MASS OF ^{8}He FROM THE FOUR-NEUTRON TRANSFER REACTION ^{26}Mg(α, ^{8}He)^{22}Mg†

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We wish to report the existence and mass of ^{8}He as determined from the four-neutron transfer reaction ^{26}Mg(α, ^{8}He)^{22}Mg. The accurate mass of ^{8}He may serve as a guide among the various[1-3] prescriptions which predict the many yet unobserved high-T states in the very light nuclei, while the development of a technique for measuring ^{8}He as a reaction product permits an exploration of nuclear masses bracketing the predicted[4] neutron-deficient edge of stability in the light elements (e.g., the masses of ^{12}O and ^{16}Ne—nuclei which are also candidates for double proton decay). While the present experiment was in progress, two other definite observations of the existence of ^{8}He were made. Cosper, Cerny, and Gatti[5] observed ~500 ^{8}He nuclei as third fragments in ^{252}Cf fission (~1 in 10^{6} fissions) utilizing counter telescope techniques similar to those described below, while Poskanzer, Esterlund, and McPherson,[6] in experiments with the Brookhaven Cosmotron, reported the decay properties and 122-msec half-life of ^{8}He.

It was first necessary to redetermine the masses of the ground and low excited states of ^{22}Mg since various systematics[7] implied that the reported data[8] were in error. By utilizing the reaction ^{24}Mg(p, t)^{22}Mg, the mass excess of ^{22}Mg was found to be -0.38 ± 0.05 MeV on the ^{12}C scale with excited states at 1.22 ± 0.03 and 3.24 ± 0.05 MeV.[9,10]

The Berkeley 88-inch cyclotron provided an analyzed beam of 80-MeV alpha particles which impinged on a ^{26}Mg target in an evacuated scattering chamber. Preliminary experiments indicated two problems which required an advance in particle-identifier technique. One was the necessity of identifying 32- to 36-MeV ^{8}He particles (depending on the correct mass prediction[1-3]) with a $d\sigma_{g.s.}$(lab) of ~50 nb/sr or about 1 ^{8}He per 10^{7} particles traversing a counter telescope. The other was the fact that the chance coincidence of an alpha particle and a deuteron traversing the telescope within the resolving time of the system can produce an energy loss and hence identification pulse almost identical to that of a ^{8}He particle, thereby introducing a difficult background problem.

The major features of the final system[11] are indicated in Fig. 1 and are as follows:

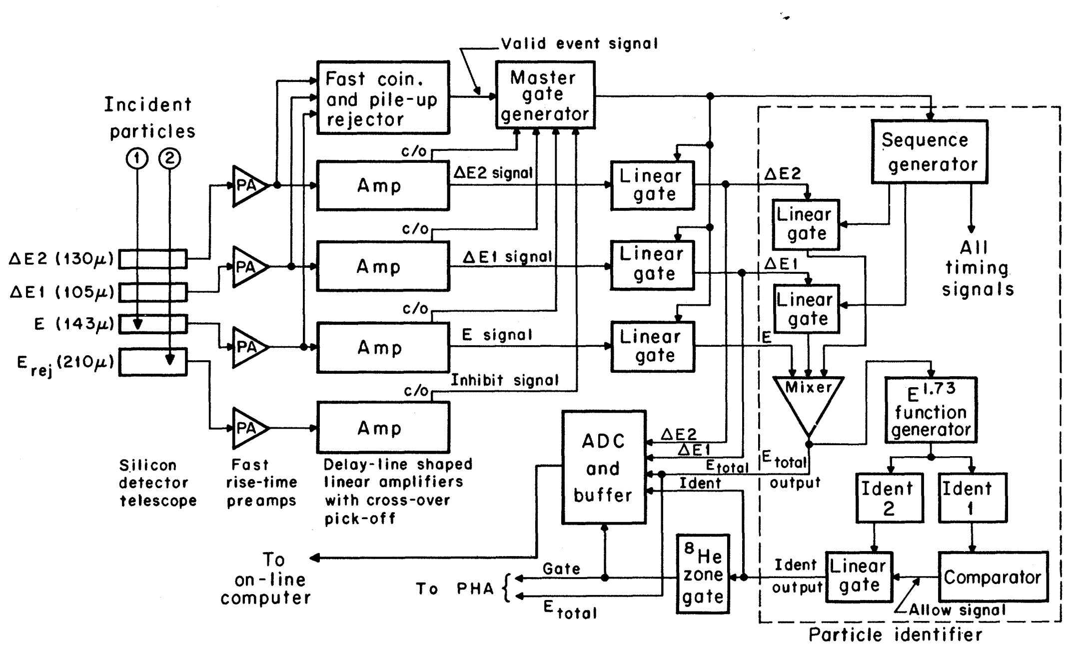

FIG. 1. An abbreviated block diagram of the electronic equipment.

