preliminary machine calculations, the reduction is not enough. Further, this model does not explain (2). The nonlocal nature[6] of the imaginary part may also be responsible for making the effective local W dependent on A and the incident angular momentum. This point has not been studied yet.

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[1]A. M. Lane, J. E. Lynn, E. Melkonian, and E. R. Rae, Phys. Rev. Letters 2, 424 (1959).

[2]K. K. Seth, Revs. Modern Phys. 30, 442 (1958). Figure 1 is reproduced from a private communication from Seth.

[3]A. M. Lane et al. stated that W is small since the level density is small near magic. W depends, however, also on the nuclear matrix elements which will be large if the level density is small. Further, we do not observe large difference between $\langle \Gamma^0/D \rangle$ for the even nucleus and the odd nucleus although the level density differs by about a factor 2. This was pointed out to the author by V. F. Weisskopf.

[4]K. K. Seth, Proceedings of the International Conference on the Nuclear Optical Model, Florida State University Studies, No. 32 (The Florida State University, Florida, 1959).

[5]A. M. Lane and C. F. Wandel, Phys. Rev. 98, 1524 (1955).

[6]A. Sugie, Progr. Theoret. Phys. (Kyoto) 21, 681 (1959).

[7]M. G. Mayer and J. H. D. Jensen, Elementary Theory of Nuclear Shell Structure (John Wiley and Sons, Inc., New York, 1955), p. 50.

[8]From Fig. 1 we see a small discrepancy in $\langle \Gamma^0/D \rangle$ near $A \sim 50$ but, since R' is normal here, the theoretical R' and $\langle \Gamma^0/D \rangle$ will be fitted to the experiment by slightly changing the depth (or the radius) of the real part of the potential, leaving W near the normal value.

[9]F. Bjorklund and S. Fernbach, Phys. Rev. 109, 1295 (1958).

FURTHER INTERPRETATION OF A MEDIUM ENERGY (p, $2p$) EXPERIMENT*

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In a previous publication,[1] the momentum transfer distribution observed in the 40-Mev (p, $2p$) angular correlation experiment of Griffiths and Eisberg[2] was interpreted as giving information about the momentum distribution of nucleons localized in the nuclear surface. After unfolding the momentum transfer distribution due to the optical potentials in the entrance and exit channels, it was found that momentum components corresponding to proton energies of about 1 Mev were most likely to be observed for the bound particle. It is the purpose of this Letter to point out some additional considerations which contribute to an understanding of the reaction.

A collision of a nucleon with a stationary free nucleon will result in an angle of 90° between the momenta of the particles in the final state. In reference 1, it is shown that the effect of the binding potential is to move the region of smallest momentum transfers to an angle less than 90°. If small momentum transfers are most probable, the result will be an angular correlation peaked at an angle less than 90° (depending on the binding and excitation energy) as is observed experimentally.

In reference 1, it was assumed that the momentum distribution was isotropic. The momentum components were estimated from the experiment. Essentially the peak in the experimental angular correlation is so narrow that only small momenta (~1 Mev) contribute. The relationship between the width of the angular correlation curve and the momentum of the struck particle is explained in reference 1.

It was also shown in reference 1 that the reactions are not isotropically distributed over the nuclear surface. They come predominantly from an equatorial belt on the surface with the incident direction as the north-south axis. Within the belt, the main contribution comes from regions A, Fig. 1, since, for one particle scattered to the left and the other to the right, one of the particles coming from region B is likely to be

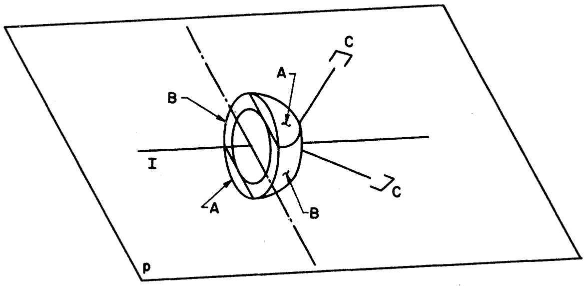

FIG. 1. Schematic diagram of a nucleus and experimental arrangement showing: P, a plane passing through the counters and the incident beam that also passes through the center of a nucleus; C, counters; I, incident beam; A and B, regions of greater and lesser importance in the $(p,2p)$ reaction, respectively.

absorbed. From simple kinematics with particles of equal mass, it may be shown that if the incident particle collides with a free particle moving at 90° with respect to it in the laboratory system, the angular correlation between the particles after collision is still given by a δ function at 90° in the laboratory system. In the approximation that the collision occurs at the equator, only the tangential component of the momentum of the struck particle in the incident direction will contribute to a spreading of the angular correlation. From the consideration of proton flux in an optical potential[3] it is observed that the incident protons travel roughly tangentially in the region of interaction.

Reactions are most likely to be observed in which the struck particle is moving tangentially. Radial motion will result in the plane of the collision either intersecting the nucleus in which case at least one particle is likely to be absorbed (regions B, Fig. 1) or out of the plane of the counters (region A, Fig. 1).

It has been shown by Baker, McCarthy, and Porter[4] that the shape of the momentum distribution that may be observed for particles localized at the nuclear surface is determined almost completely by the localization rather than by the wave function of the bound particles. The tangential momentum components for particles in higher shell model states are found to be much less than the radial components, within the restrictions imposed by the localization. The results of this calculation agree with the uncertainty principle because the region of interaction is less restricted by absorption tangentially than radially. Thus a more realistic theoretical estimate of the effective momentum distribution than the isotropic assumption of reference 1 is possible. Using the above momentum transfer components in the relationship between momentum transfer and angular correlation (Figs. 2 and 3 of reference 1), the experimental angular correlation curve may be easily understood both in position and width.

