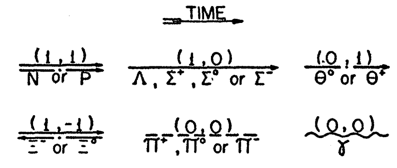

FIG. 1. Graphs for particles with the corresponding quantum numbers (N,U). For antiparticles reverse the arrows.

The following expression for S then resulted:

$$S=U-N. \tag{2}$$

It turned out that for all well-established cases[3] U has the value 0 for integral I and ±1 for $I=\frac{1}{2}$. U also changes sign for the antiparticle corresponding to a given particle.

Here we wish to emphasize the advantage of the use of the quantum number system (N,Q,U) instead of the other systems previously used. From the relations (2) and (3) it is clear that the systems which have been used up to here: (I_3,N,S), (I_3,N,Q), (I_3,Q,S), (N,Q,S) as well as the systems (N,U,Q), (I_3,N,U), (I_3,U,S), (I_3,U,Q), (N,U,S), (Q,S,U), are all equivalent. (We do not include the total isotopic spin I because we are considering only the additive quantum numbers.) However, the simplest set is (N,U,Q) because the quantum numbers N,U,Q for one particle assume only three values 0, $+1$, or -1, in contrast to I_3 and S which have five possible values.[3] Another advantage is that Q and N are always conserved and only U may not be conserved in weak interactions.

Finally we wish to propose a generalization of Feynman diagrams which we think is very suggestive for the representation of reactions involving hyperons. This is based on the fact that the quantum numbers $N,Q,$ and U are additive and may assume only the values $+1$, -1, or 0. Indeed it is this property which allows us to use in Feynman diagrams an arrow in the direction of time propagation for particles $(N=1)$ or in the opposite direction for antiparticles $(N=-1)$ and no arrow for bosons $(N=0)$. The conservation law for the number of particles assures us that a particle line can be followed from one end to the other without being interrupted or without reversal of orientation of the arrows. In the same way we can follow the charge or an isoparticle line if we use arrows in the direction of propagation for values $+1$, in the opposite direction for values -1, and no arrow for the value 0 of these constants of motion.

If we take the direction of increasing time from left to right and represent the particles $(N=1)$ by $\rightarrow$ and the isoparticles $(U=1)$ by $-\cdot\rightarrow$ the lines of propagation of the particles will be those indicated in Fig. 1. For the corresponding antiparticles all arrows should be reversed. An oriented line for the propagation of the charge could be added but is unnecessary.

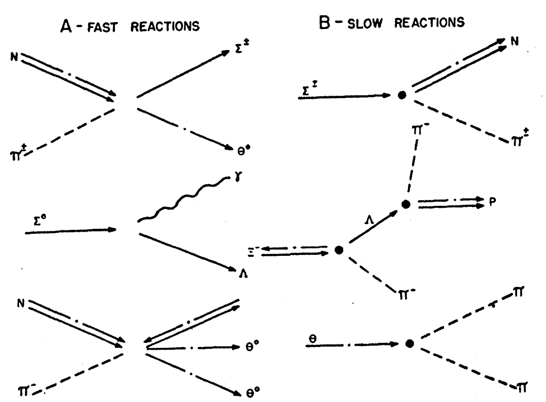

FIG. 2. Diagrams for several reactions.

In Fig. 2, column A, are given the diagrams for a number of well-established fast reactions for which there is no interruption of particle or isoparticle lines. In column B some "slow" reactions are represented for which there is a creation or annihilation of an isoparticle line.

We should mention, finally, that if the existence of Y^- particles[4] with $U=-2$ $(S=-3,\ N=1,\ I=0)$ should be proved,[3] the present scheme could still be used if they are represented by a particle line $(N=1)$ and *two* isoparticle lines. In this case the simplicity of the original scheme would be lost. It is possible that the values $U=\pm2$ should be excluded for elementary particles and allowed only for compound ones.

[1] M. Gell-Mann and A. Pais, *Proceedings of the 1954 Glasgow Conference on Nuclear and Meson Physics* (Pergamon Press, London, 1955), p. 324.
[2] B. d'Espagnat and I. Prentki, Nuclear Phys. **1**, 33 (1956).
[3] Actually there is a possibility for charged particles with $U=\pm2$, but for all well-established cases only the values 0, ±1, appear. The authors of reference 2 give, however, an argument against the possibility $U=\pm2$.
[4] Y. Eisenberg, Phys. Rev. **96**, 541 (1956); M. Goldhaber, Phys. Rev. **101**, 433 (1956).

First Excited States of Heavy Even-Even Nuclei

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THE systematic behavior of first excited states of even-even nuclei is well known, and indeed the pronounced maxima of the first excited state energies at the "magic numbers" are among the most striking manifestations of nuclear shell structure.[1,2] Between the closed shells, in the regions $155<A<185$ and $A>225$, rather flat minima are developed whose constancy and low energy point to the collective nature of the excitations.[3] In their review paper on alpha decay, Perlman and Asaro[4] point out that the first excited states of even-even nuclei in the transuranium region are always between 40 and 50 kev above the ground state and that

TABLE I. Energies of first excited states of heavy even-even nuclei.