(a) A three-counter system with two "ΔE" detectors denoted $\Delta E\,2$ and $\Delta E\,1$ is employed for identification in order to eliminate the events exhibiting abnormally high energy loss (Landau tail, blocking, etc.) or abnormally low energy loss (channeling, etc.) in a single ΔE detector and which would produce an incorrect identification pulse. To accomplish this, "Ident. 1" on Fig. 1 produces two identification pulses from our standard circuitry[12]; the first identification pulse is based on the $\Delta E\,2$ signal as the "ΔE" pulse and the sum of the $\Delta E\,1$ and E signals as the "E" pulse, while the second utilizes the $\Delta E\,1$ signal as "ΔE" and the E signal as "E." These identification pulses are normally proportional to the $\Delta E\,2$ and $\Delta E\,1$ detector thicknesses, respectively. The comparator measures the ratio of these pulses and an event is rejected if this ratio does not fall within prescribed fractional limits. In practice the great majority of "incorrect" identifications are eliminated while rejecting only 1 to 6% of the events. The final identification output ("Ident. 2") results from a third identification pulse, which utilizes the sum of $\Delta E\,2$ and $\Delta E\,1$ as its "ΔE" pulse.

(b) Fast coincidence techniques and a pile-up rejector system restrict all allowed events to within a single beam burst. Single-channel analyzers in the linear amplifiers allow signals only in the expected ^{8}He energy range.

(c) Detector thicknesses are selected to provide optimum operation only for the ^{8}He particles and a calibration group [here ^{7}Li from the reaction ^{26}Mg(α, ^{7}Li)^{23}Na]. A rejection detector removes all events (e.g., No. 2 on Fig. 1) passing through the counter telescope. Diffused Si transmission counters are used to obtain minimum window thicknesses throughout.

(d) As a final filter, all events in the ^{8}He region of the identifier are recorded in a small on-line computer which retains complete information on the $\Delta E\,2$, $\Delta E\,1$, E-total, and identifier signals. The computer also stores a pulser-simulated ^{8}He event every 12 minutes to check the entire system and provide an accurate measure of drifts. A monitor detector independently measures the beam-energy variation with time.

We wish to present the results of two runs

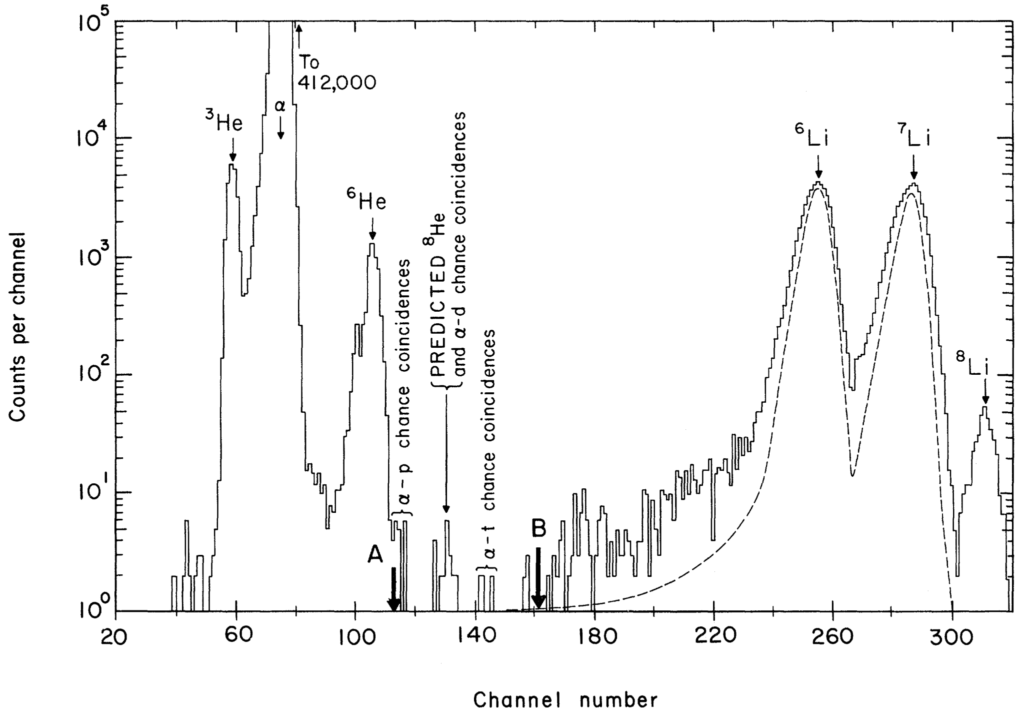

FIG. 2. A complete particle-identifier spectrum for Run 2. Single-channel analyzers were set such that only alpha particles of energy between 22.7 and 26.6 MeV were identified. Counts in the region between A and B were stored in the on-line computer. The dotted lines represent the complete particle-identifier spectrum of Run 1 for channels 150 and higher.

