Preiswerk and P. Stähelin, Helv. Phys. Acta **24**, 623 (1952).

[17] For heavy elements, the dependence of the excitation energy of even-even nuclei on A has been considered by F. Asaro and I. Perlman, Phys. Rev. **87**, 393 (1952).

[18] A. H. Wapstra [Physica **18**, 799 (1952)] discusses the branching ratio for alpha-emission leading to the first excited state of an even-even nucleus.

as 40 kev. At the last point, which denotes the first excited state of Pu^{242}, no indication of an eventual rise is noticeable. On the whole, several remarkable regularities may be discerned in Fig. 4: e.g., a certain symmetry around the points for Sn stands out. The element lines for neighboring elements are frequently arranged in parallel, which would indicate, as Preiswerk and Stähelin[16] have pointed out, that it may be possible to construct the energy function for the first excited state as a sum of functions, of which one depends only on the number of protons and the other on the number of neutrons. However, in the environment of "doubly magic" nuclei, this rule seems to be broken: the lines for A(18) and Ca(20) intersect, and the point for Pb^{204} lies below that of Hg^{202}.

B. *In a large number of examples, addition of two protons to a nucleus hardly affects the energy of the first excited state.* This is emphasized by the representation in Fig. 5 (a) and (b), in which the excitation energies of nuclei with the same number of neutrons are compared. Strong differences appear only where the proton number of one of the two nuclei is "magic." Addition of a *neutron* pair to a nucleus seems to have a slightly more disturbing effect on the position of the first level, as is indicated by the slopes of the lines in Fig. 4 connecting points for isotopes of the same element.

C. If one adds a single nucleon to an even-even core and considers the excitation of the odd nucleon and that of the core in first approximation as independent, one would expect the excitation energy of an odd A nucleus to be at least as low as, or lower than, that of its even-even core. This expectation is found to be in excellent agreement with the facts.

5. In Table I the energies, spins and parities of the three lowest excited states of even-even nuclei are listed. The method of measurement used and the reference are given for each entry. The arrangement of the table and the symbols used are explained in the caption.

Wherever the energy of a first excited state is known with reasonable certainty from the knowledge of a decay scheme or the Q value of a reaction, it appears also in Fig. 4. In cases where it is known only that a γ-ray of a certain energy is emitted but the excited state from which it starts is not identified, the energy is given in parentheses in Table I and, as a rule, not included in Fig. 4. For the determination of spin and parity of an excited state a number of different criteria were used. The most prominent among these were: (1) Measurement of the K-conversion coefficient of the γ-ray in question, which allows identification of the order of transition by means of the table of Rose *et al.*[19] (2) Measurement of the ratio of K-conversion electrons to L-conversion electrons (K/L ratio) and comparison of this value with empirical curves given by Goldhaber and Sunyar.[9] (3) Measurement of γ-γ angular or polarization correlation. (4) Measurement of β-γ angular correlation. (5) Measurement of angular correlation of γ-rays and particles emitted in a nuclear reaction. (6) Intensity ratio of L-conversion lines.[20] (7) Wherever lifetimes were measured, the multipole order of a transition could usually be derived by means of Weisskopf's formulas[21] or empirical curves.[9] (8) For the case of β-decay a clue is furnished, if spin and parity of the mother nucleus as well as the character of the beta-spectrum leading to the excited state are known. (9) Measurement of angular distribution[22] and polarization[23] of γ-rays from aligned nuclei.

Wherever the lifetime of a first excited state has been measured, it is also given in the table.

III. DISCUSSION

Let us now compare the results of this survey on spins, parities, and energy spacings of excited states of even-even nuclei with conclusions which may be derived from various nuclear models. We shall start out with the extended strong spin-orbit coupling model: An even number n of equivalent neutrons or protons in an unfilled subshell (quantum numbers l, j), interacting with each other, may be considered.

(1) For this model, under the assumption of short range forces, the lowest state is always caused by the excitation of a single pair of nucleons, with a resulting nuclear spin of 2 and even parity.[5,6] This result is clearly in agreement with most of the empirical data: the first excited states of the majority of nuclei are 2+. It also provides a possible explanation for the two certain exceptions: In O^{16} the neutron shell as well as the proton shell of 8 is filled. In order to excite this nucleus, we may have to transfer a neutron pair, say, from the $p_{1/2}$ to the $d_{5/2}$ shell, with resultant spin 0, even. Similarly, in Ge^{72} the $p_{1/2}$ neutron shell and the $p_{3/2}$ proton shell may be filled and excitation may take place by raising a proton pair or a neutron pair to a higher configuration.

However, if this model were strictly adhered to, we would not expect 2+ levels for nuclei with filled subshells. In this light the 2+ levels of nuclei like Ce^{140} ($h_{11/2}$ neutron shell and $g_{7/2}$ proton shell filled) seem to require additional explanation. On the other hand, this fact would help with the interpretation of spin 1 and even parity in a number of cases, if these assignments should prove to be right: e.g., for C^{14} this would correspond to the splitting of a proton pair, ending up with one $p_{3/2}$ and one $p_{1/2}$ proton. Similarly, a 1+ level in Si^{28} may be due to the splitting of a $d_{5/2}$ neutron pair, with one neutron being transferred to the $d_{3/2}$ shell.

In particular, on this basis doubly magic nuclei are not expected to have a lowest excited level with spin 2+. We have already seen that this is borne out for O^{16} which has a first excited state 0+. Spin and parity of the first level of Ca^{40} (20–20) are not yet determined.

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[19] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).

[20] J. W. Mihelich, Phys. Rev. **87**, 646 (1952); Gellman, Griffith, and Stanley, Phys. Rev. **85**, 944 (1952).

[21] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).

[22] Daniels, Grace, and Robinson, Nature **168**, 780 (1951); Gorter, Poppema, Steenland, and Benn, Physica **17**, 1050 (1951).

[23] Bishop, Daniels, Goldschmidt, Halban, Kurti, and Robinson, Phys. Rev. **88**, 1432 (1952).

Pb^{208} (82–126), however, is known to have $I=2$, even, in its first excited state, in disagreement with this rule. Pryce[24] has discussed this difficulty in some detail.

Another explanation for the 0+ level of O^{16} has been given on the basis of the alpha-particle model.[25]

The liquid drop model yields a spin of 2 and even parity for the first excited state of any even-even nucleus. Therefore, the spin of the first excited state of Pb^{208} is compatible with it. For light nuclei this model is, however, expected to break down.

On the whole, it may be said that the evidence concerning the spin of the first excited state does not allow a definite distinction between the various models to be made at present.

(2) For the second excited state of an even-even nucleus, the extended spin-orbit coupling model as defined in Sec. II, 1 predicts 4+ for 2 nucleons or 2 holes with $j=5/2, 7/2, 9/2, 11/2, \cdots$, if it is assumed that no change of configuration takes place.[26,27] For 4 nucleons with $j=7/2$ and 4 or 6 nucleons with $j=9/2$, however, a second 2+ state is possible. This fact may explain why light nuclei (low j values) have predominantly a second excited state with $I=4+$, whereas for medium heavy and heavy nuclei both possibilities appear. In this simplified model (no interaction between protons and neutrons) a 3+ state appears for the first time for 4 or 6 nucleons with $j=9/2$. At least one of the two 3+ states in Fig. 2, that of A^{38}, cannot be explained in this way. If one considers the interaction of 2 loose protons and 2 loose neutrons with the same j, one finds that a 3+ state may result. However, for A^{38} (filled neutron shell) this assumption does not apply. In addition, even under the assumption of the splitting up of a pair of nucleons a 3+ state cannot be explained for A^{38}. The 1+ state of Nd^{144} may be attributed to the coupling of the spin 2+ of a proton pair with that of a neutron pair. The $I=0+$ state of Pd^{106} may be due to the change of configuration of a neutron pair.

The odd parity states require a change of configuration of at least one nucleon in the j-j coupling model. The $I=3-$ state of O^{16} may be interpreted as due to the splitting up of a $p_{1/2}$ neutron pair, with one neutron changing over to a $d_{5/2}$ state. According to Dennison,[25] four alpha-particles can also be coupled to give a spin 3−. The $I=7-$ state of Pb^{204m} can be ascribed to the splitting up of an $i_{13/2}$ neutron pair with one neutron going to the $p_{1/2}$ shell.