Owing to the imperfection of the tangential approximation, there will be a contribution from the tangential component perpendicular to the incident beam and from the radial component. Although they cannot appreciably spread the angular correlation, they will cause a preponderance of events in which the energies of the final particles differ if the counters are placed fairly symmetrically about the incident direction [see Fig. 2]. This effect was observed in the experiment.

The small momentum transfers observed in the $(p,2p)$ experiments are essentially due to the anisotropy of the momentum distribution and the fact that the interaction does not effectively occur uniformly throughout the nuclear surface. Thus

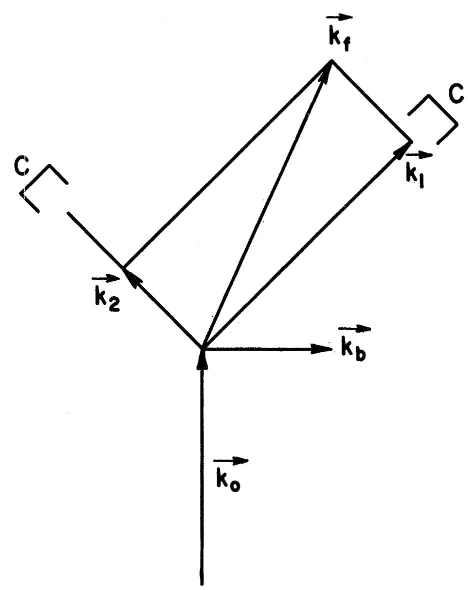

FIG. 2. Sketch showing conservation of momentum under certain conditions: $\vec{k}_0$ = incident momentum; $\vec{k}_b$ = radial component of the momentum of a bound particle (region B) = the tangential component of the momentum of a bound particle that is perpendicular to the incident momentum (region A); $\vec{k}_f$ = final momentum; $\vec{k}_1$, $\vec{k}_2$ = momenta of particles in the final state. Conservation of momentum requires $k_1^2 > k_2^2$.

one would suspect that a theory analogous to the Butler theory should not predict the correct, rather narrow angular correlation since (*a*) it does not contain information about the momentum distribution in different regions of the nuclear surface, and (*b*) it does not distinguish between the regions of the nuclear surface as to which are more likely to contribute to the reaction. Calculations using such a theory confirm this prediction.

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[1] I. E. McCarthy, E. V. Jezak, and A. J. Kromminga Nuclear Phys. 12, 274 (1959).
[2] R. J. Griffiths and R. M. Eisberg, Nuclear Phys. 12, 225 (1959).
[3] I. E. McCarthy, Nuclear Phys. 10, 583 (1959).
[4] G. A. Baker, I. E. McCarthy, and C. E. Porter (to be published).

NUCLEAR MATRIX ELEMENTS IN THE BETA DECAY OF Sb^{124}†

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After the recent clarification of the beta interaction it has become of interest to study the relative contributions of the various matrix elements to first forbidden β transitions. It is the purpose of this paper to demonstrate that an unambiguous determination of matrix elements in a nonunique β transition (e.g., Sb^{124}) is possible on the basis of precise β-γ directional and β-γ circular polarization correlation measurements, if the β transition shows appreciable deviation from the ξ approximation.[1-3]

The ξ approximation was first introduced by Konopinski and Uhlenbeck[1] to explain the statistical shape of most nonunique first-forbidden beta spectra. In this approximation the beta transition probability is expanded in powers of the nuclear radius R and only the leading terms are taken into account, which are associated with the Coulomb factor $\xi = \alpha Z/2R$. Deviations from this approximation may be caused by selection rule effects which inhibit contributions from matrix elements other than $\int B_{ij}$. The contribution of the $\int B_{ij}$ term, which is of rank $\lambda = 2$ and which describes the component of the lepton field carrying away two units of angular momentum, may then become very important. The spectra of such β transitions exhibit deviations from the statistical shape and their ft values ($\log ft > 10$) are considerably larger than the characteristic ft values of nonunique first forbidden transitions ($\log ft \cong 8$).

It was suggested[2,3] that such a selection rule effect rather than a mutual cancellation of matrix elements explains the large ft value of the 2.31-Mev β transition of Sb^{124} ($\log ft = 10.6$). The results of the present investigation confirm this hypothesis.

The angular and energy dependence of the β_1-γ_1 directional correlation of Sb^{124} involving the β_1 component of 2.31-Mev maximum energy (refer to inset of Fig. 1) was measured with the vacuum chamber described previously.[4] The directional correlation $W_{\beta\gamma}(\theta, \overline{W}_\beta = 4.8)$ of the β_1-γ_1 cascade measured at a fixed average energy of $\overline{W}_\beta = 4.8$ (in units of mc^2) is shown in Fig. 1. A least-squares fit of the experimental points to the correlation function:

$$W_{\beta\gamma}(\theta, \overline{W} = 4.8) = 1 + A_2(4.8) P_2(\cos\theta) + A_4(4.8) P_4(\cos\theta), \quad (1)$$

yielded the following values for the correlation coefficients:

$$A_2(4.8) = -0.390 \pm 0.011,$$
$$A_4(4.8) = +0.004 \pm 0.013. \quad (2)$$

The absence of a $P_4(\cos\theta)$ term provides further evidence against the decay scheme $4^+(\beta_1)2^+(\gamma_1)0^+$.

The dependence of the coefficient $A_2(W)$ on the β energy is shown in Fig. 2. A simultaneous measurement of the energy dependence of the β_2-γ_2 directional correlation made it possible to correct the data for the presence of the β_2-γ_1 directional correlation at β energies below the maximum energy of the β_2 spectrum ($W_0 = 4.15$). There is, however, some uncertainty in this correction due to the fact that the sign of the $E2$-$M1$ mixing ratio δ of the γ_2 transition is not