spite the difficulties, is a simultaneous measurement of reflectivity and PEM current.

We have derived expressions[6] for the PEM effect when there are many-valleyed bands and anisotropic mobilities. For bismuth in the present orientation, the PEM current through the second order in magnetic field B is

$$i \cong weI(\mu_1+\nu_1)B(2\nu_3E_0\tau/3)^{1/2}, \qquad (1)$$

where w is the sample width, e the electronic charge, I the absorbed photon flux density, μ_1 and ν_1 the binary-axis components of the equilibrium electron and hole mobility tensors, respectively, ν_3 is the trigonal component of hole mobility, E_0 the band overlap, and τ the electron-hole recombination time. [Mks units are used in (1)]. Mobility components quite small compared to others have been ignored in (1); hence, the approximation sign. Also, surface recombination is assumed to be negligible,[7] and the quantum efficiency of absorbed photons is taken to be unity. The square-root term is the effective diffusion length.

The next term after (1) is of order B^3. We confine ourselves to the small-field case because of certain unexplained transport phenomena at higher fields.[3] The PEM current is found to be linear with B up to ~1 gauss, and even the earth's field is detectable.

Mobility values from reference 3, corrected for the resistivity ratio of the present sample, are inserted in (1) and give the recombination time $\tau \sim 2\times10^{-8}$ sec, with an uncertainty factor of 3; this is mainly due to the uncertain value of ν_3 in bismuth and the estimate of the absorbed light flux I. Electron and hole relaxation times[3] for this sample are probably about 4×10^{-10} and 8×10^{-10} sec, respectively.

Two previous claims of observation of the PEM effect in bismuth are doubtful. The first,[8] for a deposited film at 300°K, reports a spectral response (between 1 and 4 μ) which apparently is proportional to radiant power, not photon flux. The second case,[9] for very thin crystals at 300°K that only give a voltage when intensely illuminated edgewise, is almost certainly a magnetothermal effect due to a temperature gradient, particularly since the sample temperature climbed to 28°C under illumination.

Thanks are due to Mr. G. E. Smith for providing the sample and for helpful discussions.

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ENERGY LEVELS OF He^4†

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A number of recent experiments[1-6] using the reactions $T(d,n)He^{4*}$, $T(p,p)T$, and $He^3(d,p)He^{4*}$ have indicated the existence of an excited state in He^4 about 20 MeV above the ground state. Because this state lies above the threshold for breakup into a proton and a triton, reactions such as $T(d,n)He^{4*}$ and $He^3(d,p)He^{4*}$ actually lead to three-body final states, e.g., $T+D \rightarrow T+p+n$, where excited states in He^4 are seen as final-state interactions between the outgoing proton and triton. In order to remove the ambiguity which can be introduced by measuring the energy of only one member of such a three-body system, we have extended the investigation of the energy levels of He^4 by using two-dimensional analysis of the energies of two coincident charged particles from the He^3 + D reactions.[7,8]

The magnetically analyzed 31.8-MeV He^3 beam from the Brookhaven 60-inch cyclotron was collimated to a diameter of 2 mm and used to bombard a thin (~1 mg/cm^2) deuterated polyethylene foil target. Charged particles were detected by two movable telescopes which could be positioned to ±0.1° and each of which had an angular resolution of ±1°. Each of these telescopes contained a 50μ silicon detector[9] followed by a 3-mm lithium-drifted silicon detector. The two signals from each telescope, labeled ΔE (50μ detector) and E (3-mm detector), were added to obtain $E + \Delta E$, the total energy of the charged particle, and were also combined in a pulse multiplier[10] to provide an identification of the charged particle as a p, d, t, He^3, or He^4. Pulse-height analysis of the energies of the coincident charged particles was accomplished using an SDS-910 computer coupled to two 20-Mc/sec analog-to-digital converters. The usual fast-slow coincidence ($2\tau \approx 50$ nsec) was required between the two $E + \Delta E$ pulses, and the computer was programmed to collect data simultaneously in three 64×64 arrays, with the routing determined by the identifications of the two coincident particles.

Most of our runs were taken with the routing requirement that the particle in one of the telescopes be a proton. Figure 1 shows an example of the projection onto the proton-energy axis of the triton-proton coincidence data from a run where θ(proton) = +45° and θ(triton) = −25°. At these angles the kinematically allowed solutions for the three-body reaction D(He^3,pt)H^1 are a doubled-valued function of the proton energy,[11] and therefore we have analyzed and plotted the data for each of the solutions separately in Figs. 1(a) and 1(b). Figure 1(c) presents a summation of the projections in Figs. 1(a) and 1(b) with similar projections of the proton-proton and He^3-proton coincidence data taken during the same run. (A more detailed presentation of the experiment and the analysis of the two-dimensional spectra will be published elsewhere.[12]

In the data of Figs. 1(a) and 1(b) there are two prominent peaks, a broad one centered near channel 53 and a narrower one centered near channel 59. Similar data were obtained

