Murakawa and Ross, where the influence of the respective atomic electrons has not been eliminated.

The fact that most of the ratios in Fig. 1 are much smaller than unity can be explained by the assumption[3,7,8] that the addition of neutrons to a nucleus usually does not cause a uniform expansion of the nuclear charge distribution proportional to $A^{1/3}$ and that the added neutrons are mainly in the outer region of the nucleus. The exceptionally high points for $Eu^{151}-Eu^{153}$ and $Sm^{150}-Sm^{152}$ at $N=90$ have been related[2,7] to the quadrupole moments of europium.

Figure 1 also shows, as has been mentioned before,[3] that the values obtained for different isotopic pairs of the same element[9] show a tendency to follow the general trend of the values for different elements. The measurement of Murakawa and Ross[1] on the isotope shift $Ce^{138}-Ce^{140}$ can be considered an instructive example of this fact.

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[6] For detailed discussion, accuracy (on the average about 10–20 percent) and literature see reference 3. The points for cerium 138–140 (only upper limit known) and lead 208–210 have been added. The new values for Pd are from Steudel (to be published), the relative shifts of the osmium isotopes have been corrected according to Suwa [Phys. Rev. **83**, 1258 (1951)].
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[9] The corresponding points have been connected by full lines in Fig. 1.

An Attempt to Produce Nuclear Orientation in Mercury Vapor*

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THE absorption of polarized resonance radiation by a vapor produces unequal populations of the magnetic sublevels of the excited state, and also of the ground state after re-emission. Kastler[1] has suggested that, as a consequence of these facts, polarized light may be used to orient nuclei. An experimental demonstration of this effect was attempted, and yielded a negative result.

A sample of mercury enriched in the isotope with mass number 199 and spin $\frac{1}{2}$ was supplied by the Atomic Energy Commission. The level structure of this isotope is shown in Fig. 1. The sample was placed in a quartz resonance lamp in a magnetic field of a few hundred gauss and illuminated by circularly polarized resonance radiation incident in a direction parallel to the field. Atoms in the ground state with $m=\frac{1}{2}$ can be excited only to the $^3P_1$ level with $F=\frac{3}{2}$ and $m=\frac{3}{2}$, and, in the absence of collisions, can return only to the ground state sublevel from which they came. On the other hand, atoms originally in the ground state sublevel with $m=-\frac{1}{2}$ are excited exclusively to levels with $m=+\frac{1}{2}$, and may return by radiating to either of the two ground levels. The net result is an optical "pumping" as Kastler suggests, from $m=-\frac{1}{2}$ to $m=+\frac{1}{2}$, or a tendency in the direction of nuclear orientation. This is in competition with a disorienting tendency caused by collisions.

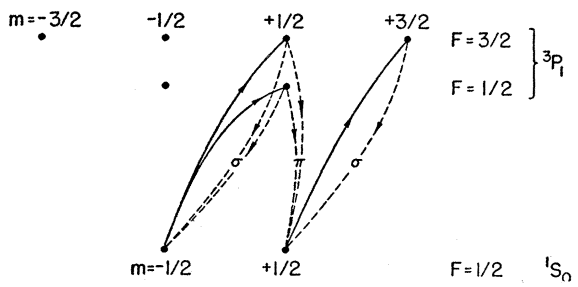

FIG. 1. Optically induced transitions in Hg^{199}.

If an appreciable degree of preferred nuclear orientation is produced, the intensity of the π-component of the resonance radiation with $\Delta m=0$ is less than for a disoriented vapor because fewer atoms are in the $m=-\frac{1}{2}$ ground level. This criterion was used to detect nuclear orientation. A radiofrequency field, of such frequency as to induce transitions between the ground state magnetic sublevels, was applied to the resonance lamp. We estimate that when the magnetic resonance condition $\omega=\gamma H$ is fulfilled, a change in the intensity of the π component of the optical resonance radiation should be observed if the polarized light has produced an excess of $m=\frac{1}{2}$ over $m=-\frac{1}{2}$ of at least a few percent. No such effects were observed.

Further experimentation is under way in an attempt to isolate the reasons for the negative results reported.