Isotope	Energy (kev)	Lines seen	Measured from	Reference
U^{230}	51.7±0.1	L_{II}, L_{III}, M_{II}, M_{III}	Pa^{230}	a
U^{232}	47.2±?	L_{II}, L_{III}, M, N_{IIIII}	Pa^{232}	b
U^{234}	43.50±0.04	L_{II}, L_{III}, M_{II}, M_{III}, N, O	Pu^{238}	c
U^{236}	45.28±0.06	L_{II}, L_{III} M_{II}, M_{III}, N	Np^{236}, Pu^{240}	d
Pu^{236}	44.63±0.1	L_{II}, L_{III} (weak lines)	Np^{236}	d
Pu^{238}	44.11±0.05	L_{II}, L_{III}, M_{II}, M_{III}, N_{II}, N_{III}, O	Cm^{242}	e
Pu^{240}	42.88±0.05	L_{II}, L_{III}, M_{II}, M_{III}, N_{II}, N_{III}, O	Cm^{244}	e
Pu^{242}	44.50±0.06	L_{II}, L_{III}, M_{II}, M_{III}, N_{II}, N_{III}, O	Am^{242m}	f
Pu^{242}	44.52±0.1	L_{I}, L_{II}, L_{III}, M_{II}, M_{III}, N, O	Am^{242m}	g
Cm^{242}	42.12±0.06	L_{II}, L_{III}, M_{II}, M_{III}, N_{II}, N_{III}, O	Am^{242m}	f
Cm^{242}	42.18±0.1	L_{II}, L_{III}, M_{II}, M_{III}, N_{II}, N_{III}, O	Am^{242m}	g
Cm^{246}	42.9±0.1	L_{II}, L_{III}	Cf^{250}	h
Cm^{248}	43.4±0.1	L_{II}, L_{III}	Cf^{252}	h

[a] Hill, Asars, Stephens, and Hollander (unpublished data, 1956).
[b] O. P. Hok and G. J. Sizoo, Physica **20**, 77 (1954).
[c] W. G. Smith and J. M. Hollander (unpublished data, 1955).
[d] R. G. Albridge and J. M. Hollander (unpublished data, 1956).
[e] W. G. Smith and J. M. Hollander, Phys. Rev. **101**, 746 (1956).
[f] Albridge, Harvey, and Hollander (unpublished data, 1956).
[g] S. A. Baranov and K. M. Shlyagin, *Proceedings of the Moscow Meeting, July, 1955* (Akad. Nauk, S.S.S.R., Moscow, 1955) p. 252.
[h] B. G. Harvey and J. M. Hollander (unpublished data, 1956).

they follow smooth curves when plotted against neutron number.

It is the purpose of this Letter to assemble some recent data which illustrate the "second-order" systematics of these excited states. Most of the energies quoted here were obtained from precision measurements of conversion electron spectra in the Berkeley permanent-magnet beta spectrographs. These data are given in Table I, and they are plotted against neutron number in Fig. 1. Although they are as yet fragmentary, these results show that the energies of the first excited states do not decrease monotonically with N or A, but exhibit large variations from the average value (~44 kev) which are well outside the experimental errors. The uranium and plutonium curves also show minima.

Since the excitation energy of the first excited state of a rotational band is determined essentially by the nuclear moment of inertia, such measurements allow one to examine the very small changes in nuclear deformation brought about by the addition of pairs of nucleons to the already deformed core. It may be possible to relate these small changes in shape to the character of the nucleon pairs, specifically to the total angular momentum (or component along the symmetry axis, Ω) of the odd particles which make up the last pair.

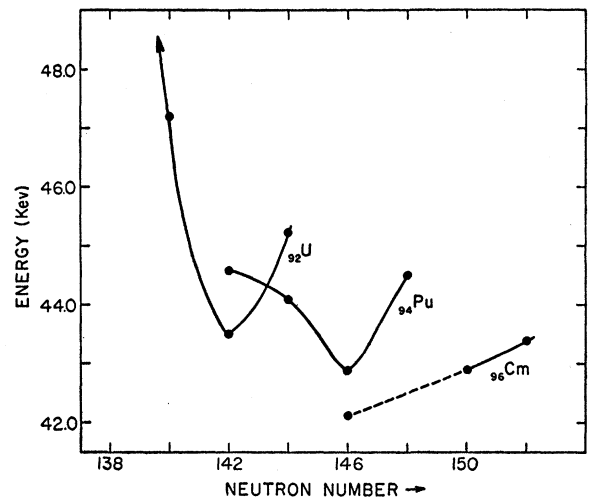

FIG. 1. Energies of first excited states of even-even heavy nuclei.

The energy values of the first excited states of the curium isotopes are of some interest in view of the existence of small discontinuities in the alpha-decay energies at around 152 neutrons, interpreted by Ghiorso *et al.*[5] as evidence for a "subshell" closure at $N=152$. Although the present data indicate that the energies of the first excited states in curium rise as one approaches $N=152$ (Cm^{248}), the effect is very small and even less than the variations in the uranium and plutonium curves. Thus, as pointed out by Ghiorso *et al.*,[5] such a "subshell" at $N=152$ would have to be of a fundamentally different nature than the major closed shells, especially since the moment of inertia of Cm^{248} does not appear to be substantially lower than that of the neighboring nuclides.

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[2] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953).
[3] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **27**, No. 16 (1953).
[4] I. Perlman and F. Asaro, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Stanford, 1954), Vol. 4, p. 157.
[5] Ghiorso, Thompson, Higgins, Harvey, and Seaborg, Phys. Rev. **95**, 293 (1954).