of the Weisskopf formula. The lifetime measurements are compaticle with a spin assignment of 2 for the first excited state of both Os^{186} and Os^{188} and indicate that both transitions are of the $E2$ type.

Using the gamma-ray energies and intensities, determined from this investigation, it is possible to propose a decay scheme for Re^{188}. Assuming that the 0.155-Mev gamma ray is electric quadrupole and using the beta-branching ratio for the first excited state given by Richmond *et al.*,[6] the decay scheme presented in Fig. 1 accounts for all of the available data.

This scheme agrees in part with that proposed by Richmond *et al.*[6] and is consistent with their coincidence measurements. Further experiments are in progress to determine the beta-branching ratios and to determine the angular correlation function for the cascade gamma rays.

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Double Scattering of High-Energy Protons by Hydrogen and Carbon*

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Measurements have been made of the asymmetry in the second scattering of protons first scattered from an internal target in the 240-Mev proton beam of the cyclotron. Referring to Fig. 1, protons scattered at 27° are collimated, selected roughly in energy, and pass into a second-scattering apparatus outside the cyclotron vacuum tank. This apparatus is rigidly mounted in a cylindrical can rotatable about an axis which can be made to coincide with the direction of the protons from target I. The useful beam is defined by a cylindrical scintillation counter on the axis. With a polyethylene second target a $p-p$ scatter is detected by quadruple coincidence among the beam-defining counter, a two-counter telescope detecting the protons scattered into a range about 27°, and a counter for the low-energy recoil. An exploratory counter 15 inches behind the beam-defining counter is used in coincidence with it to align the beam with the mechanical axis of the can to better than 0.4°. The beam spread determined by this method is 2° and is approximately symmetric. Target II is $\frac{2}{3}$ the diameter of the beam-defining counter, and both are optically set on axis. As expected from these dimensions, the quadruple rate was insensitive to small displacements of the second target from the axis.

The background, about 10 percent, was evaluated by replacing the second target with one of carbon. Magnetic shielding eliminated distortion of the trajectories from the second scattering. Light pipes led to photomultipliers in a region of low field where additional shielding reduced the variation in multiplier sensitivity with can rotation to less than 2 percent.

With a first target of carbon and an effective hydrogen second target, the asymmetry $2e$ was found to be 20.6±2.2 percent. The measurement was made in a series of runs at angles ϕ of 0°, 90°, 180°, and 270°. The 90° and 270° rates agreed satisfactorily

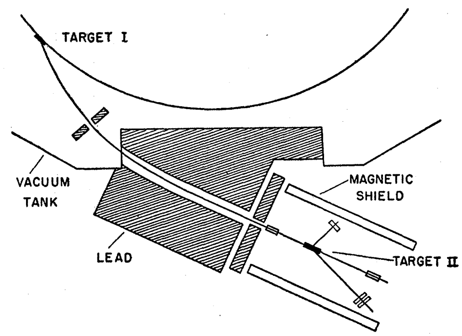

Fig. 1. Schematic arrangement of apparatus in orientation $\phi=0$.

with the mean of the 0° and 180° rates. The quoted errors are standard deviations and are largely statistical.

The fractional polarization in a single scatter is $P(\theta)=2\langle S_y\rangle$. The asymmetry in the second scattering is of the form $I(\phi)=I_0(1+e\cos\phi)$. For a mixed scattering from carbon and from hydrogen, $e=P_CP_H$.

With a polyethelene first target, 50±5 percent of the protons accepted in the second scattering were from the hydrogen in the first target. The asymmetry $2e$ observed in this case was 15.2±2.2 percent. From these values we calculate the asymmetry $2e$ in a double $p-p$ scattering to be 9.8±5 percent. Therefore, neglecting any energy degradation effect, $P_H=22\pm5$ percent, $P_C=47\pm13$ percent.