The predictions made on the basis of the "liquid drop" model[4] for the second excited state of an even-even nucleus are: $I=0$, 2, or 4; even parity.

(3) For the higher excited states not too definite conclusions can be drawn in the framework of the "loose particle" picture. However, the rule derived empirically: $I\leq 2n$ for the nth excited state is in agreement with this model and also with the liquid drop model. The only well-studied case of an even-even isomer, that of Pb^{204m} which was discussed above, is an exception to the rule $I\leq 2n$. In this connection the isomer Mo^{93m} is of interest.[28] It can be explained as due to isomerism of the core (spins 2, 4, 8 for first, second, and third excited state, respectively), while the odd neutron probably does not change its configuration.

(4) The rather smooth variation with A of the energy of the first excited state of an even-even nucleus and the deep troughs between closed shells may speak for the existence of interconfigurational mixing.[29] The greatest amount of mixing takes place in the middle of a shell, which has the effect of lowering the level in question due to the interaction of various configurations.

The low energies of first excited states in the rare earth region may be responsible for the scarcity of odd-proton isomers for $50<Z<82$, which, as mentioned above, presents one of the difficulties for the strict single particle model: Since the even-even core is easily excited, the single proton may prefer to couple with the 2+ state of the core to form the first excited state. Thus, the requirement for isomerism, $\Delta I\geq 3$, will be very rarely realized. On the other hand, the core excitation energies for $50<N<82$ are of the order of 0.5 Mev, which is usually higher than the excitation energy for the single neutron. Hence, a great number of isomers appear for odd neutron isotopes.[14]

The generally smooth behavior of the energy function agrees well with the liquid drop picture, but the specific features of this function cannot be derived from it. However, it is possible to compare the distortion parameter β^4 derived from different nuclear properties, namely, from quadrupole moments and the variation of isotope shifts, with the same parameter β derived from the energies of the first excited states of even-even nuclei. This has been carried out by Ford.[30] The fit is fairly good in the rare earth region, where a liquid drop model seems to be most adequate, but differences appear for lighter nuclei. For the heaviest nuclei few data on quadrupole moments and isotope shifts exist.

SUMMARY

In conclusion, it may be stated that both the j-j coupling model and the "liquid drop model" of the nucleus can explain the regularities found for spins and parities of first and second excited states of even-even nuclei. The extended j-j coupling model can explain more specific features, but not all the spins of these low-lying states. The smooth variation of the energy spacing between the ground state and the first excited state may be understood on the basis of the liquid drop model, but not the shell structure aspects of the energy spacing. The assumption of interconfigurational mixing may be necessary for a qualitative understanding of both features. Apart from the theoretical interest the

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[24] M. H. L. Pryce, Proc. Phys. Soc. (London) **A65**, 773 (1952).

[25] D. M. Dennison, Phys. Rev. **57**, 454 (1940).

[26] H. J. Maehly and P. Stähelin, Helv. Phys. Acta **25**, 624 (1952).

[27] D. C. Peaslee (unpublished).

[28] M. Goldhaber, Phys. Rev. **89**, 1146 (1953).

[29] A. de-Shalit and M. Goldhaber (unpublished).

[30] K. W. Ford, Phys. Rev. **90**, 29 (1953).

smooth variation found for the energy of the first excited state as a function of proton and neutron number has many experimental uses, e.g., in the studies of decay schemes and inelastic scattering of particles.

I should like to thank M. Goldhaber for frequent inspiring discussions, and A. de Shalit and J. Weneser for enlightening arguments of a theoretical nature.

REFERENCES TO TABLE I

(T1) J. T. Dewan *et al.*, Phys. Rev. **86**, 416 (1952).

(T2) F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

(T3) V. L. Telegdi, Phys. Rev. **84**, 600 (1951).

(T4) Cohen, Schafroth, Class, and Hanna, Phys. Rev. **87**, 206 (1952).

(T5) R. Malm and W. W. Buechner, Phys. Rev. **81**, 519 (1951).

(T6) Hubbard, Nelson, and Jacobs, Phys. Rev. **87**, 378 (1952).

(T7) G. M. Lewis, Phil. Mag. **43**, 690 (1952).

(T7a) R. G. Thomas and T. Lauritsen, Phys. Rev. **88**, 969 (1952).

(T8) G. Harris and W. T. Davies, Proc. Phys. Soc. (London) **A65**, 564 (1952).

(T9) Devons, Hereward, and Lindsey, Nature **164**, 586 (1949).

(T10) D. E. Alburger, Phys. Rev. **88**, 1257 (1952).

(T11) D. E. Alburger, Phys. Rev. **76**, 435 (1949).

(T12) Hinman, Brower, and Leamer, Bull. Am. Phys. Soc. **28**, No. 1, 41 (1953).

(T13) D. E. Alburger and E. M. Hafner, Brookhaven National Laboratory Report BNL-T-9, July 1949 (unpublished).

(T14) E. L. Brady and M. Deutsch, Phys. Rev. **78**, 558 (1950).

(T15) S. D. Bloom, Phys. Rev. **88**, 312 (1952).

(T16) Hausman, Allen, Arthur, Bender, and McDole, Phys. Rev. **88**, 1296 (1952).

(T17) H. Slätis and K. Siegbahn, Arkiv Mat. Astron. Fysik **4**, 485 (1952).

(T17a) J. Ambrosen, Nature **169**, 408 (1952).

(T18) P. M. Endt *et al.*, Phys. Rev. **86**, 518 (1952).

(T19) J. E. May and B. P. Foster, Bull. Am. Phys. Soc. **28**, No. 1, 41 (1953).

(T20) R. W. King, *Beta Decay Schemes and Nuclear Structure Assignments*, Washington University, St. Louis, 1952 (unpublished).

(T21) H. H. Landon, Phys. Rev. **83**, 1081 (1951).

(T22) D. M. van Patter *et al.*, Phys. Rev. **83**, 212 (1951).

(T23) R. H. Dieke and J. Marshall, Phys. Rev. **63**, 86 (1943).

(T24) Arthur, Allen, Bender, Hausman, and McDole, Phys. Rev. **88**, 1292 (1952).

(T25) L. Ruby and J. R. Richardson, Phys. Rev. **80**, 760 (1950).

(T26) N. Hole and K. Siegbahn, Arkiv. Mat. Astron. Fysik. **33A**, No. 9 (1946).

(T27) R. M. Steffen, Phys. Rev. **80**, 115 (1950).

(T28) M. L. Good, Phys. Rev. **81**, 891 (1951).

(T29) P. Morrison, Phys. Rev. **82**, 209 (1951).

(T30) J. A. Harvey, Phys. Rev. **88**, 162 (1952).

(T31) K. Siegbahn, Arkiv. Mat. Astron. Fysik **34B**, No. 4 (1947).

(T32) J. R. Beyster and M. L. Wiedenbeck, Phys. Rev. **79**, 728 (1950).

(T33) J. A. Bruner and M. Langer, Phys. Rev. **79**, 606 (1950).

(T34) F. T. Porter and C. S. Cook, Phys. Rev. **81**, 640 (1951).

(T35) F. Metzger and M. Deutsch, Phys. Rev. **78**, 551 (1950).

(T36) G. F. Pieper, Phys. Rev. **88**, 1299 (1952).

(T37) P. S. Jastram and C. E. Whittle, Phys. Rev. **87**, 1133 (1952).

(T38) W. C. Peacock and M. Deutsch, Phys. Rev. **69**, 306 (1946).

(T39) B. Hamermesh, Phys. Rev. **87**, 528 (1952).

(T40) Robinson, ter Pogossian, and Cook, Phys. Rev. **75**, 1099 (1949).

(T41) Way, Fano, Scott, and Thew, *Nuclear Data* (National Bureau of Standards Circular 499, 1950).

(T42) M. Deutsch and L. G. Elliot, Phys. Rev. **65**, 211 (1944).

(T43) L. G. Elliot and M. Deutsch, Phys. Rev. **63**, 321 (1943).

(T44) K. Strauch, Phys. Rev. **79**, 487 (1950).

(T45) Bishop, Daniels, Goldschmidt, Halban, Kurti, and Robinson, Phys. Rev. **88**, 1432 (1952).

(T45a) Cheng, Pick, and Kurbatov, Phys. Rev. **88**, 887 (1952).

(T46) D. E. Alburger, Phys. Rev. **76**, 435 (1949).

