pion ratio between threshold and 250 Mev, a more realistic estimate obtained for $\sigma_S^0(\theta)$ is

$$\sigma_S^0(\theta) \approx 1.1\times10^{-30}\chi\nu\{0.2+0.2\eta^2\} \text{ cm}^2/\text{sterad}.$$

Then the interference term becomes

$$\sigma_{SP}^0(\theta) \approx -1.1\times10^{-30}\chi\nu\eta \cos\theta \text{ cm}^2/\text{sterad},$$

when the P-state term[6] used is

$$\sigma_P^0(\theta) \approx 3.3\times10^{-30}\chi\nu\eta^2(1-0.6\cos^2\theta) \text{ cm}^2/\text{sterad}.$$

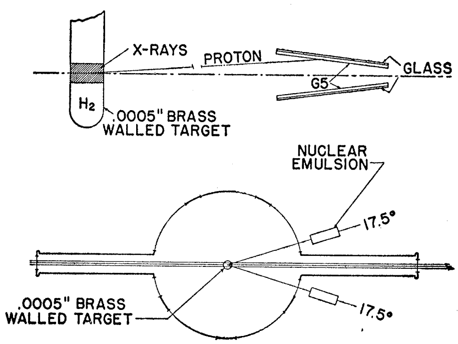

FIG. 1. Schematic diagram of liquid target and nuclear emulsion detectors.

Figure 2 illustrates the role of the interference term. The differential cross section may be written

$$d\sigma^0/d\Omega = A_0 + A_1\cos\theta + A_2\cos^2\theta.$$

Values of $A_0+A_2\cos^2\theta$ shown as the dotted curve are deduced from total cross sections measured in the counter experiment[7] by setting $A_2=-0.6A_0$. Addition of the interference term $A_1\cos\theta=\sigma_{SP}^0(\theta)$ yields the solid curve, in closer agreement with the measured differential cross sections.

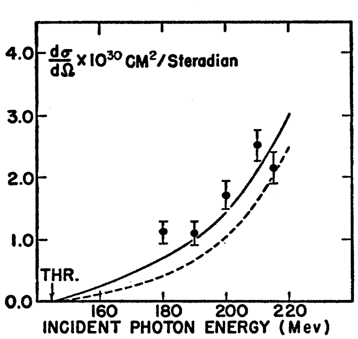

FIG. 2. Differential cross sections at 135° in the center-of-mass system *versus* laboratory photon energies. For discussion of curves see text.

Because the monitoring system was the same as that used by Bernardini and Goldwasser,[1] a direct comparison of results gives the neutral-to-positive production ratios of Table I.

Cross sections presented above are based on measurements of about half of the observed tracks. Complete

TABLE I. Neutral-to-positive photoproduction ratios at 135°.

Incident photon energy (Mev)	$\sigma^0(135°)/\sigma^+(135°)$
180	0.14±0.03
190	0.12±0.02
200	0.16±0.03
210	0.21±0.02

results will be described in the near future, together with a more detailed comparison with theory. The author wishes to thank Professor G. Bernardini for many valuable discussions.

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System of Even-Even Nuclei*

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PREVIOUS investigations of even-even nuclei have yielded the following main results:

(1) While the ground state has presumably always the character (spin and parity) 0+, the first excited state has 2+ with very few exceptions.[1,2]

(2) The character of the second excited state, where known, is either 4+, 2+, 0+, or (odd, ±).[2]

(3) The energy of the first excited state, E_1, increases as the number of neutrons or protons approaches the end of a shell, and shows a very pronounced peak at the filled shell.[2,3] As a rule E_1 varies less when two protons are added to the nucleus, than when two neutrons are added.[2]

We have now studied second excited states in the region $36\leqslant N\leqslant 88$ in more detail, and have found the following:

(1) The characters of the second excited states, where known, are preponderantly 2+, occasionally 4+, 0+, and (odd, −), whereas second excited states of a rotational band,[4] occurring for $90\leqslant N\leqslant 108$, have always the character 4+.

(2) The energy of the second excited state, E_2, shows a dependence on A similar to E_1.[5] In Fig. 1 the ratio