The asymmetry in a double scattering from carbon targets has been measured omitting the low-energy counter from the coincidence arrangement. An absorber in the telescope rejected scattered protons under 140 Mev. This essentially required a nucleon-nucleon collision within the carbon nucleus, as did the energy selection from the first scattering. The measured $2e$ was 49.5±8 percent. Again neglecting energy degradation, $P_C=49.8\pm4$ percent. Using this improved value of P_C, the above data give $P_H=20.6\pm2.7$ percent, or for the asymmetry in a double $p-p$ scattering, $2e=8.5\pm2.2$ percent.

The asymmetry in the double $p-p$ scattering is a measure of the noncentral force between protons. Wolfenstein[1] has made a general study of polarization effects in proton reactions, while calculations based on specific models for the $p-p$ interaction have been made by Goldfarb and Feldman[2] and by Swanson.[3] At 240 Mev the approximate predictions for $2e$ considering the angular acceptance of the apparatus is 0.5 percent for the Jastrow hard-core model,[2] 13 percent for the Christian-Noyes tensor model,[2] 30 percent for the Case-Pais LS coupling model,[2] and 3 percent for Swanson's revised Christian-Noyes model.[3] Of these models, only the Jastrow model gives the proper flat $p-p$ cross section at small scattering angles.[2,4] The polarization in scattering from carbon is of the same sign but considerably larger than that from hydrogen. Some enhancement of the effect in carbon might be expected if there is a suppression of those partial waves which contribute little to the polarization in the $p-p$ case. The chief $p-p$ polarization effects are from the ^3P and the coupled $^3F_2$ phases.[2] The waves higher than D, which are essentially nonpolarizing, have impact parameters greater than the internucleon distance and, therefore, are more probably associated with multiple nucleon interactions and suppressed.

In the experiment of Wouters[5] on the polarization of high-energy neutrons, no polarization was found in the scattering from carbon. It should be noted, however, that in that experiment only $p-n$ internal interactions are involved, whereas in the present experiment both $p-p$ and $p-n$ collisions contribute, and, further, the angle of the $p-n$ collision is the supplement to that of Wouters.

The highly polarized beam from carbon may be useful in other studies. At higher energies the beam may be used to select nucleon states in meson production. Slowing the beam in absorbers will produce little depolarization[1] and, therefore, it could be used for low-energy nuclear reactions.

Further measurements are being made which will include the determination of polarization effects in deuterium and several other elements. A preliminary measurement indicates the polarization produced by copper is even larger than that produced by carbon.

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Dipole Photonuclear Reactions and the Independent Particle Model

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CROSS sections for electric dipole photoexcitation of neutrons in an independent particle model nucleus have been calculated as a function of photon energy. Characteristics of the potential well and bound neutron levels (Fig. 1) were chosen to correspond to the nuclide Cu^{63}, and antisymmetric nuclear wave functions made up from the exact single-particle solutions of Schroedinger's equation were used. The energy levels are eigenvalues of the problem, but they were filled according to the shell model[1] in order to provide the (presumably) correct distribution of neutron angular momenta in the nuclear ground state; the main results of the calculation, in any case, turn out to be quite insensitive to variations in ordering. Substantially the same results should be obtained for proton excitation.[2]

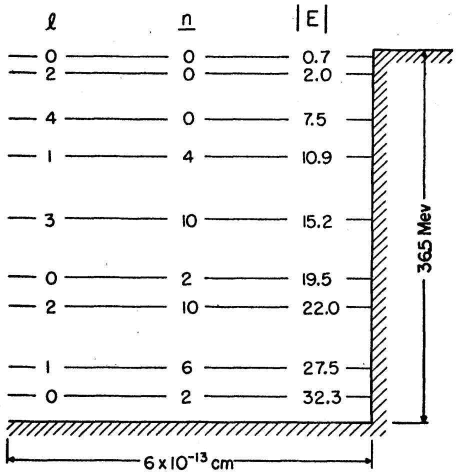

FIG. 1. Potential well and bound neutron levels. $|E|$ is the level binding energy in Mev, l is the angular momentum in units of $\hbar$, and n is the number of neutrons in the level when the nucleus is in its ground state.