(T47) M. Deutsch and K. Siegbahn, Phys. Rev. **77**, 680 (1950).

(T48) A. H. Williams and M. L. Wiedenbeck, Phys. Rev. **78**, 822 (1950).

(T49) Parmley, Meyer, and Lilly, Phys. Rev. **75**, 619 (1949).

(T50) Brower, Hinman, Lang, Leamer, and Rose, Phys. Rev. **86**, 1054 (1952).

(T51) G. Friedlander and D. E. Alburger, Phys. Rev. **84**, 231 (1951).

(T52) Roderick, Meyerhof, and Mann, Phys. Rev. **84**, 887 (1951).

(T53) A. Mukerji and P. Preiswerk, Helv. Phys. Acta **23**, 516 (1950).

(T54) Bowe, Goldhaber, Hill, Meyerhof, and Sala, Phys. Rev. **73**, 1219 (1948).

(T55) McGowan, deBenedetti, and Francis, Phys. Rev. **75**, 1761 (1949).

(T56) Johansson, Cauchois, and Siegbahn, Phys. Rev. **82**, 275 (1951).

(T57) J. J. Kraushaar and M. Goldhaber, Phys. Rev. **89**, 1081 (1953).

(T58) Siegbahn, Hedgran, and Deutsch, Phys. Rev. **76**, 1263 (1949).

(T59) C. M. Huddleston and A. C. G. Mitchell, Phys. Rev. **88**, 1350 (1952).

(T60) D. G. Karraker and D. H. Templeton, Phys. Rev. **80**, 646 (1951).

(T61) H. R. Muether and S. L. Ridgeway, Phys. Rev. **80**, 750 (1951).

(T62) D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).

(T63) F. R. Metzger and H. C. Amacher, Phys. Rev. **88**, 147 (1952).

(T64) D. N. Kundu and M. L. Pool, Phys. Rev. **76**, 183A (1949).

(T65) P. Preiswerk and P. Stähelin, Helv. Phys. Acta **24**, 300 (1951).

(T66) Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta **23**, 299 (1950).

(T67) P. Stähelin and P. Preiswerk (private communication from H. Medicus).

(T68) House, Colligan, Kundu, and Pool, Phys. Rev. **86**, 654 (1952).

(T69) G. E. Boyd (private communication).

(T70) D. Maeder and P. Preiswerk, Helv. Phys. Acta **24**, 625 (1951).

(T70a) F. A. Johnson, Proc. Roy. Soc. (Canada) **46**, A135 (1952).

(T71) M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

(T72) Arfken, Klema, and McGowan, Phys. Rev. **86**, 413 (1952).

(T73) D. E. Alburger, Phys. Rev. **88**, 339 (1952).

(T74) M. Goodrich and E. C. Campbell, Phys. Rev. **85**, 742 (1952).

(T75) Johns, Cox, Donelly, and McMullen, Phys. Rev. **87**, 1134 (1952).

(T76) Johns, Cox, and McMullen, Phys. Rev. **86**, 632 (1952).

(T77) E. D. Klema and F. K. McGowan, Phys. Rev. **87**, 524 (1952).

(T78) Blaser, Boehm, and Marmier, Helv. Phys. Acta **24**, 623 (1950).

(T79) M. J. Glaubman and F. R. Metzger, Phys. Rev. **87**, 203 (1952).

(T80) F. R. Metzger, Phys. Rev. **86**, 435 (1952).

(T81) J. W. Barnes and A. J. Freedman, Phys. Rev. **84**, 365 (1951).

(T82) M. L. Perlman and G. Friedlander, Phys. Rev. **82**, 449 (1951).

(T83) D. T. Stevenson and M. Deutsch, Phys. Rev. **84**, 1071 (1951).

(T84) K. Siegbahn and N. Hole, Phys. Rev. **70**, 133 (1946).

(T85) Roberts, Elliot, Downing, Peacock, and Deutsch, Phys. Rev. **64**, 268 (1943).

(T86) A. P. Smith *et al.*, Phys. Rev. **87**, 454 (1952).

(T87) Maienschein, Bair, and Baker, Phys. Rev. **83**, 477 (1952).

(T88) Waggoner, Moon, and Roberts, Phys. Rev. **80**, 420 (1950).

(T89) S. Katcoff and M. McKeown (private communication).

(T90) M. M. Cransden and W. S. Boyle, Phys. Rev. **82**, 447 (1951).

(T91) B. L. Robinson and L. Madansky, Phys. Rev. **84**, 600 (1951).

(T92) L. M. Langer and R. B. Duffield, Phys. Rev. **89**, 907 (1953).

(T93) B. L. Robinson and L. Madansky, Phys. Rev. **84**, 1067 (1951).

(T94) E. N. Jensen *et al.*, Phys. Rev. **80**, 862 (1950).

(T95) D. E. Alburger *et al.*, Phys. Rev. **82**, 322 (1951).

(T96) D. E. Alburger and J. Kraushaar, Phys. Rev. **86**, 633 (1952).

(T96a) Hollander, Perlman, and Seaborg, UCRL 1928 (1952).

(T97) Hoff, Rasmussen, and Thompson, Phys. Rev. **83**, 1068 (1951).

(T98) Mack, Prickett, and Pool, Phys. Rev. **86**, 633 (1952).

(T99) Mack, Prickett, and Pool (verbal report).

(T100) J. K. Long and M. L. Pool, Phys. Rev. **85**, 137 (1952).

(T101) C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **88**, 943 (1952).

(T102) H. B. Keller and J. M. Cork, Phys. Rev. **84**, 1079 (1951).

(T103) J. W. Mihelich (private communication).

(T104) M. Deutsch and W. E. Wright, Phys. Rev. **82**, 277 (1951).

(T105) R. Katz and M. R. Lee, Phys. Rev. **85**, 1038 (1952).

(T106) E. L. Church (private communication).

(T107) F. K. McGowan, Phys. Rev. **85**, 151 (1952).

(T108) F. K. McGowan, Phys. Rev. **85**, 142 (1952).

(T109) G. Wilkinson, University of California Radiation Laboratory Report UCRL-677 (unpublished).

(T110) F. K. McGowan, Phys. Rev. **80**, 923 (1950).

(T111) Scharff-Goldhaber, der Mateosian, and Mihelich, Phys. Rev. **85**, 734 (1952).

(T112) F. K. McGowan, Phys. Rev. **87**, 542 (1952).

(T113) G. Wilkinson, Phys. Rev. **80**, 495 (1950).

(T114) Brown, Bendel, Shore, and Becker, Phys. Rev. **84**, 292 (1951).

(T115) Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).

(T116) F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).

(T116a) F. Metzger, private communication.

(T117) F. K. McGowan, Phys. Rev. **81**, 1066 (1951).

(T118) Richmond, Grant, and Rose, Proc. Phys. Soc. (London) **A65**, 484 (1952).

(T119) J. W. Mihelich (private communication).

(T120) T. C. Chu, Phys. Rev. **79**, 582 (1950).

(T121) Cork, LeBlanc, Stoddard, Childs, Branyan, and Martin, Phys. Rev. **82**, 258 (1951).

(T121a) Mihelich, de Schalit, and Gillon, (private communication).

(T122) J. M. Cork *et al.*, Phys. Rev. **83**, 222 (1951).

(T123) C. E. Whittle and P. S. Jastram, Phys. Rev. **87**, 203 (1952).

(T124) M. Lindner, Phys. Rev. **84**, 240 (1951).

(T125) R. M. Steffen and D. M. Roberts, Phys. Rev. **83**, 222 (1951).

(T126) P. Stähelin, Phys. Rev. **87**, 375 (1952).

(T127) L. G. Elliot and J. L. Wolfson, Phys. Rev. **82**, 333 (1951).

(T128) C. Y. Fan, Phys. Rev. **87**, 252 (1952).

(T129) J. W. Mihelich, Phys. Rev. **87**, 646 (1952).

(T130) R. L. Graham and R. E. Bell, Phys. Rev. **84**, 380 (1951).

(T131) H. P. Israel and R. G. Wilkinson, Phys. Rev. **83**, 1051 (1951).

(T132) G. Wilkinson, Phys. Rev. **79**, 1014 (1950).

(T133) N. J. Hopkins, Phys. Rev. **88**, 680 (1952).

(T134) Sunyar, Alburger, Friedlander, Goldhaber, and Scharff-Goldhaber, Phys. Rev. **78**, 326 (1950).