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The Scattering of 9.6-Mev Protons by Carbon, Aluminum, and Magnesium

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A REMOTELY controlled scattering chamber, which will be described in detail later, has been used to investigate the scattering of 9.6-Mev protons by some light nuclei. The source of protons was the extracted beam of the Birmingham 60-in. cyclotron. The beam passes through a steering magnet which brings it to a focus just in front of the chamber. After collimation to $\frac{1}{2}°$ by rectangular slits, the beam passes through a scattering foil and is collected in a Faraday cup. The foils were about 4 mg/cm² in thickness, and the proton currents varied between 1 and 5×10^{-9} amp.

The scattered particles were detected by a counter telescope consisting of three proportional counters which fed a flexible coincidence or anticoincidence circuit. A set of fifty graded aluminum absorbers before counter 1, and a further set of five between counters 2 and 3, could be used to measure the ranges of the scattered particles. The proton current entering the Faraday cup was passed through a high resistance, and the resulting dc potential integrated electronically to give an absolute measure of the charge collected during a run.

Differential range curves were taken by observing coincidences between pulses in the first two counters for different thicknesses of absorber in front of counter 1. Counter 1 was biased low enough to count all particles which traversed it, while counter 2 was biased high so as to count only those particles which stopped in counter 2. This arrangement was insensitive to the large background of pulses because of fast neutron recoils in the counter gas. Figure 1 shows a range distribution curve for 9.6-Mev protons scattered through 60° (lab. angle) by a magnesium foil of normal isotopic constitution, set so that the normal to the foil bisected the scattering angle.

The three large peaks correspond, respectively, to elastic scattering and to excitation of the 1.38- and 4.14-Mev levels of Mg^{24}. The widths of these peaks are only slightly greater than those to be expected from range straggling in the absorber alone, so that the effects of energy spread of the incident beam, thickness of the scattering foil, range of energies accepted by counter 2, and the spread in scattering angle are small, as anticipated from detailed calculations.

Particle ranges in aluminum, corrected for energy loss in the scattering foil and the counter, were converted to energies by

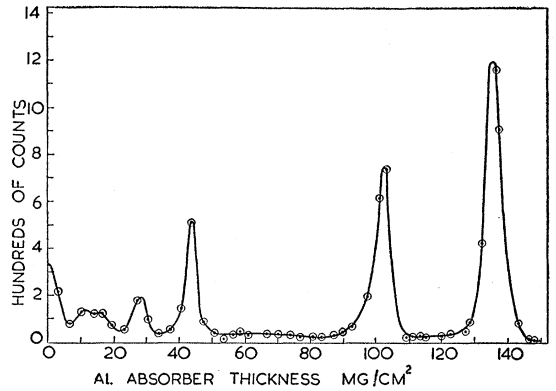

FIG. 1. Range distribution curve for 9.6-Mev protons scattered through 60° (lab. angle) by magnesium of normal isotopic constitution.

means of a range-energy relation which is an experimentally corrected version (to be described later) of the figures of Smith.[1]

The 1.38- and 4.14-Mev levels in Mg^{24} are well known,[2] and were used to estimate the accuracy of the determination of nuclear excitation energies by the present method. Measurements at four angles gave mean values of 1.34 and 4.17 Mev for these two levels. A further check was made by measuring the scattering from carbon, in which the first excited state of C^{12} is at an energy of 4.44 ± 0.01 Mev.[3,4] Carbon foils prepared by burning filter paper were used, and measurements at five angles gave a mean value of 4.40 Mev for this level. From these results, the accuracy of the determinations of excitation energies is estimated to be 0.05 Mev for well resolved peaks.

For aluminum, observations at six angles yielded the levels of Al^{27} shown in Table I. The probable errors have been assigned on an appraisal of the resolution of the peaks, and the spread between observations at different angles.

In these experiments, no certain evidence was found for the 0.8- or 2.78-Mev levels. The levels at 3.93, 4.39, 4.66, and 5.46 Mev have not previously been reported from studies of the inelastic scattering of protons, but a level at 3.83 ± 0.07 Mev has been found independently by this method.[6,7] In the magnesium curves, three peaks have been found which correspond to excitation energies higher than 4.14 Mev. One of these yields a level at 6.38 ± 0.08 Mev which may be assigned to Mg^{24} on the basis of a level at 6.3 Mev found from studies of the inelastic scattering of deuterons by separated Mg^{24}.[8]

