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OBSERVATION OF CHARGED-PARTICLE REACTION PRODUCTS

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Nuclear reactions of the type $(X,\alpha\gamma)$ have received, as yet, little detailed experimental study despite their particular interest in terms of the reaction mechanisms involved. This neglect has resulted largely from the inherent difficulties in resolving the product alpha particles from backgrounds of neutrons, gamma rays, and longer range charged particles. Detectors such as gridded ionization chambers, which provide adequate energy resolution, have pulse rise-time characteristics insufficiently short to permit millimicrosecond particle-gamma and particle-particle coincidence studies.

The use of Au-Ge junctions for the detection of alpha particles[1] and fission fragments[2] has been reported. It is the purpose of this Letter to summarize the results of a number of new measurements on the physical characteristics of the junctions. These measurements serve to demonstrate the great potential usefulness of junction detectors in heavy-particle nuclear spectroscopy.

The measurements have been carried out on junctions made according to the technique developed by Pantchechnikoff.[3] By comparison of the voltage pulses produced by Pu^{240} alpha particles absorbed in the junction with those from a calibrated signal generator injected through a known small capacitor, a value of 2.84 ± 0.12 ev per electron hole pair was found for germanium. This is in accord with the previously reported value[4] 2.94 ± 0.15 ev. By measuring the junction capacitance a junction thickness is obtained; this thickness varies with method and conditions of manufacture, and increases with applied voltage.

For protons, He^3 ions, and He^4 ions (from a Van de Graaff generator) the output pulse is proportional to the incident energy provided that the particle range is less than the junction thickness. Figure 1(a) shows results obtained with a liquid nitrogen cooled 2×2 mm junction of thickness appropriate to the energies available. The proton curve shows clearly a loss of pulse height for longer range particles.

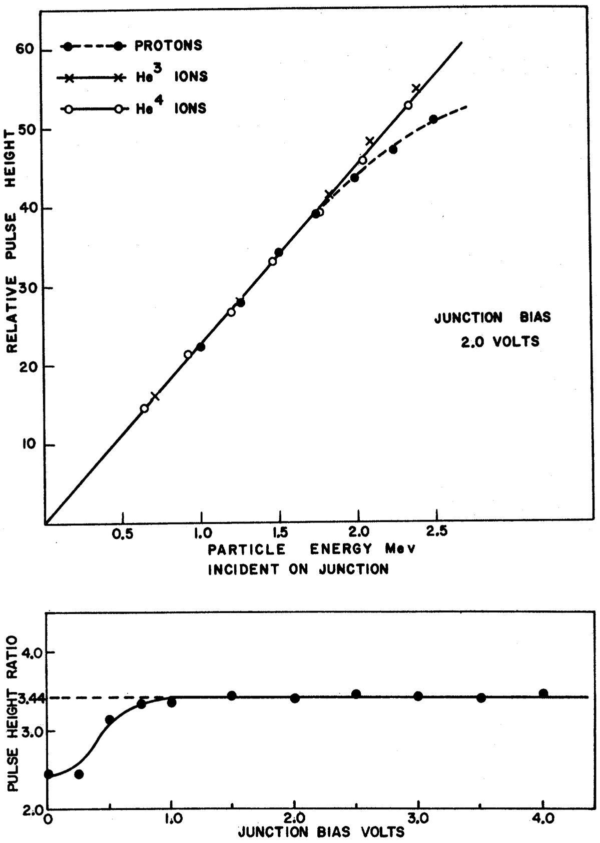

FIG. 1. (a) The junction response to protons, He^3 ions, and He^4 ions as a function of the energy of the incident particle. At the higher energies the proton range exceeds the effective junction thickness. (b) Pulse-height ratio, for 5.16-Mev alpha particles and 1.5-Mev protons, as a function of junction bias voltage. The energy ratio is 3.44.

The curve Fig. 1(b) is the pulse-height ratio (of 5.16-Mev alpha particles to 1.5-Mev protons) as a function of junction bias. As these particles have a range less than the junction thickness, the curve shows that the response is independent of particle specific ionization (i.e., pulse-height ratio is equal to the energy ratio) provided the junction bias is sufficient to prevent recombination. The decrease in the pulse-height ratio at low applied voltage is consistent with the greater electron-hole recombination in the denser alpha-particle ionization column.

At a given energy input the output pulse is independent of the junction temperature if, as the temperature is increased, the applied voltage is maintained constant, by increasing the quiescent series current, to avoid changing the junction capacitance. The noise, however, becomes serious at higher temperatures.