(T135) M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).

(T136) Sunyar, Alburger, and Friedlander, Phys. Rev. **78**, 326 (1950).

(T137) D. E. Alburger and G. Friedlander, Phys. Rev. **81**, 523 (1951).

(T138) S. deBenedetti and G. H. Minton, Phys. Rev. **85**, 944 (1952).

(T139) G. Lindström, Phys. Rev. **87**, 678 (1952).

(T140) H. E. Petch and M. W. Johns, Phys. Rev. **80**, 478 (1950).

(T141) H. Slätis and K. Siegbahn, Arkiv. Fysik **4**, 485 (1952).

(T142) D. G. E. Martin and H. O. W. Richardson, Proc. Phys. Soc. (London) **A62**, 223 (1950).

(T143) M. Miwa, S. Kazeyama, J. Phys. Soc. Japan **5**, 416 (1951).

(T144) Way, Fano, Scott, and Thew, *Nuclear Data*, National Bureau of Standards Circular 499, Supplement No. 3.

(T145) S. Rosenblum, Valadares, Guillot, Compt. rend. **234**, 1767 (1952).

(T146) S. Rosenblum and M. Valadares, Compt. rend. **234**, 2359 (1952).

(T147) Cork, Branyan, Stoddard, Keller, LeBlanc, and Childs, Phys. Rev. **83**, 681 (1951).

(T148) Victor, Teillac, Falk-Vairant, Boussières, J. phys. et radium **13**, 565 (1952).

(T149) F. Asaro and I. Perlman, Phys. Rev. **87**, 393 (1952).

(T150) S. Rosenblum and M. Valadares, Compt. rend. **235**, 238 (1952).

(T151) C. J. D. Jarvis and M. A. S. Ross, Proc. Phys. Soc. (London) **A64**, 535 (1951).

(T152) D. C. Dunlavey and T. Seaborg, Phys. Rev. **87**, 165 (1952).

(T153) J. Kyles, Edinburgh (private communication to Wapstra, Amsterdam).

(T154) J. Teillac, Compt. rend. **230**, 1056 (1950).

(T155) G. Scharff-Goldhaber, Brookhaven National Laboratory Report BNL-103, p. 17 (unpublished).

(T156) B. Zajac, Phil. Mag. **42**, 264 (1952).

(T157) G. Albouy and J. Teillac, Compt. rend. **234**, 829 (1952).

(T158) D. A. Orth and G. D. O'Kelley, Phys. Rev. **82**, 758 (1951).

(T159) A. Prohaska, University of California Radiation Laboratory Report UCRL-1395 (unpublished).

(T160) G. D. O'Kelley, UCRL 1243 (1951).

TABLE I. The known energies, spins and parities of the first three excited states of even-even nuclei are listed. Columns XX and XXI refer to the half-life of the first excited state and the corresponding reference. Under "Method" the method of production of the excited state as well as the method of measuring the excitation energy is given. Wherever the excited state has been produced by a nuclear reaction, the bombarded nucleus A, the incoming particle b and the outgoing particle c are indicated in the following fashion: $A+b-c$. If the energy of the state was determined by measuring the energy of the outgoing particle, this is indicated by the remark "c obs." If γ-rays have been observed, this is also stated. If the excited state of nucleus Z^A is reached by β decay, this is indicated by $(Z-1)^A\beta^-$; if it is reached by electron capture or positron emission, the notation used is $(Z+1)^A$ E.C. (and/or) β^+. For the methods of measurement of γ-ray energies the notation used by K. Way *et al.* in *Nuclear Data* (National Bureau of Standards Circular 499) and its three supplements has been adhered to. Measurements with a curved crystal gamma-ray spectrometer are indicated by "cryst; γ." As bases for the survey, Circular 499 and the article by M. Goldhaber and R. D. Hill [Revs. Modern Phys. **24**, 179 (1952)] were extensively used. The references usually refer to the latest papers which, in turn, give references to previous work.

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,[a] Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
$_2He^6$	1.71	$Li^7+t-\alpha$ α obs	(T1)																	
$_4Be^8$	2.94	$B^{11}+p-\alpha$ α obs	(T2)	2+	$C^{12}+\gamma$; energy distr. of α's measured	(T3)	4.05	$Li+d-n$	(T2)				4.9	$Li+d-n$	(T2)					
$_4Be^{10}$	3.37	Be^9+d-p p and γ obs	(T2)	2 +	$p-\gamma$ ang. correl. ang. distr. of protons	(T4) (T2)	6.3	Be^9+d-p	(T2)				7.38	Be^9+d-p	(T2)	3+		(T2)		
$_6C^{12}$	4.44	$N^{14}+d-\alpha$ α and γ obs	(T5)	2+	$\left.\begin{array}{l}B^{11}+p\\ \gamma-\gamma \text{ ang. correl.}\end{array}\right\}$	(T6)	7.5	$Be^9+\alpha-n$	(T2)	0 ?	Internal pair formation coeff.	(T2)	9.62	$N^{14}+d-\alpha$	(T5)				$<3\times10^{-13}$ seo	(T7a)
					$p, \gamma, \gamma(\theta)$	(T7)	$\sim$7	$Be^9+\alpha-n$ pairs obs	(T8)											
$_6C^{14}$	6.110	$C^{13}+d-p$ γ obs	(T2)	1 or 2	Energy distr. of internally formed positrons	(T2)														
$_8O^{16}$	6.05	$F^{19}+p-\alpha$ α and pairs obs	(T2)	0+	pair emission; energy distr. of positrons and electrons; lifetime	(T2)	6.13	$F^{19}+p-\alpha$ other reactions	(T2)	3−	$\alpha-\gamma$ ang. correl.	(T2)	6.91	$F^{19}+p-\alpha$	(T2)	2+	$\alpha-\gamma$ ang. correl.	(T2)	7×10^{-11} sec	(T9)
$_{10}Ne^{20}$	1.631	$\left\{\begin{array}{l}F^{20}\beta^- \text{ from}\\ F^{19}+d-p\end{array}\right.$ sl; pe$^-$, Compt.	(T10)	2+ or 1+	decay argument	(T10)	2.2 ?	$Ne^{20}+p-p'$	(T2)				4.3	$F^{19}+d-n$ $Ne^{20}+p-p'$	(T2)					
$_{10}Ne^{22}$	1.277	$Na^{22}\beta^+$; sl; pe$^-$	(T11)	2+	From ft value of 0.542 Mev positron and shape: $I=2$. Odd parity excluded by lack of measurable lifetime.		3.4	$F^{19}+\alpha-p$	(T2)				4.5	$F^{19}+\alpha-p$	(T2)					
					K conv. coeff.	(T12)														

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[a] Doubtfully assigned energy values for the first excited state are given in parentheses in the second column. The following is a comparison of these energies with the energy function represented in Fig. 4.

Se^{78}: None of the 3 energy values fits.
Mo^{92}: 1.5 Mev seems correct assignment.
Mo^{98}: 0.86 Mev seems too high.
Pd^{108}: 0.42 Mev seems correct assignment.
Xe^{130}: probably 0.537 state lowest as plotted in Fig. 4.
Ba^{132}: 1 Mev seems too high; about 0.7 Mev expected.
Ba^{136}: ~1.2 Mev seems more probable than 0.9 Mev.
Sm^{146}: 0.45 Mev seems too low. Better measurement of gamma-ray energy desirable.
Sm^{148}: 0.54 Mev seems slightly too high.
Gd^{156}: 0.0888 Mev fits well.
Gd^{158}: 0.0792 Mev fits well.
$\left.\begin{array}{l}Dy^{162}\text{: 0.1 Mev}\\ Hf^{178}\text{: 0.1 Mev}\end{array}\right\}$ More accurate measurements seem desirable.
W^{182}: The two values given are chosen to fit the plot best.
Os^{190}: 0.17 Mev fits fairly well.
Os^{192}: 0.283 Mev probably correct.
Hg^{200}: 0.365 Mev fits best.
Pb^{202}: 0.89 Mev seems high. A lower energy γ-ray may follow this isomeric transition.
Po^{210}: 1 Mev seems reasonable.