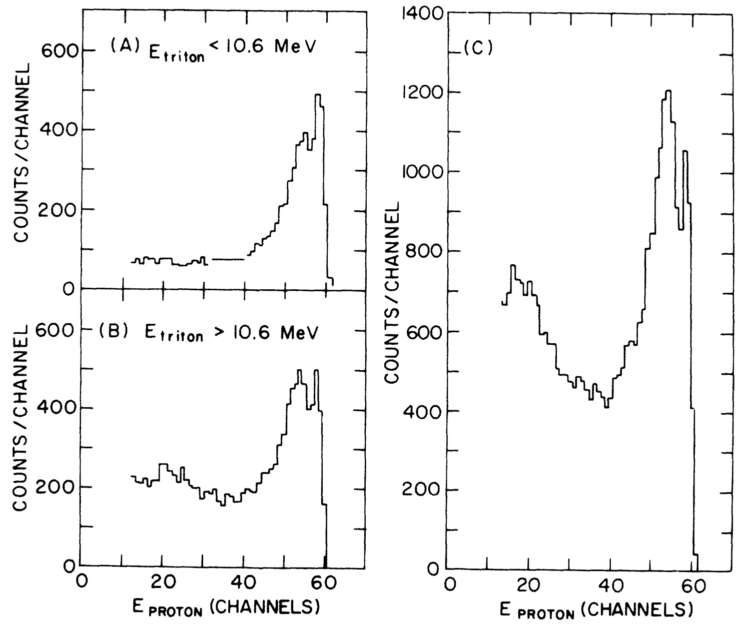

FIG. 1. Projections onto the proton-energy axis of two-dimensional coincidence data taken during a run with the proton telescope set +45° from the beam and with the other telescope set −25° from the beam axis. (a) The projection of the triton-proton coincidence data corresponding to kinematic solutions with $E_{\text{triton}} < 10.6$ MeV. (b) The projection of the triton-proton coincidence data corresponding to kinematic solutions with $E_{\text{triton}} > 10.6$ MeV. (c) Summation of the projections in Figs. 1(a) and 1(b) together with similar projections of the proton-proton and He^3-proton coincidence data taken during the same run.

at 21 sets of angles. An analysis of all these data shows that the behavior of these two peaks, as a function of angle, is exactly what would be expected if these peaks were due to final-state interactions corresponding to excited states in He^4. In other words, as the laboratory angles are varied, the laboratory position and laboratory width of each of these two peaks changes so as to retain a constant excitation and width in the He^4 system. The broad peak centered near channel 18 in Fig. 1(c) is associated with the projection of the He^3-proton coincidence data and is due to a final-state interaction in the p-n system corresponding to the formation of singlet ($T = 1$) deuterons in the system $He^3 + p + n$. The absence of a corresponding prominent peak in our triton-proton coincidence data, e.g., Fig. 1(b), indicates that the singlet di-proton leads to a much weaker final-state interaction, as has recently been pointed out by Zupančič.[13]

Analysis of all the projections onto the proton-energy axis indicates that in the He^4 system the broad peak (channel 53) is centered at an excitation of 21.24 ± 0.2 MeV and has a width of 1.1 ± 0.2 MeV. The narrow peak (channel 59) corresponds to a state which lies very close to the threshold for decay into a triton and proton. This peak lies in a region where the triton energy is much more sensitive than the proton energy to the excitation energy in He^4. Consequently our analysis of this level has been carried out using projections of our triton-proton coincidence data onto the triton-energy axis. (This state lies below the He^3 $+n$ threshold and therefore does not appear in the He^3-proton coincidence data.) For all the runs taken at angles where it is kinematically possible to study the population and decay of the region of excitation in He^4 within 50 keV of the triton-proton threshold, these projections onto the triton-energy axis were transformed into the triton-proton center-of-mass system, weighted according to their statistics, and then summed to give the histogram in Fig. 2. From Fig. 2 it can be seen that this peak is centered at 125 ± 20 keV in the triton-proton center-of-mass system, or at an excitation in He^4 of 19.94 ± 0.02 MeV. The width of the peak in Fig. 2 is 175 ± 25 keV in the triton-proton center-of-mass system. Some of this width, however, can be accounted for in terms of the solid angle of the detectors [±1° $\rightarrow \Delta E(He^4) = 104$ keV], the detector resolution [$\Delta E(\text{triton}) \approx 100$ keV $\rightarrow \Delta E(He^4) \approx 18$ keV], and the target thickness [$\Delta E(He^3) \approx 150$ keV $\rightarrow \Delta E(He^4)$ ≈ 10 keV], so that the net width of this level is only 140 ± 25 keV.