For a 2×2 mm junction at liquid nitrogen temperature Fig. 2 shows a charged particle spectrum, at 90° to the incident beam, from the reactions induced by 2.0-Mev He^3 ions on isotopically pure Li^7. This reaction was selected because it provided proton, deuteron, and alpha groups with energies ranging up to 11.3 Mev, 10.4 Mev, and 8.6 Mev, respectively, together with proton and effective deuteron continua extending downward in energy from ~8.4 Mev and ~7.5 Mev. A 2.73-mg/cm² Al foil was placed between the target and detector to absorb the elastically scattered He^3 ions. As expected the detector behaves as a thin ionization chamber; the groups labelled A, B, and C correspond to alpha particles which are stopped in the junction.

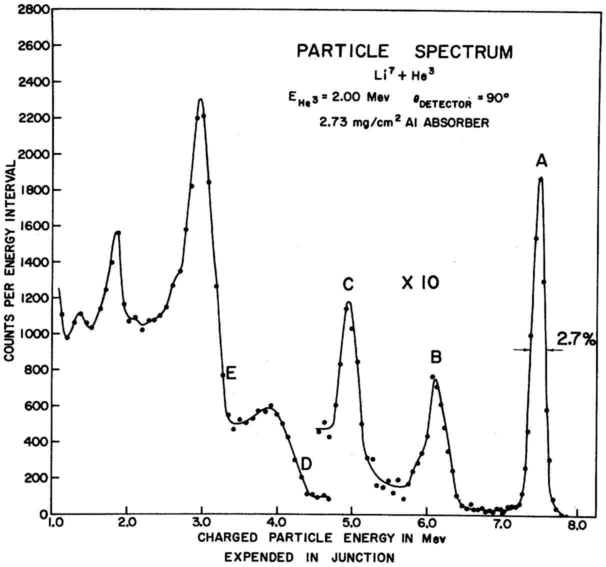

FIG. 2. Particle spectrum resulting from He^3 bombardment of an isotopically pure Li^7 target (100 μg/cm² on 0.020-in. tantalum). Peaks A, B, C correspond to alpha particles to the ground state and first two excited states of Li^6. The weaker alpha-particle group corresponding to the low-energy shoulder on peak B results from the prolific $F^{19}(p,\alpha)O^{16}$ reaction with the HHH^+ beam contaminant on the F^{19} target contamination. As discussed in detail in the text, the pulse-height steps at D and E correspond to deuterons and protons, respectively.

The steps at D and E correspond respectively to the maximum pulse heights obtainable from continua of incident deuterons and protons. This follows from the observations that with increasing absorber interposed between the target and detector, the steps individually remain fixed in pulse height, but decrease in intensity, until the absorber thickness is sufficient to reduce the particle energies below those corresponding to a range equal to the junction thickness. Beyond this point the pulse height decreases. The steps for this junction correspond to proton energies of 3.3 ± 0.1 Mev and deuteron energies of 4.4 ± 0.1 Mev giving an effective junction thickness of $(6 \pm 0.3) \times 10^{-3}$ cm in fair agreement with that obtained with the capacitance measurement. The indicated energy resolution for the highest energy alpha group is 2.7%. Using a Pu^{240} source, energy resolutions of 2% have been obtained. For these particles the energy resolution is not determined by the signal to noise ratio.

Simultaneous examination of natural alpha particles and elastically scattered proton beams has demonstrated that, for counting rates up to 5×10^4 counts/sec, the gain shift with counting rate is less than $\frac{1}{2}$%. By using a delay cable to reflect the leading edge the pulse rise time was found to be less than 3×10^{-9} sec. An approximate calculation, assuming a junction thickness of 6×10^{-3} cm and the published hole mobilities[5] in Ge at liquid nitrogen temperature, suggests a pulse rise time of 5×10^{-10} sec.

Although the measurements reported herein have been carried out with 2×2 mm junctions, a 10×10 mm unit has been tested but had decreased resolution due to increased noise. Further work is directed toward the problems of producing junctions of controlled thickness and to the examination of the characteristics of both Ge and Si crystals[6, 7] with other junction components.