Figure 2 is a schematic plot of the resulting photon-capture cross section. The histogram represents capture by neutrons which end up in bound levels, where the corresponding delta-function cross sections are arbitrarily made one Mev wide, and the continuous curve shows capture from transitions to final states in which the excited neutron has positive energy. The various numbers on the graph give the percentage contributed to the total integrated capture cross section, $\int \sigma dE$, by the transitions indicated. A smoothed version of the calculated photon-capture curve is compared with the observed photoneutron cross section in Fig. 3.

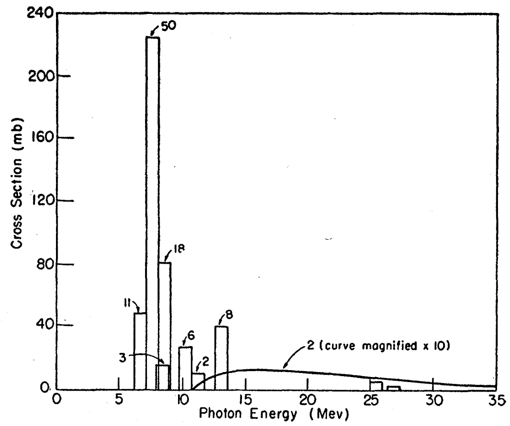

FIG. 2. Calculated photon-capture cross section. Histogram shows transitions to bound levels; line curve shows transitions to continuum. Line curve is magnified ten time for clarity. Numbers are percentages of total $\int \sigma dE$.

Although the areas ($\int \sigma dE$) and shapes of the two curves in Fig. 3 are qualitatively similar, most of the calculated absorption takes place at too low energy. Directly ejected neutrons (those excited to positive energy states) are produced in only 2 percent of the capture events. If all other capture with $\hbar\omega \geq 10.9$ Mev is assumed to lead to neutron evaporation from an excited compound nucleus (a drastic assumption here because it implies the abandonment of the independent particle model as soon as photon capture has occurred), it is still found that only 12 percent of the total calculated photon capture can produce neutron emission. Thus the independent particle model by itself would not agree with experiment.

One might suppose that other modes of photon capture could account for the remainder of the observed neutron yield and require that direct ejection produce only the high-energy anisotropic photoneutron groups emitted from copper and many other nuclei. The calculated angular distribution for the direct neutrons is of the form $A+B\sin^2\theta$, with B/A somewhat less than unity for

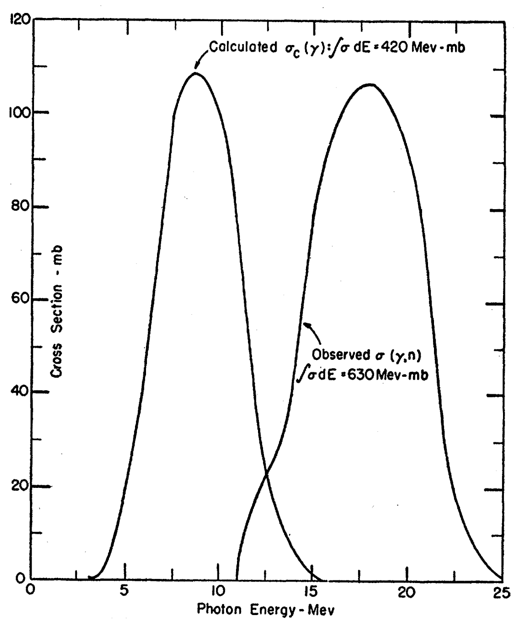

FIG. 3. Comparison of cross sections. Calculated photon-capture curve has been smoothed. Observed photoneutron cross section taken from L. Katz and A. Cameron, Can. J. Phys. **29**, 518 (1951).