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II E,[a] Mev	III Method	IV Reference	V Spin and parity	VI Method	VII Reference	VIII E Mev	IX Method	X Reference	XI Spin and parity	XII Method	XIII Reference	XIV E Mev	XV Method	XVI Reference	XVII Spin and parity	XVIII Method	XIX Reference	XX Half-life of first excited state	XXI Reference
${}_{12}\mathrm{Mg}^{24}$	(1.38)	$\mathrm{Mg}^{24}+p-p'$ $\mathrm{Mg}^{24}+n-n$ $\mathrm{Na}^{24}\rightarrow\beta^-$; γ obs	(T13)	2+	$\gamma-\gamma$ ang. correl. pair conv. coeff. shape of pair spectrum pair conv. coeff.	(T14) (T15) (T17)	4.14	$\mathrm{Mg}^{24}+p-p'$ $\mathrm{Na}^{24}\rightarrow\beta^-$; γ obs	(T13)	4+	$\gamma-\gamma$ ang. correl. pair conv. coeff.	(T14) (T15) (T17)	5.51 4.24	$\mathrm{Mg}^{24}+p-p'$ $\mathrm{Al}+p-\alpha$	(T13) (T16)					
${}_{12}\mathrm{Mg}^{26}$	1.84	$\mathrm{Mg}^{25}+d-p$ p obs	(T17a)				2.85	$\mathrm{Na}^{23}+\alpha-p$ $\mathrm{Mg}^{25}+d-p$	(T13)				4.0	$\mathrm{Na}^{23}+\alpha-p$	(T13)					
	1.825	$\mathrm{Mg}^{25}+d-p$ ppl γ obs, scin	(T18) (T19)				3.00	$\mathrm{Mg}^{25}+d-p$ p obs γ obs, scin	(T17a) (T19)				4.00	$\mathrm{Mg}^{25}+d-p$ γ obs, scin	(T17a) (T19)					
${}_{14}\mathrm{Si}^{28}$	1.8	$\mathrm{Al}^{27}+d-n$; n obs $\mathrm{Al}^{28}(\beta^-)$; γ obs	(T13)	2+ or 1+	Analysis of disint. scheme. Spin of Al^{28} is 3+, $\log ft=4.87$	(T20)	4.47	$\mathrm{Al}^{27}+d-n$; n obs	(T13)				4.91	$\mathrm{Al}^{27}+d-n$; n obs	(T13)					
${}_{14}\mathrm{Si}^{30}$	2.3	$\mathrm{Al}^{27}+\alpha-p$ $p-\gamma$ coinc.	(T21)				3.6	$\mathrm{Al}^{27}+\alpha-p$ $p-\gamma$ coinc.	(T21)				4.9	$\mathrm{Al}^{27}+\alpha-p$ $p-\gamma$ coinc.	(T21)					
	2.25	$\mathrm{Si}^{29}+d-p$ p obs	(T22)				3.5	$\mathrm{Si}^{29}+d-p$ p obs	(T22)				3.8	$\mathrm{Si}^{29}+d-p$ p obs	(T22)					
${}_{16}\mathrm{S}^{32}$	2.25	$S+p-p'$ p obs	(T23)				4.34 3.81	$\mathrm{S}+p-p'$ $\mathrm{S}+p-p'$	(T23) (T24)											
${}_{16}\mathrm{S}^{34}$	2.13	Cl^{34} E.C.; β^+ sl; ce$^-$; pe$^-$; Compt.	(T25)				3.30	Cl^{34} E.C.; β^+ sl; ce$^-$; pe$^-$	(T25)											
${}_{18}\mathrm{A}^{38}$	2.15	$\mathrm{Cl}^{38}\beta^-$	(T26)	2+	$\gamma-\gamma$ ang. correl.	(T27)	3.75	$\mathrm{Cl}^{38}\beta^-$	(T26)	3+	$\gamma-\gamma$ ang. correl.	(T27)								
${}_{18}\mathrm{A}^{40}$	1.459	K^{40} E.C.; s; pe$^-$; Compt.	(T28)	2+	Analysis of disintegr. scheme	(T29)														
${}_{20}\mathrm{Ca}^{40}$	3.8*	$\mathrm{Ca}^{40}+p-p'$ p obs; a	(T30)																	
${}_{20}\mathrm{Ca}^{42}$	1.51	$\mathrm{K}^{42}\beta^-$ $\beta^--\gamma$ coinc.	(T31)	2+	$\beta-\gamma$ ang. correl.	(T32)														
${}_{20}\mathrm{Ca}^{44}$	1.16	$\mathrm{Sc}^{44}\beta^+$, E.C. sπ; ce$^-$; pe$^-$	(T33)	1+ or 2+	from shell model considerations and shape of β^+ spectrum	(T33)														
${}_{22}\mathrm{Ti}^{46}$	1.12	$\mathrm{Sc}^{46}\beta^-$	(T34)	2+	K conv. coeff. $\gamma-\gamma$ ang. correl.	(T34) (T35)	2.01	$\mathrm{Sc}^{46}\beta^-$	(T34)	4+	K conv. coeff. $\gamma-\gamma$ ang. correl.	(T34) (T35)								
${}_{22}\mathrm{Ti}^{48}$	1.33	$\mathrm{Ti}^{47}+d-p$ p obs	(T36)	2+	$\gamma-\gamma$ ang. correl.	(T37)	2.31	$\mathrm{Sc}^{48}\beta^-$ sl; pe$^-$, Compt. $\mathrm{V}^{48}\beta^+$; sπ; pe$^-$, Compt.	(T38) (T40)	4+	$\gamma-\gamma$ ang. correl.	(T37)	3.29	$\mathrm{Ti}+n-p$; β^- scin. 3γ's in cascade	(T39)					
${}_{22}\mathrm{Ti}^{50}$	1.58	$\mathrm{Ti}^{49}-d-p$ p obs	(T36)				3.0	$\mathrm{Ti}^{49}+d-p$ p obs	(T36)				4.14	$\mathrm{Ti}^{49}+d-p$ p obs	(T36)					
${}_{24}\mathrm{Cr}^{52}$	1.46	Mn^{52}(5.8-day) E.C. β^+ sl; pe$^-$	(T38)				2.40	$\mathrm{Mn}^{52}\beta^+$; E.C. s	(T41)				3.13	$\mathrm{Mn}^{52}\beta^+$; E.C. s	(T41)					
	1.45	$\mathrm{V}^{52}\beta^-$; a	(T41)				2.43	$\mathrm{Cr}+p-p'$ p obs		(T16)			2.99	$\mathrm{Cr}+p-p'$	(T16)					

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* *Note added in proof:* According to a private communication by W. W. Buechner, the 3 lowest levels in Ca^{40} found by inelastic proton scattering have the following energies: 3.35, 3.74, and 3.90 Mev (Braams, Bockelman, Browne, and Buechner, Bull. Am. Phys. Soc., Washington Meeting, April 29–May 1, 1953).