at 14 deg lab of length 52 hours (Run 1) and 60 hours (Run 2) and of alpha-particle energies 78.4 and 80.0 MeV, respectively. Run 2 will be considered in more detail since it employed the pile-up rejector and the on-line computer; otherwise, the runs were essentially identical. The complete particle-identifier spectrum for Run 2 is shown in Fig. 2 along with the spectrum for the region above ^{8}He from Run 1. The tailing on the ^{6}Li peak during Run 2, which was not present during Run 1 (dashed lines in Fig. 2), was due to relaxed single-channel-analyzer settings on $\Delta E2$ and $\Delta E1$ which permitted storage of ^{8}Li pulses as a further calibration but failed to reject ^{6}Li ions of marginal behavior. Complete data on particles whose identification pulse appeared in region A-B were stored in the computer and later analyzed in detail. This analysis revealed that no ^{6}Li ions were present in region A-B. Otherwise, this region encompassed the ^{8}He peak as predicted from range-energy systematics and most of two other peaks due to alpha-proton chance coincidences and alpha-triton chance coincidences, which simulate ^{7}He and ^{9}He particles, respectively. [^{7}He has been predicted to be particle unstable from calculations based on the $T=\frac{3}{2}$ states in mass seven,[13] and Ref. 5 places an upper limit for its emission in ^{252}Cf fission as <1 per 3000 ^{6}He fragments or <1 per 30 ^{8}He fragments. ^{9}He would not be expected to be stable on general systematics.] The observed alpha-proton and alpha-triton chance coincidences agreed within statistics with those predicted from the appropriate singles rates and led us to expect 12 ± 4 alpha-deuteron chance coincidences among the 26 events in the ^{8}He identifier peak. No significant grouping of the alpha-proton or alpha-triton energy spectra was observed.

Figure 3 presents energy spectra from both runs arising from the same identifier region. The energy range over which valid events could have been observed is indicated; no ^{8}He events from the minor target impurities (^{12}C, ^{16}O, ^{24}Mg) were energetically possible. The noticeable reduction of "background" events in Run 2 was due primarily to the pile-up rejector. Further, 8 of the 26 possible ^{8}He events in Run 2 can be excluded, having been shown through