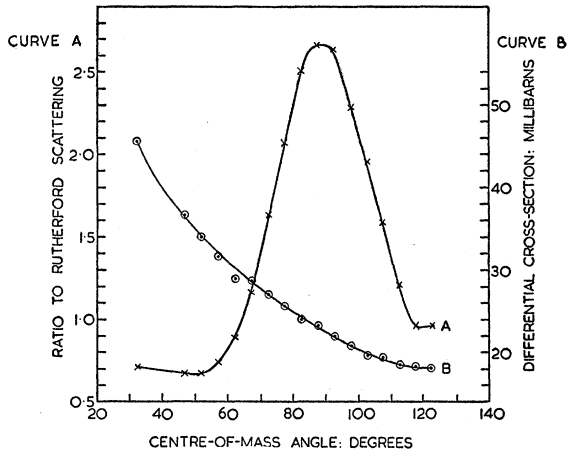

FIG. 2. Angular distributions for 9.6-Mev protons scattered by magnesium. Curve A: absolute ratio to Rutherford scattering for protons elastically scattered. Curve B: absolute differential cross sections (corrected to center-of-mass) for protons scattered inelastically (1.38-Mev level of Mg^{24}).

TABLE I. Energy levels in Al^{27}.

Observed level Mev	Reported level[a] Mev	Observer reference No.
	0.804	(2)
0.99 ± 0.05	1.02	(2)
1.72 ± 0.15	1.85	(2)
2.22 ± 0.08	2.15	(2)
	2.78	(2)
3.00 ± 0.05	3.03	(2)
3.63 ± 0.12	3.65 ± 0.07	(5)
3.93 ± 0.10	3.83 ± 0.07	(6)
4.39 ± 0.12	4.33 ± 0.07	(5)
4.66 ± 0.10		
5.46 ± 0.08	5.32 ± 0.07	(5)

[a] See reference 7.

Absolute cross sections and angular distributions were measured by observing coincidences between counters 1 and 2, both biased low enough to count all particles which traversed them. The reliability of the system in this condition was checked by measuring the elastic scattering from gold, for which the absolute cross sections found agreed within 3 percent with those calculated on the assumption of Rutherford scattering. Figure 2 shows the ratio of measured to Rutherford scattering for 9.6-Mev protons elastically scattered by magnesium (Curve A), and absolute differential cross sections (corrected to center-of-mass) for one group of inelastically scattered protons (1.38-Mev level of Mg^{24}) (Curve B). The elastic scattering of protons by carbon and aluminium gave curves which are similar in shape to Curve A of Fig. 2: the ratio to Rutherford scattering at the peak is higher, and the peak is shifted to larger angles for the lighter nuclei.

We wish to acknowledge our indebtedness to Mr. H. I. S. Allwood and Dr. C. H. Westcott for the large part they played in the original design of the scattering chamber.

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[7] Since this work was completed there has appeared an abstract by Reilley, Allen, Arthur, Bender, Ely, and Hausman, Bull. Am. Phys. Soc. 26, No. 6, 8 (1951), listing 22 energy levels in Al^{27} which have been found by the magnetic analysis of the inelastic scattering of 8.0-Mev protons from Al.
[8] MIT Progress Report, July, 1950, p. 174.

The Elastic Scattering of Deuterons by Deuterons

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AN analytical solution of the problem of the elastic scattering of deuterons by deuterons is obtained for the case of an interaction between nucleons of the type,[1]

$$V_{ij}=-(g_1+MP_{ij}+g_2Q_{ij}+gP_{ij}Q_{ij})W_0\exp(-\mu^2r_{ij}^2), \quad (1)$$

where $M=1-g-g_1-g_2$. In addition, a Coulomb repulsion between the two protons of the system is included. The deuteron ground state is assumed to be a ^3S state,[1,2] described by the Gaussian wave function,

$$\psi_0(r)=a\exp(-\lambda^2r^2), \quad \text{where} \quad a^2=2^{\frac{3}{2}}\lambda^3/\pi^{\frac{3}{2}}; \quad (2)$$

that is, the ^3D state is not included in the calculation. In addition polarization of the deuterons is neglected.

The procedure employed in the calculation is to set up the wave equation, including the total interaction between the four nucleons of the system, express it in suitable coordinates in the center-of-mass system and then proceed to a solution of the properly symmetrized wave function which describes the elastic scattering. This solution obeys the Pauli principle with respect to exchanges