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II E,ᵃ Mev	III Method	IV Reference	V Spin and parity	VI Method	VII Reference	VIII E Mev	IX Method	X Reference	XI Spin and parity	XII Method	XIII Reference	XIV E Mev	XV Method	XVI Reference	XVII Spin and parity	XVIII Method	XIX Reference	XX Half-life of first excited state	XXI Reference
$_{24}$Cr^{54}	0.835	Mn^{54} E.C. sl; pe$^-$	(T42)																	
$_{26}$Fe^{56}	0.845	Mn^{56} β^-, s Co^{56} β^+ sl; pe$^-$	(T41) (T43)				2.66	Mn^{56} β^-, s	(T41)				2.98	Mn^{56} β^-, s	(T41)					
$_{26}$Fe^{58}	0.805	Co^{58} E.C., β^+ sl; ce$^-$	(T44)	2+	γ ang. correl. for aligned nuclei K conv. coeff.	(T45) (T45a)														
$_{28}$Ni^{60}	1.332	Co^{60} β^- sl; pe$^-$	(T46)	2+	$\gamma-\gamma$ polarization direction correl.	(T35) (T48)	2.507	Co^{60} β^- sl; pe$^-$	(T46)	4+	$\gamma-\gamma$ pol. correl.	(T35)								
	1.338	Co^{60} β^- sl; ce$^-$	(T47)				2.512		(T47)		$\gamma-\gamma$ ang. correl.	(T48)								
$_{28}$Ni^{62}	1.3	Co^{62} β^-; a	(T49)																	
$_{28}$Ni^{64}	1.34	Cu^{64} E.C., β^+ sl; ce$^-$	(T50)	≤2	*K* conv. coeff.	(T50)														
$_{30}$Zn^{66}	1.044	Cu^{66} β^- sl; ce$^-$	(T51)	2+ or 1+	derived from decay scheme	(T52)	2.762	Ga^{66} E.C.; β^+ sl; pe$^-$ Compt.	(T53)	2+ (or 1+)	Analysis of disintegr. scheme									
$_{30}$Zn^{68}	1.10	Ga^{68} β^+ sl; pe$^-$, Compt.	(T53)	2+ or 1+	derived from decay scheme	(T53)														
$_{32}$Ge^{72}	0.68	Ga^{72} β^- sl; ce$^-$	(T41)	0+	*K* conv. coeff. and lifetime	(T54)	0.84	Ga^{72} β^- sl; pe$^-$	(T41)	1+ or 2+	derived from decay scheme								0.3×10^{-6} sec	(T55)
$_{32}$Ge^{74}	0.5963	As^{74} E.C. β^+ s$\pi\sqrt{2}$; pe$^-$	(T56)	2+ (or 1+)	derived from decay scheme	(T56)														
$_{34}$Se^{74}	0.6352	As^{74} β^- S$\pi\sqrt{2}$; pe$^-$	(T56)	2+ (or 1+)	derived from decay scheme	(T56)														
$_{34}$Se^{76}	0.567	As^{76} β^-; s	(T41)	2+	$\gamma-\gamma$ ang. correl.	(T57)	1.21	As^{76} β^-, scint.	(T57)	2+	$\gamma-\gamma$ ang. correl.	(T57)	2.67	scint.	(T41)					
$_{34}$Se^{78}	(0.27) (0.046) (0.108)	As^{78} β^-, a Br^{78}, E. C., β^+; sc	(T41)																	
$_{36}$Kr^{82}	0.77	Br^{82} β^-; ce$^-$; s	(T58)				1.378	Rb^{82} β^+ sl; pe$^-$	(T59)											
	0.768	Rb^{82} β^+ sl; pe$^-$	(T59)																	
$_{36}$Kr^{84}	0.85	Rb^{84} E.C.; β^+ a	(T60)	2+	Analysis of disintegration scheme	(T59)														
	0.89	Rb^{84} E.C.; β^+ sπ; ce$^-$; scin.	(T59)																	
$_{38}$Sr^{86}	1.076	Rb^{86} β^- sl; pe$^-$	(T61)	2+	$\beta-\gamma$ ang. correl.	(T62)														
$_{38}$Sr^{88}	1.853	Rb^{88} β^- Y^{88} E.C., β^+ s	(T41)	2+ (or 1+)	*K* conv. coeff. Y^{88} *K* capt.	(T63)	2.76	Rb^{88} β^- Y^{88} E.C., β^+	(T41)	3− (or 2−)	*K* conv. coeff.	(T63)								
$_{40}$Zr^{90}	(2.03)	Nb^{90} β^+; a	(T64)																	

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,[a] Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
$_{40}\mathrm{Zr}^{92}$	0.930	Nb^{92} E.C. sl; pe$^-$	(T65)																	
$_{42}\mathrm{Mo}^{92}$	(1.5)	Tc^{92} E.C., β^+	(T41)																	
$_{42}\mathrm{Mo}^{94}$	0.87	Tc^{94} E.C., β^+ sl; Compt.	(T66)	2+	K conv. coeff.	(T66)	2.73	Tc^{94} E.C., β^+ sl; Compt.	(T66)	3+	derived from decay scheme	(T66)	3.27	Tc^{94} E.C. sl; Compt.	(T66)	2+	derived from decay scheme	(T66)		
$_{42}\mathrm{Mo}^{96}$	0.770	Tc^{96} E.C. sl; ce$^-$, pe$^-$	T(66)	2+	K conv. coeff.	(T67)	1.60	Tc^{96} E.C. sl; ce$^-$, pe$^-$	(T66)	3+ or 4+	K conv. coeff.	(T67)	1.84	Tc^{96} E.C. sl; pe$^-$	(T65)					
$_{42}\mathrm{Mo}^{98}$	(0.86)	Tc^{98} E.C.; a	(T68)																	
$_{44}\mathrm{Ru}^{100}$	0.55	Tc^{100} β^-	(T69)																	
$_{46}\mathrm{Pd}^{104}$	0.56	Rh^{104} β^-; scin.	(T70)																	
	0.555	Ag^{104} β^+	(T70a)																	
$_{46}\mathrm{Pd}^{106}$	0.513	Rh^{106} β^-; sl; Ag^{106} β^+ sl; pe$^-$	(T71)	2+	$\gamma-\gamma$ ang. correl. K conv. coeff.	(T71) (T73)	1.137	Rh^{106} β^- Ag^{106} β^+ sl; pe$^-$	(T71)	0+	$\gamma-\gamma$ ang. correl.	(T71)	1.55	Rh^{106} β^- Ag^{106} β^+ sl; pe$^-$	(T71)	2+	$\gamma-\gamma$ ang. correl.	(T72)		
$_{46}\mathrm{Pd}^{108}$	0.42 (0.19)	Ag^{108} E.C. scin.	(T74)																	
$_{48}\mathrm{Cd}^{110}$	0.656	Ag^{110} β^- In^{110} β^+	(T71)	2+ (or 1+)	K conv. coeff.	(T71)	1.415	Ag^{110} β^- In^{110} β^+	(T71)				1.54	Ag^{110} β^- In^{110} β^+	(T71)					
$_{48}\mathrm{Cd}^{114}$	0.550	In^{114} E.C. sl; pe$^-$	(T71)	2+	$\gamma-\gamma$ ang. correl.	(T71) (T76) (T77)	1.263	In^{114} E.C. sl; pe$^-$	(T71)	2+	$\gamma-\gamma$ ang. correl.	(T71) (T76) (T77)	1.856	In^{114} E.C. s; pe$^-$	(T75)	0 or 2	derived from decay scheme	(T75)		
$_{50}\mathrm{Sn}^{116}$	1.274	In^{116} β^- sl; pe$^-$	(T71)				2.09	In^{116} β^- sl; pe$^-$	(T71)				2.36	In^{116} β^- sl; pe$^-$	(T71)					
$_{50}\mathrm{Sn}^{120}$	1.30	Sb^{120} E.C.	(T78)				2.20	Sb^{120} E.C.	(T78)											
$_{52}\mathrm{Te}^{122}$	0.568	Sb^{122} β^-	(T71)	2+	$(\beta-\gamma)+(\gamma-\gamma)$ ang. correl. K conv. coeff. $\beta-\gamma$ ang. correl.	(T71) (T79)	1.24	Sb^{122} β^-	(T71)	2+	$\gamma-\gamma$ ang. correl. K conv. coeff.	(T71) (T79)								
$_{52}\mathrm{Te}^{124}$	0.607	Sb^{124} β^- I^{124} E.C.	(T71)	2+	K conv. coeff.	(T80)														
$_{52}\mathrm{Te}^{126}$	0.64	I^{126} E.C. scin.	(T82)		(Sb^{124} β^-)															
	(0.4 or 0.9)	Sb^{126} β^- scin.	(T81)				1.3	Sb^{126} β^-	(T81)											
$_{54}\mathrm{eX}^{126}$	0.382	I^{126} β^- sl; ce$^-$	(T82)	2+	$\beta-\gamma$ ang. correl.	(T83)														
$_{54}\mathrm{Xe}^{128}$	0.428	I^{128} β^- sl; ce$^-$	(T84)	2+ (or 1+)	derived from beta spectra	(T84)														
$_{54}\mathrm{Xe}^{130}$	(0.537 or 0.667 or 0.744)	I^{130} β^- sl; ce$^-$	(T85)																	
		No γ, Cs^{130} β^+ scin.	(T86)																	
$_{54}\mathrm{Xe}^{132}$	0.68	I^{132} β^- scin.	(T87)																	