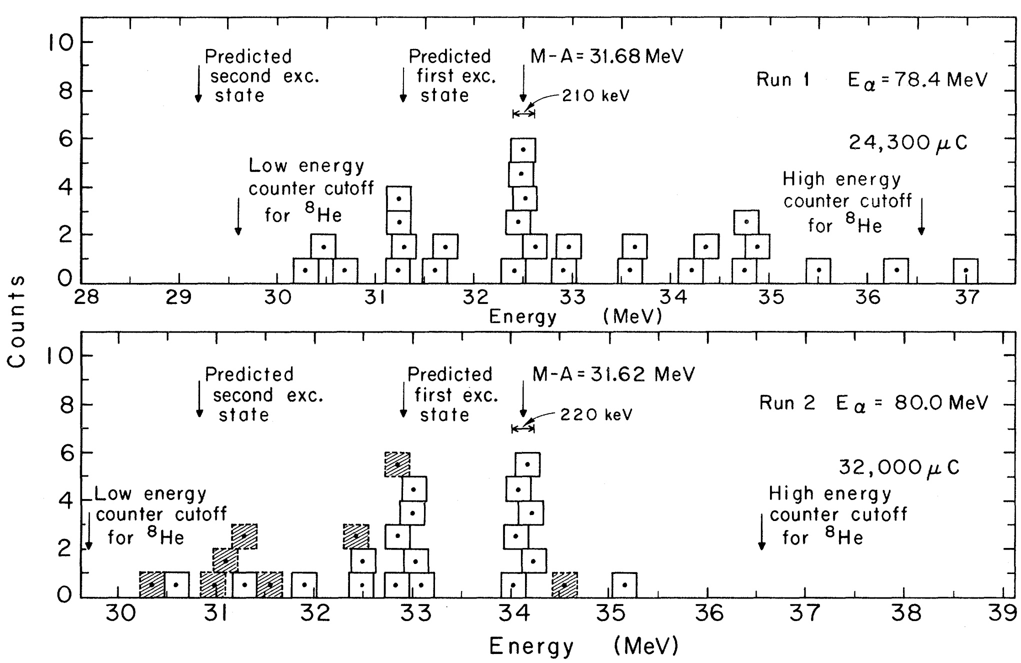

FIG. 3. The energy spectra from the reaction ^{26}Mg(α, ^{8}He)^{22}Mg at 14 deg for both Runs 1 and 2. The block width of each count corresponds to the expected full width of a ^{8}He peak, and the central dot represents the exact energy of each event. Shaded counts in the Run-2 spectrum can be excluded from consideration as true ^{8}He particles through an analysis of their energy losses in the ΔE detectors. The predicted ^{8}He energies for leaving ^{22}Mg in its first and second excited states are indicated.

analysis of their losses in the $\Delta E2$ and $\Delta E1$ detectors to be alpha-deuteron coincidences and not real ^{8}He nuclei. [Only some of the chance coincidences can be eliminated in this manner; the excluded events do not affect our mass arguments and are the shaded ones in Fig. 3.]

The last problem that must be discussed is the likelihood of obtaining distorted spectra from the presence of correlated alpha-deuteron coincidences from the breakup of any ^{6}Li* ions in the exit channel.[14] Only breakup of ^{6}Li ions excited to the 2.18-MeV level could be observed as correlated coincidences due to the restrictions imposed by kinematics, geometry, and detector thicknesses. Since the population of this level is not known, we assumed as an upper limit[15] that it is of the same order as the average ^{6}Li g.s. continuum cross section; with this assumption, at most three correlated alpha-deuteron coincidences would be present in the data of Run 2.

Figure 3 clearly indicates two ^{26}Mg(α, ^{8}He)^{22}Mg transitions common to the runs whose spacing is that between the ground and first excited states of ^{22}Mg. Run 1 could not have observed transitions to the second excited level of ^{22}Mg and Run 2 apparently did not; it is of interest that this second level is only weakly populated in the reaction ^{24}Mg(p, t)^{22}Mg at the observed forward angles. The ground-state peaks in both spectra agree in absolute value to 60 keV and determine a mass excess for ^{8}He of 31.65 ± 0.12 MeV on the ^{12}C scale. A mass excess of 32.4 $\pm$ 1.5 MeV for ^{8}He was calculated from the decay experiment of Poskanzer, Esterlund, and McPherson.[6] The lightest particle-unstable channel of ^{8}He is ^{6}He + $2n$ with a mass excess of 33.7 MeV.

Three theoretical predictions of the mass of ^{8}He are of current interest and that of Goldanskii[1] agrees best with these results. His prediction is based on the assumption that the pairing energy of the last two neutrons in ^{8}He is less than that in ^{6}He (2.86 MeV) and greater than that in ^{9}Li (2.02 MeV); based on the ^{7}He mass calculated in Ref. 13, a mass excess for ^{8}He of 32.0 ± 0.4 MeV would be predicted. The expression of Garvey and Kelson[2] predicts $29.7^{+\sim1.5}_{-\sim0.5}$ MeV, while Jänecke's systematics[3] predict $34.2 \pm \sim 2$ MeV.[16]

Of the light nuclei whose existence is related to the mass of ^{8}He,[17] only[18] the tetraneutron remains as possibly particle stable. Our measured ^{8}He mass and the observed β decay[6] require a binding energy of less than 3.06 ± 0.12 MeV for ^4n. Tang and Bayman[19] summarize the experimental status of ^4n and can calculate no bound state.

The experimental technique reported herein now makes possible the exploration of the neutron-deficient edge of particle stability in the lighter elements from (α, ^{8}He) transitions. Masses of $T_z = -2$ nuclei such as ^{12}O, ^{16}Ne, ^{20}Mg, etc., are additionally of interest since they will permit a further test of the isobaric-multiplet mass equation.

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[7]We wish to thank Paul C. Rogers for first bringing this to our attention.

[8]F. Ajzenberg-Selove, L. Cranberg, and F. S. Dietrich, Phys. Rev. 124, 1548 (1961).

[9]We wish to thank Gerald T. Garvey for participating in this measurement.

[10]This ^{22}Mg mass compares well with measurements of -0.33 ± 0.03 MeV (private communication, R. W. Kavanagh) and -0.34 ± 0.05 MeV (private communication, W. Whaling and C. Moss).