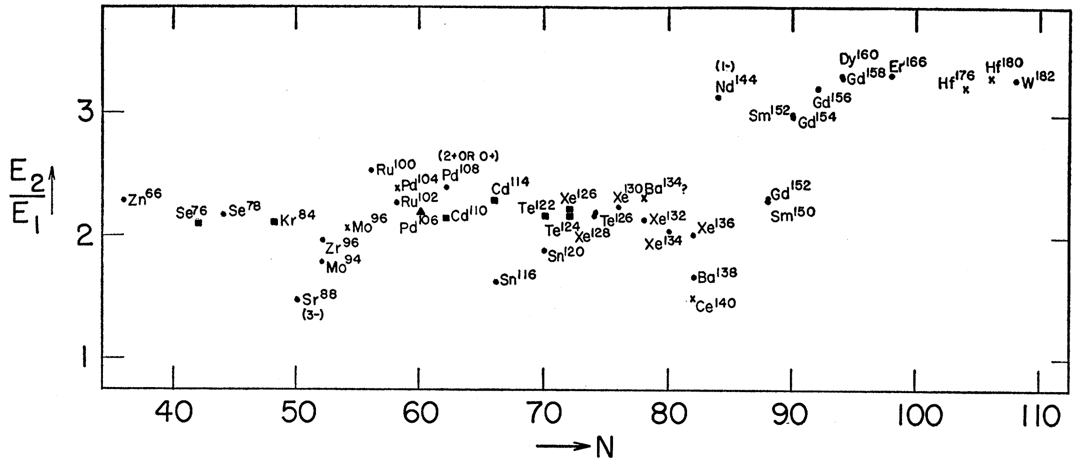

FIG. 1. Ratio of energies E_2/E_1 as function of neutron number N ($36 \leqslant N \leqslant 108$). The character of the second excited state of the nucleus is denoted by ▲(0+), ■(2+), × (4+), and • (not known, unless given in parentheses).

E_2/E_1 is plotted against N. For $N \leqslant 88$, it is seen that this ratio is remarkably constant, fluctuating around 2.2, except where I_2 is odd. Rotational states, with E_2/E_1 approaching 3.33, are also shown. In Fig. 2, E_2/E_1 is plotted against E_1, omitting points with odd I_2. Here the distinction between the two groups is even more striking. Group (a), consisting of nuclei with rotational states ($90 \leqslant N \leqslant 108$), covers a small range of energies between $70 \leqslant E_1 \leqslant 125$ kev. Group (b) begins at $E_1 \approx 330$ kev and extends to almost 2 Mev. Above 1200 kev, all points refer to nuclei whose neutron or proton number is magic. In this region a few deviations toward lower values for E_2/E_1 occur. The gap between groups (a) and (b) indicates an abrupt transition which occurs as N changes from 88 to 90. Again we find that N, rather than A, seems to determine the nature of the system of excited states of a nucleus. This is brought out strikingly by recent work on the dual decay of Eu^{152} (12 yr),[6,7] which yields for Sm^{152} ($N=90$) $E_1=123$ kev, $E_2=367$ kev, $E_2/E_1=3.0$ and for Gd^{152} ($N=88$) $E_1=344$ kev, $E_2=754$ kev, $E_2/E_1=2.19$.

(3) In group (b), two intensity rules govern the electromagnetic transitions: (I) Between a second and first 2+ state the transition is usually mainly $E2$, with only a small $M1$ admixture. (II) The probability for the $E2$ part of this transition relative to that for the competing transition to the ground state is much higher than would be expected on the basis of the single-particle model. Both these intensity rules were pointed out by Kraushaar and Goldhaber,[8,9] and have meanwhile been supported by further examples.

(4) Coulomb excitation data[10] for group (b) indicate that the probability for a transition from the first excited state to the ground state are 10 to 20 times higher than would be expected on the basis of a single-particle model.

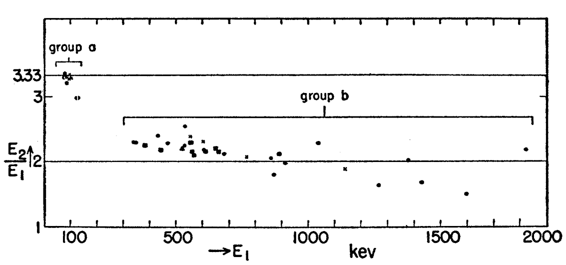

FIG. 2. Ratio of energies E_2/E_1 as function of E_1 for $36 \leqslant N \leqslant 108$. The character of the second excited state of the even-even nucleus is denoted by ▲(0+), ■(2+), × (4+), and • (not known). Points for nuclei with odd spin for the second excited state are omitted from this figure.

The uniformity and simplicity of the empirical pattern over a large range of even-even nuclei of group (b) suggest that the pattern arises from a single feature. Two facts are especially suggestive: the pattern exists in nuclei immediately adjacent to those in which the Bohr-Mottelson rotational pattern is manifest, and it also obtains very near to closed shells where the coupling must be weak. It is therefore tempting to assume that the Bohr-Mottelson model[11] in the region of weak to moderate coupling should yield the above results.