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,[a] Mev	Method	Reference	Spin and parity	Method	Reference	*E* Mev	Method	Reference	Spin and parity	Method	Reference	*E* Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
${}_{54}\mathrm{Xe}^{134}$	(1.03 or 1.17 ?)	Cs^{134} E.C.?	(T88)																	
${}_{54}\mathrm{Xe}^{136}$	1.38	$\mathrm{I}^{136}\,\beta^-$ scin.	(T89)																	
${}_{56}\mathrm{Ba}^{132}$	(1.0)	$\mathrm{La}^{132}\,\beta^+$ a	(T90)																	
${}_{56}\mathrm{Ba}^{134}$	0.794	$\mathrm{Cs}^{134}\,\beta^-$ sl; ce$^-$, pc$^-$	(T41)	2+	$\gamma-\gamma$ ang. correl.	(T14)	1.36	$\mathrm{Cs}^{134}\,\beta^-$ sl; ce$^-$, pe	(T41)	4+	$\gamma-\gamma$ ang. correl.	(T14)	1.93	$\mathrm{Cs}^{134}\,\beta^-$ sl; ce$^-$. pe$^-$	(T41)	5	$\gamma-\gamma$ ang. correl.	(T91)		
${}_{56}\mathrm{Ba}^{136}$	(0.9) (1.2)	$\mathrm{Cs}^{136}\,\beta^-$ a	(T41)																	
${}_{56}\mathrm{Ba}^{138}$	1.44	$\mathrm{Cs}^{138}\,\beta^-$ scin., coinc.	(T92)				2.42	$\mathrm{Cs}^{138}\,\beta^-$ scin.	(T92)				2.88	$\mathrm{Cs}^{138}\,\beta^-$ scin.	(T92)					
${}_{58}\mathrm{Ce}^{140}$	1.6	$\mathrm{La}^{140}\,\beta^-$ s; ce$^-$; scin.	(T41)	2+	$\gamma-\gamma$ ang. correl.	(T93)	2.42	$\mathrm{La}^{140}\,\beta^-$ s; ce$^-$; scin.	(T41)	4+	$\gamma-\gamma$ ang. correl.	(T93)								
${}_{60}\mathrm{Nd}^{142}$	1.576	$\mathrm{Pr}^{142}\,\beta^-$ sl; pe$^-$	(T94)	2+ (or 1+)	derived from shape of β spectrum and decay scheme	(T94)														
${}_{60}\mathrm{Nd}^{144}$	0.695	$\mathrm{Pr}^{144}\,\beta^-$ sl; pe$^-$	(T95)	2+ (or 1+)	$\gamma-\gamma$ ang. correl.	(T96)	2.185	$\mathrm{Pr}^{140}\,\beta^-$ sl; pe$^-$	(T95)	1+	$\gamma-\gamma$ ang. correl.	(T96)								
${}_{60}\mathrm{Nd}^{146}$	(0.490)	$\mathrm{Pr}^{146}\,\beta^-$ scin	(T96a)																	
${}_{62}\mathrm{Sm}^{146}$	(0.45)	Eu^{146} E.C. a	(T97)																	
${}_{62}\mathrm{Sm}^{148}$	(0.69)	Eu^{148} E.C. a	(T98)	(2+)	*K* conv. coeff.	(T99)														
	(∼0.54)	$\mathrm{Pm}^{148}\,\beta^-$ a	(T100)																	
${}_{62}\mathrm{Sm}^{150}$	0.3367	Sm^{149} neutron capt. sπ; ce$^-$	(T101)	(2+)	*K*/*L* ratio	(T101)	(0.777)	Sm^{149} neutron capt. sπ; ce$^-$	(T101)	4+	*K*/*L* ratio	(T101)								
${}_{62}\mathrm{Sm}^{152}$	0.122	Eu^{152} E.C. sπ; ce$^-$	(T102)	2+	*K*/*L* ratio	(T103)														
${}_{64}\mathrm{Gd}^{152}$	0.3441	$\mathrm{Eu}^{152}\,\beta^-$ sπ; ce$^-$	(T102)	2+	*K*/*L* ratio	(T103)													$<3\times10^{-9}$ sec	(T104)
${}_{64}\mathrm{Gd}^{154}$	0.122	$\mathrm{Eu}^{154}\,\beta^-$ sπ; ce$^-$	(T105) (T103)																	
${}_{64}\mathrm{Gd}^{156}$	(0.0888)	Gd+*n* sπ; ce$^-$	(T106)	2+	Rel. int. of *L* lines	(T106)														
${}_{64}\mathrm{Gd}^{158}$	(0.0792)	Gd+*n* sπ; ce$^-$	(T106)	2+	Rel. int. of *L* lines	(T106)														
${}_{66}\mathrm{Dy}^{160}$	0.085	$\mathrm{Tb}^{160}\,\beta^-$ sl; ce$^-$	(T41)	2+	*K* conv. coeff.	(T107)													1.8×10^{-9} sec	(T108)
${}_{66}\mathrm{Dy}^{162}$	(∼0.1)	Ho^{162} E.C.	(T109)																	
${}_{68}\mathrm{Er}^{166}$	0.080	$\mathrm{Ho}^{166}\,\beta^-$ sπ; ce$^-$	(T71)	2+	*K*/*L* ratio lifetime	(T71)	1.44	$\mathrm{Ho}^{166}\,\beta^-$ sl; pe$^-$	(T71)										1.7×10^{-9} sec	(T110)

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,[a] Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
$_{70}\mathrm{Yb}^{170}$	0.084	$\mathrm{Tm}^{170}\,\beta^-$ sl; ce$^-$	(T41)	2+	K conversion coeff.	(T107) (T41)														
$_{72}\mathrm{Hf}^{176}$	0.089	$\mathrm{Lu}^{176m}\,\beta^-$ sπ; ce$^-$	(T111)	2+	K/L ratio	(T111)													1.35×10^{-9} sec	(T112)
$_{72}\mathrm{Hf}^{178}$	(~0.1)	Ta (9.35 min) E.C., β^+	(T113)																	
$_{72}\mathrm{Hf}^{180}$	0.093	Ta^{180} E.C. sπ; ce$^-$	(T114)	2+	K/L ratio	(T114)														
$_{74}\mathrm{W}^{180}$	0.102	$\mathrm{Ta}^{180}\,\beta^-$ sπ; ce$^-$	(T114)	2+?	K conv. coeff.	(T114)														
$_{74}\mathrm{W}^{182}$	(0.100 or 0.113 or others)	$\mathrm{Ta}^{182}\,\beta^-$ cryst; γ	(T115)																	
$_{74}\mathrm{W}^{186}$	0.123	Re^{186} E.C. sπ; ce$^-$, pe$^-$	(T116)	2+	K conv. coeff.	(T116)														
$_{76}\mathrm{Os}^{186}$	0.137	$\mathrm{Re}^{186}\,\beta^-$ sπ; ce$^-$; pe$^-$	(T116)	2+	K conv. coeff. Lifetime	(T116) (T117)	0.764	$\mathrm{Re}^{186}\,\beta^-$ sl; pe$^-$	(T116)	2+	$\gamma-\gamma$ ang. correl.	(T116a)							~0.8×10^{-9} sec	(T117)
$_{76}\mathrm{Os}^{188}$	0.154	$\mathrm{Re}^{188}\,\beta^-$ sl; ce$^-$	(T118)	2+	K/L ratio	(T118)													$<5\times10^{-9}$ sec	(T104)
	0.1549		(T119)		K conv. coeff. $L_{\mathrm{I}}L_{\mathrm{II}}L_{\mathrm{III}}$ int. ratios	(T119)														
$_{76}\mathrm{Os}^{190}$	(0.17)	Ir^{190} E.C. a	(T120)																	
$_{76}\mathrm{Os}^{192}$	(0.283)	Ir^{192} E.C. sl; ce$^-$	(T121)				0.4843	Ir^{192} E.C. sl; ce$^-$	(T121)				0.690	Ir^{192} E.C. sl; ce$^-$	(T121)					
$_{78}\mathrm{Pt}^{192}$	(0.316 or 0.295)	$\mathrm{Ir}^{192}\,\beta^-$ sl; ce$^-$ Au^{192} E.C. sπ; ce$^-$	(T121) (T121a)				0.6115	$\mathrm{Ir}^{192}\,\beta^-$ sl; ce$^-$	(T121)				0.783	$\mathrm{Ir}^{192}\,\beta^-$ sl; ce$^-$	(T121)					
$_{78}\mathrm{Pt}^{194}$	0.327	$\mathrm{Ir}^{194}\,\beta^-$ s; ce$^-$	(T122)	2 (or 1)	$\gamma-\gamma$ ang. correl.	(T123)	1.81	$\mathrm{Ir}^{194}\,\beta^-$ a Au^{194} E.C. sl; ce$^-$	(T41)	2	$\gamma-\gamma$ ang. correl.	(T123)	2.1	Au^{194} E.C. s	(T41)					
		No γ	(T124)	2+	K/L ratio	(T119)														
	0.328	Au^{194} E.C. sl; ce$^-$	(T41)																	
$_{78}\mathrm{Pt}^{196}$	0.358	Au^{196} E.C. sl; ce$^-$	(T41)	2+	$\gamma-\gamma$ ang. correl.	(T115)	0.688	Au^{196} E.C. sl; ce$^-$	(T41)	2+	$\gamma-\gamma$ ang. correl.	(T125)								
$_{80}\mathrm{Hg}^{196}$	0.426	$\mathrm{Au}^{196}\,\beta^-$ s; ce$^-$	(T126)	2+	L conv. coeff.	(T126)														
$_{80}\mathrm{Hg}^{198}$	0.411	$\mathrm{Au}^{198}\,\beta^-$ sl; ce$^-$	(T41)	2+	K conv. coeff. $L_{\mathrm{II}}/L_{\mathrm{III}}$ ratio	(T127) (T128) (T129)	1.087	$\mathrm{Au}^{198}\,\beta^-$ sπ; ce$^-$	(T127)	2+	K conv. coeff. and β^- decay scheme	(T127)							$<0.08\times10^{-9}$ sec	(T130)
$_{80}\mathrm{Hg}^{200}$	(0.365 or 0.577 or 0.622)	Tl^{200} E.C. scin.	(T131)																	
$_{80}\mathrm{Hg}^{202}$	0.427	Tl^{202} E.C. s; ce$^-$	(T132)																	