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[13]C. Détraz, J. Cerny, and R. H. Pehl, Phys. Rev. Letters 14, 708 (1965).

[14]No contribution from ^{6}Li g.s. dissociation, as reported by R. W. Ollerhead, C. Chasman, and D. A. Bromley, Phys. Rev. 134, B74 (1964), is possible.

[15]The population of the ^{7}Li*(0.478 MeV) level is at

most one-third that of the ^{7}Li g.s. in $(\alpha, {}^7\text{Li})$ reactions induced on light targets at these beam energies.

[16]It is of interest to note that Jänecke's prediction of 15.9 ± 2 MeV for $\Delta T_{3/2,1/2}$ in mass seven also does not agree with the experimental value (see Ref. 13) of 10.96 ± 0.22 MeV.

[17]A. I. Baz, V. I. Goldanskii, and Ya. B. Zeldovich, Usp. Fiz. Nauk 85, 445 (1965) [translation: Soviet Phys.–Usp. 8, 177 (1965)].

[18]If we use the result of J. Cerny, C. Détraz, and R. H. Pehl, Phys. Rev. Letters 15, 300 (1965), that ^{4}H is unbound by 2 MeV, then Goldanskii's systematics (see Ref. 1) also preclude the existence of ^{5}H, which is in accord with experiment.

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RENORMALIZATION OF THE STRANGENESS-CHANGING AXIAL-CURRENT COUPLING CONSTANT

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Recently, several authors have computed the renormalization of the axial-vector coupling constant in strangeness-preserving β decay,[1,2] and strangeness-changing β decay,[3] using the method proposed by Fubini and Furlan.[4]

In the case of the strangeness-changing β decay, the calculation was carried out by taking the matrix element of the commutator of the V-spin lowering and raising operators, between physical proton states, and isolating the contributions from the possible one-particle intermediate states. In this case, as there are two possible one-particle intermediate states, namely the Λ and the Σ^0, one only obtains results for a combination of the coupling constants of the Λ and the Σ^0. The purpose of this note is to show how to separate the contribution of the Σ from that of the Λ.

Our assumptions are essentially those made in Refs. 1, 2, and 3, namely: (I) The hadronic current which is responsible for the leptonic weak decays is of the form

$$J_\lambda = G_v^{\,0} V_\lambda^{\,I_+} + G_v^{\,0s} V_\lambda^{\,K_+} + G_A^{\,0} A_\lambda^{\,I_+} + G_A^{\,0s} A_\lambda^{\,K_+}; \qquad (1)$$

our notation is the same as that in Ref. 3. (II) The space integrals of the time components of the vector and axial-vector currents generate at equal times the algebra $SU(3)\otimes SU(3)$, and obey its commutation relations. From these we will use the relation

$$[F_5^{\,K_+}(t), F_5^{\,K_-}(t)] = Q + Y, \qquad (2)$$

where Q and Y denote the total charge and hypercharge operators, respectively. (III) Our next assumption is that of generalized partial conservation of axial-vector current (PCAC),[5] namely,

$$\partial_\mu A_\mu^{\,i} = (m_i^{\,2}/2f_i)\varphi_i. \qquad (3)$$

Here φ_i is the ith component of the renormalized wave function of the meson octet, m_i^2 the square of its mass, and f_i is a parameter related to its decay.[5]

We define the renormalized coupling constant by taking the matrix element of (1) between any two physical baryon states:

$$\langle B_2(q_2)|A_\lambda|B_1(q_1)\rangle = \left(\frac{M_{B_1}M_{B_2}}{E(q_1)E(q_2)}\right)^{1/2} \frac{G_A^{\,B_1B_2}}{G_A^{\,0}} \bar{U}_{B_2}(q_2)\gamma_\lambda\gamma_5 U_{B_1}(q_1). \qquad (4)$$

The method of calculation is similar to that used in Refs. 1, 2, and 3. The one difference is that we compute the matrix element of (2) between two physical neutrons and not between protons:

$$\langle n(q_2)|[F_5^{\,K_+}(t), F_5^{\,K_-}(t)]|n(q_1)\rangle = \delta^{(3)}(q_2 - q_1). \qquad (5)$$

On introducing a complete set of states in the left-hand side of (5), we have only one possible one-particle intermediate state, namely the Σ^-, which we isolate.

The rest of the calculation is carried out in the same manner as in Refs. 1, 2, and 3, and we get an expression for the renormalized coupling constant in terms of total cross sections