We first consider the limit of zero coupling. The first and second excited states, due to core excitations, are at $\hbar\omega$, $2\hbar\omega$ above the ground state; thus $E_2/E_1=2$. At $2\hbar\omega$ lies a degenerate triplet, of characters 0+, 2+, 4+. Intensity rule II follows from the favored nature of one phonon jumps. Also, there is no $M1$ radiation, because the current is directly proportional to the velocity of the fluid. The collective nature of the excitation gives rise to fast $E2$ transitions.

The theory has been extended into the weak to moderate coupling region by a Tamm-Dancoff calculation, which we have, however, only been able to carry out with a cutoff at three phonons. The Bohr-Mottelson Hamiltonian is modified by the introduction of forces between the outer nucleons; for reasons of definiteness

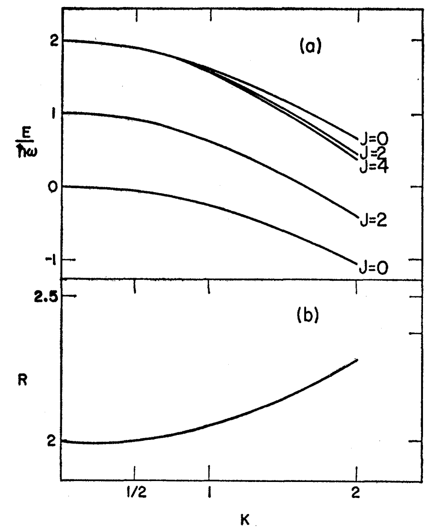

FIG. 3. (a) The energy levels as a function of the coupling strength K. $K=0.67[(\hbar^2/2B)/\hbar\omega]^{\frac{1}{2}}k$, where B denotes the mass parameter and k the coupling parameter. (b) $R=E_2/E_1$, where E_1, E_2 denote the energy above the ground state of the first and second 2+ state respectively. The anharmonic terms are not included.

and simplicity, the outer nucleons are taken as $(f_{7/2})^4$, and $E(J=2, s=2)=3\hbar\omega$, $E(J, s=4)\sim 6\hbar\omega$.[12] The choice of other, perhaps more realistic conditions, does not appear to change the qualitative conclusions. In addition, it is necessary to increase the mass parameter B by a factor 5 to fit the experimental data.[13] The results of the calculations of the energy levels are shown in Fig. 3. For the range of coupling strength shown, the intensity rules are found to be essentially the same as in the zero-coupling case, with the exception that a weak $M1$ component is introduced. The $E2$ transition probability between the first 2+ state and the ground state also remains nearly the same; for zero coupling the ratio of the transition probability to that given by the simple shell model is:

$$\mathfrak{M}(\text{coll})/\mathfrak{M}(\text{shell})=\left[\frac{9}{16\pi^2}Z^2\left(\frac{\hbar^2/2B}{\hbar\omega}\right)R^4\right]\Big/\left(\frac{1}{25}R^4\right)\sim 25,$$

where $\hbar^2/2B=0.008$ Mev, $\hbar\omega=0.75$ Mev, $Z=40$.

The addition of possible anharmonic terms affects the position of the energy levels. Reasonable assumptions result in effects opposite to that of the coupling between the core and the particles and of similar magnitude. Hence, superposition of anharmonic terms and coupling does not affect the general agreement with the empirical results, although it may change the sequence of the triplet levels.

These ideas are proving valuable for the interpretation and construction of decay schemes. However, the existence of the triplet of levels together with the natural extension of the intensity rules for all these levels need further examination.

Although it seems difficult to explain the great uniformity of the pattern without a collective model approach, it would be interesting to study the alternative interpretation in terms of a shell model. The electromagnetic intensity rules I and II would follow directly from seniority considerations.[9] It is conceivable that the simple behavior of E_2/E_1 could be obtained, and moderate speed-up factors of the $E2$ transition probability are possible for suitable mixing.

We wish to thank M. Goldhaber for many valuable discussions, and Betty Oppenheim for assistance in carrying out the calculations.

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First-Forbidden Nonunique Beta Spectra in Re^{186}†

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THE anomaly of the isotropic β-γ angular correlation[1] and the apparent[2] alpha shape of the first inner beta group in Re^{186} led us to an examination of the beta spectrum in coincidence with the 137-kev gamma. Six-mm-diameter samples of Re^{186} (10 μg/cm^2) volatilized onto 100-μg/cm^2 aluminum backing, containing <0.1 percent Re^{188}, were measured in the double-lens spectrometer at a transmission of 6 percent with a resolution of 6 percent. Gammas were counted at 3 percent geometry in NaI(Tl) crystal 1 in. behind the sample, and betas with a 1-mm-thick×11-mm-diameter anthracene disk, using 24-in. Lucite light guides and DuMont 6292 photomultipliers. Amplified shaped pulses were counted in fast ($2\tau_F=0.12$ μsec) coincidence and then in slow coincidence ($2\tau_F=2.6$ μsec) with the