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,ᵃ Mev	Method	Reference	Spin and parity	Method	Reference	*E* Mev	Method	Reference	Spin and parity	Method	Reference	*E* Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
$_{82}\mathrm{Pb}^{202}$	(0.89)	$\mathrm{Tl}+p\rightarrow\mathrm{Pb}^{202m}$ (5.6 sec) $\mathrm{Po}^{206}\rightarrow\alpha$(?)	(T133)																	
$_{82}\mathrm{Pb}^{204}$	0.374	Pb^{204m} I.T. sl; ce$^-$ Bi^{204} E.C. sl: ce$^-$	(T134)	2+	*K*/*L* ratio *K* conv. coeff.; lifetime	(T135)	1.279	Pb^{204m} I.T. sl; ce$^-$	(T136)	7−	Lifetime Total conv. coeff. *K*/*L* ratio	(T135)							3×10^{-7} sec	(T134)
$_{82}\mathrm{Pb}^{206}$	0.803	$\mathrm{Po}^{210}\,\alpha$ Bi^{206} E.C. sl; ce$^-$	(T137)	2+	$\alpha-\gamma$ ang. correl.	(T138)														
$_{82}\mathrm{Pb}^{208}$	2.614	Tl^{208}(ThC″) β^-	(T139)	2+	$\gamma-\gamma$ ang. correl. pair formation coeff. $\gamma-\gamma$ polarization correl.	(T140) (T141) (T57)	3.20	Tl^{208}(ThC″) β^-	(T41)	4+	$\gamma-\gamma$ ang. correl. $\gamma-\gamma$ polarization correl.	(T140) (T57)	3.48	$\mathrm{Tl}^{208}\,\beta^-$	(T41)					
$_{84}\mathrm{Po}^{210}$	(1)	At^{210} E.C. a	(T41)																	
$_{84}\mathrm{Po}^{212}$	0.729	Bi^{212}(ThC)β^-	(T115)	2+	*K* conv. coeff.	(T142)	0.83	$\mathrm{Bi}^{212}\beta^-$	(T41)				1.60]	$\mathrm{Bi}^{212}\beta^-$	(T41)					
$_{84}\mathrm{Po}^{214}$	0.606	Bi^{214}(RaC)β^- sπ; ce$^-$	(T41) (T144)	2+	*K*/*L* ratio	(T143)														
$_{86}\mathrm{Em}^{220}$	0.241	$\mathrm{Th}^{224}\,\alpha$ sπ; ce$^-$	(T145)	2+	*K* conv. coeff.	(T145)														
$_{86}\mathrm{Em}^{222}$	0.188	$_{88}\mathrm{Ra}^{226}\alpha$ α fine structure	(T41)	2+	Rel. int. of *L* lines, *K* conv. coeff. total conv. coeff. *K*/*L* ratio	(T146) (T147) (T148)														
$_{88}\mathrm{Ra}^{222}$	0.117	$\mathrm{Th}^{226}\,\alpha$ α fine structure	(T149)																	
$_{88}\mathrm{Ra}^{224}$	0.0844	$_{90}\mathrm{Th}^{228}$(RdTh)α α fine structure	(T150)	2+	$L_{\mathrm{II}}/L_{\mathrm{III}}$ ratio total conv. coeff.	(T150) (T148)														
$_{88}\mathrm{Ra}^{226}$	0.0678	$_{90}\mathrm{Th}^{230}\,\alpha$ sπ; ce$^-$	(T145) (T151)	2+	Rel int. of *L* lines	(T146)														
$_{88}\mathrm{Ra}^{228}$	0.055	$_{90}\mathrm{Th}^{232}\,\alpha$ ce$^-$; ppl	(T152)																	
$_{90}\mathrm{Th}^{226}$	0.070	$\mathrm{U}^{230}\,\alpha$ α fine structure	(T149)																	
$_{90}\mathrm{Th}^{228}$	0.060	$\mathrm{U}^{232}\,\alpha$ ce$^-$; ppl	(T152)	2+	Rel. int. of *L* lines for γ from $\mathrm{Ac}^{228}\rightarrow\beta^-$	(T153)														
	0.058	α fine struct.	(T149)																	
	0.058	$\mathrm{Ac}^{228}(\mathrm{M_5Th_2})\beta^-$	(T41)																	
$_{90}\mathrm{Th}^{230}$	0.055	$\mathrm{U}^{234}\,\alpha$ ce$^-$; ppl	(T154)				0.117 or 0.167*	$\mathrm{U}^{234}\,\alpha$ scin.	(T155)											
	0.050	scin.	(T155)																	

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* Bohr and Mottelson, Phys. Rev. (to be published) suggest that 0.167 Mev fits better, if both lowest levels of Th^{230} are interpreted as rotational states of a deformed nucleus.

TABLE I.—*Continued.*

Nucleus	First excited state						Second excited state						Third excited state							
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
	E,^{a} Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	E Mev	Method	Reference	Spin and parity	Method	Reference	Half-life of first excited state	Reference
$_{90}\mathrm{Th}^{234}$	0.048	$\mathrm{U}^{238}\alpha$ ce^{-}; ppl	(T156)																	
	~0.045	ce^{-}; ppl	(T152)																	
	0.050	ce^{-}; ppl	(T157)																	
$_{92}\mathrm{U}^{232}$	0.045	$\mathrm{Pu}^{236}\alpha$ ce^{-}; ppl	(T152)																	
$_{92}\mathrm{U}^{234}$	0.040	$\mathrm{Pu}^{238}\alpha$ ce^{-}; ppl	(T152)																	
	0.043	α fine structure	(T149)																	
$_{92}\mathrm{U}^{236}$	0.044	$\mathrm{Pu}^{240}\alpha$ α fine structure	(T149)																	
$_{94}\mathrm{Pu}^{236}$	(0.150)*	$\mathrm{Np}^{236}\beta^{-}$ $s\pi\sqrt{2}$; ce^{-}	(T158)																	
$_{94}\mathrm{Pu}^{238}$	0.045	$\mathrm{Cm}^{242}\alpha$ α fine structure	(T149)	2+	Rel. intensities of L conv. lines	(T159)	0.150	$\mathrm{Cm}^{242}\alpha$ α fine structure	(T149)											
		ce^{-}; ppl	(T152)																	
$_{94}\mathrm{Pu}^{240}$	0.045	$\mathrm{Am}^{244}\alpha$ α fine structure	(T149)																	
$_{94}\mathrm{Pu}^{242}$	0.038	Am^{242} E.C. $s\pi\sqrt{2}$; ce^{-}	(T71)																	
$_{96}\mathrm{Cm}^{242}$	0.053	$\mathrm{Am}^{242}\beta^{-}$ $s\pi\sqrt{2}$; ce^{-}	(T160)																	

* A re-interpretation of the conversion electron spectrum shown in (T160) suggests that the strongest gamma-ray line may have an energy of 0.04 Mev.