Among the advantages which these detectors have for nuclear charged particle spectroscopy are the following: (a) fast pulse rise for coincidence applications; (b) the minimizing of vacuum problems both because of the low voltages involved and the elimination of the windows required in gas counters; (c) small geometric size for minimal scattering of associated radiation; (d) convenience in assembly of complex detection systems, for example, in the focal plane of high-resolution magnetic spectrographs; (e) stability both in time and under high counting rates; (f) insensitivity to both gamma radiation and neutrons; however, the addition of a B^{10} foil over the junction has permitted the detection of neutrons by the $B^{10}(n, \alpha)Li^7$ reaction.

We are indebted to Mr. R. J. Toone for his assistance in the measurements reported.

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NUCLEAR MAGNETIC MOMENT AND SPIN OF EUROPIUM-152m*

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Goldhaber, Grodzins, and Sunyar[1] have made a determination of the helicity of the neutrino by studying the decay of the 9.3-hour isomeric state of Eu^{152}. Their conclusions rest, in part, upon a knowledge of the spin and parity of this state. At the time their experiment was performed, the possible assignments for this state were considered to be 0^-, 1^-, and 1^+. Higher spin values were ruled out by the fact that the partial lifetime for the decay of the isomeric state to the spin 3 ground state of Eu^{152} was found to be greater than 5000 hours. From a study of the β-γ correlation in the decay of Eu^{152m} to Gd^{152}, Grodzins and Sunyar[2] have been able to rule out definitely the 1^+ assignment.

We have performed an atomic beam flop-in experiment with radioactive detection on Eu^{152m} in order to distinguish between the 0 and 1 assignments. A Eu^{152m} beam was formed by evaporating neutron-irradiated Eu metal from a tantalum oven at about 650°C. Detection was effected with sulfur-coated metal buttons. A Eu^{152m} resonance obtained at a field value of 1.4 gauss is shown in Fig. 1. Resonance curves have also been obtained at 0.8 and 1.0 gauss. The resonance frequency has been found to vary linearly with the field and to correspond to a Landé g factor of nearly 2.0. Woodgate[3] has found that $g_J = 1.994$ for europium. These observations show either that the spin of Eu^{152m} is zero or that if the spin were different from zero, the hfs splitting of the atomic ground state must be very small compared with 4 Mc/sec. If the spin were 1 or 2 and if the splitting were large, the apparatus would detect the transition $\Delta F = 0$, $m_F(-F \leftarrow -F+1)$ and a resonance would have occurred at the points marked 1 or 2 in Fig. 1. If the spin were different from zero and

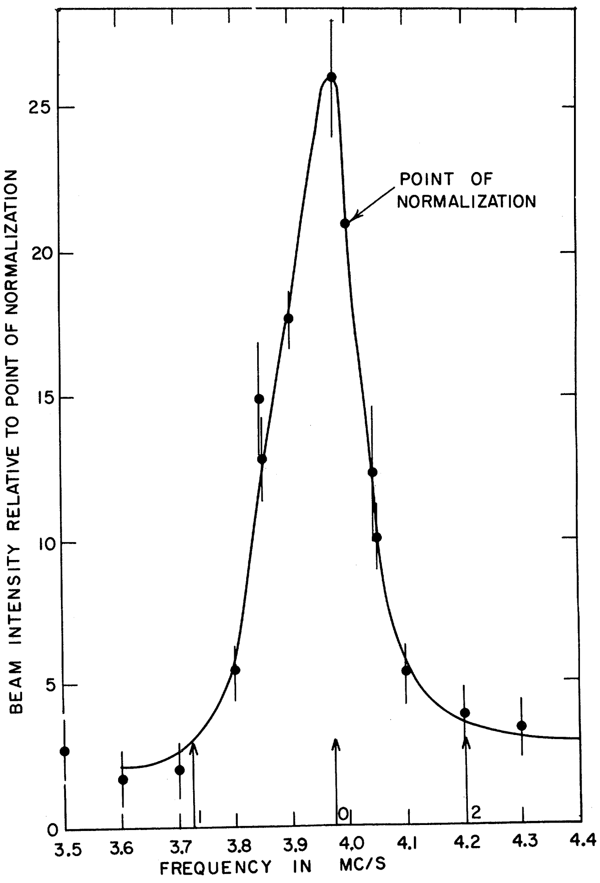

FIG. 1. Resonance curve obtained for Eu^{152m} at a field of 1.4 gauss. A counter background of about 9 cpm has been subtracted from all of the observations and the data have been corrected for decay. The beam intensity showed a steady decrease with time. Every fifth observation was taken at 4.0 Mc/sec and this information was used to normalize the points on the remainder of the curve.