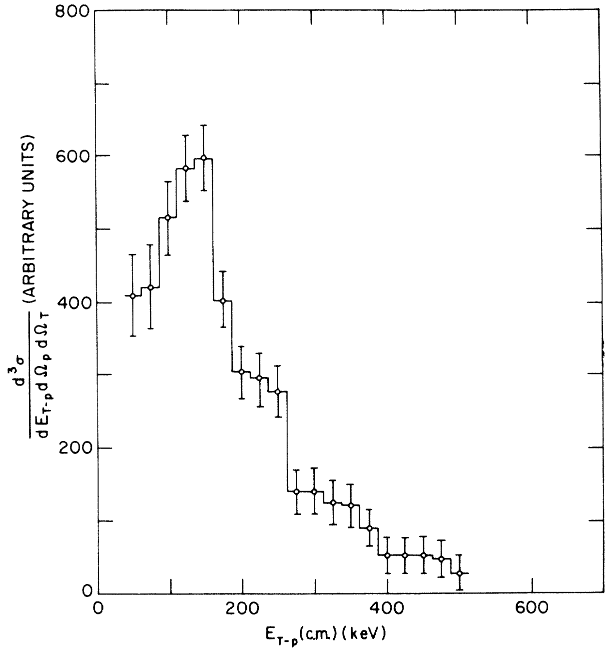

FIG. 2. The first excited state of He^4; a sum of data taken at many pairs of angles, projected onto the triton-energy axis and transformed into the triton-proton center-of-mass system. The ordinate is the number of counts per unit energy in the triton-proton system in relative units, and the abcissa is the energy in the triton-proton system.

The excitation of 19.94 ± 0.02 MeV which we have measured for this level using two-dimensional analysis of the three-body final state can be compared with the values of 20.1 ± 0.1 and 20.08 ± 0.05 obtained from one-dimensional analysis of similar three-body systems[1-3,6] and the value of 20.3 ± 0.1 obtained from an analysis[5] of the direct observation[4] of the state as a resonance in the reaction T(p,p)T. Detailed discussions of the results that should be expected from such comparisons are presented elsewhere.[2,13,14]

In summary, by studying the particle-particle correlations in the three-body systems resulting from the bombarding of deuterium with a 31.8-MeV He^3 beam, we have identified two excited states in the He^4 nucleus, one at an excitation of 19.94 ± 0.02 MeV with a width of 140 ± 25 keV and the second at an excitation of 21.24 ± 0.2 MeV with a width of 1.1 ± 0.2 MeV. The 19.94-MeV level is observed to decay by

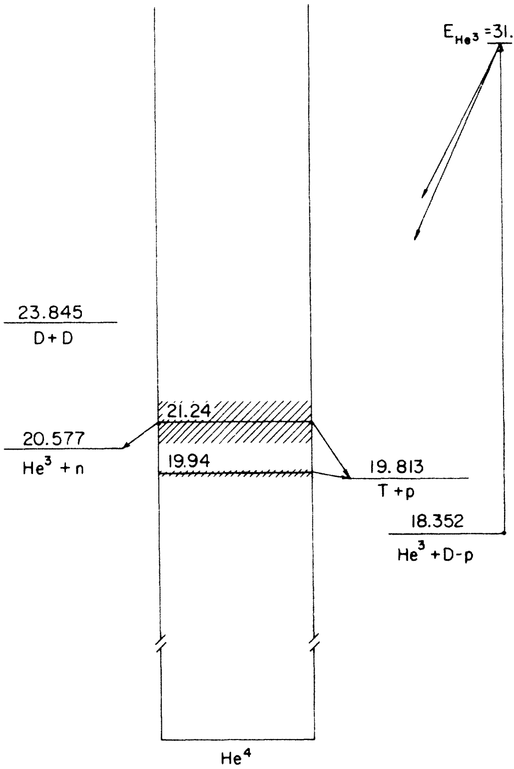

FIG. 3. Energy-level diagram of He^4.

proton emission and is presumably the same level that has been reported recently by a large number of groups.[1-6] The 21.24-MeV level does not appear to have been reported elsewhere; it is observed to decay by both proton emission and neutron emission. These results are summarized in the level diagram in Fig. 3. Further measurements are planned with the object of determining the spins of these levels from the angular correlation patterns of their decays.

It is a pleasure to express our appreciation to the operating crew of the Brookhaven 60-inch cyclotron, to Dr. C. P. Baker and Dr. H. E. Wegner for their help and cooperation on this experiment, and to Professor Č. Zupančič for many helpful discussions.

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HYPERNUCLEAR SPECTROSCOPY, UNITARY SYMMETRY, AND POSSIBLE ANALOG STATES*

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The application of unitary symmetry to multibaryon states such as complex nuclei and hypernuclei is not straightforward because of the following two difficulties: (1) Severe symmetry-breaking effects can be expected[1,2] from the π-K and Σ-Λ mass differences. Nuclear binding forces of the meson-exchange type can be expected to change appreciably with the type of meson being exchanged. Furthermore, the hypernuclear states of strangeness -1 which belong in a given SU(3) multiplet contain a mixture of Λ and Σ. Since the Σ-Λ mass difference is an order of magnitude larger than the binding energy per baryon in a nucleus, the observable hypernuclear states contain only Λ's and are therefore mixtures of states from different