the $f_{7/2}$ level to be full, while in reality excitations can very easily take place from this level to the $f_{5/2}$, $p_{3/2}$, and $p_{1/2}$ levels, the use of t-matrix elements with the inclusion of core-polarization effects was very vital. Such matrix elements to be used in the Ni region have recently been reported by Kuo.[8] Unfortunately, the HJ t-matrix elements used in our present work were deficient in this respect, and hence the inadequacy of the HJ potential, found here, is not surprising. Kuo's matrix elements have been already used by Lawson *et al.*[7] to perform the calculation for all Ni isotopes. A similar remark is true about the Tabakin potential, for a different reason. It has been shown[15] recently that there is a fairly significant second-order contribution to the Tabakin matrix elements for shell-model work. Our work, as reported here, did not use these additional contributions.

[15] M. K. Pal, J. P. Svenne, and A. Kerman, in Proceedings of the International Conference on Nuclear Physics, Oak Ridge National Laboratory, 1966 (unpublished).

ACKNOWLEDGMENTS

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Energies and Decay Modes of Ne^{19} States: Energies of First Excited States of Ne^{21}, Na^{21}, and Mg^{22}†

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The energies and γ-decay modes of the lowest six energy levels of Ne^{19} were investigated with the aid of Ge(Li) and NaI(Tl) γ-ray detectors. Ne^{19} levels were populated by the $Ne^{20}(He^3,\alpha)Ne^{19}$ reaction. Measurements were made of the energies of the first excited states of Ne^{21}, Na^{21}, and Mg^{22}. These states were also formed by reactions initiated by $Ne^{20}+He^3$.

I. INTRODUCTION

We have already described[1] an investigation of the low-lying levels of Na^{22} using the reaction $Ne^{20}(He^3,p)Na^{22}$ ($Q=+5.783$ MeV) at bombarding energies between 5.0 and 7.0 MeV. At the incident He^3 energies used in this work, four further nuclides could be formed by the following reactions[2]:

$$Ne^{20}(He^3,\alpha)Ne^{19},\quad Q=+3.702\text{ MeV}$$
$$Ne^{20}(He^3,2p)Ne^{21},\quad Q=-0.958\text{ MeV}$$
$$Ne^{20}(He^3,d)Na^{21},\quad Q=-3.047\text{ MeV}$$
$$Ne^{20}(He^3,n)Mg^{22},\quad Q=+(165\pm30)\text{ keV}.$$

γ rays resulting from all four of these reactions, as well as those from the $Ne^{20}(He^3,p)Na^{22}$ reaction, were observed using Ge(Li) and NaI(Tl) γ-ray detectors. For the bound states of Ne^{19}, we were able to determine accurate values for the excitation energies and also the major γ-ray decay modes. The energies of the first excited states of the nuclei Ne^{21}, Na^{21}, and Mg^{22} were also determined.

II. EXPERIMENTAL PROCEDURE AND RESULTS

γ rays from the He^3 bombardment of Ne^{20} were observed using an 8-cc Ge(Li) detector placed at 90° to the beam and 5.6 cm from the gas target. A beam energy of 6.6 MeV gave an effective bombarding energy of 6.3 MeV when allowance was made for the energy loss in the Ni entrance foil of the gas target. Enriched Ne^{20} gas at a pressure of $\frac{1}{3}$ atm was used.[3] The length of gas traversed by the beam was 2 cm, while the beam current was 3 nA. The singles Ge(Li) spectrum was accumulated using a 4096-channel analog-to-digital converter which

† Work performed under the auspices of the U. S. Atomic Energy Commission.
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[2] T. Lauritsen and F. Ajzenberg-Selove, *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences–National Research Council, Washington 25, D. C., 1961), NRC 61-5, 6; P. M. Endt and C. Van der Leun, Nucl. Phys. **34**, 1 (1962); J. H. F. Mattauch, W. Thiele, and A. H. Wapstra, *ibid.* **67**, 1 (1965); A. Gallmann, G. Frick, E. K. Warburton, D. E. Alburger, and S. Hechtl, Phys. Rev. (to be published).
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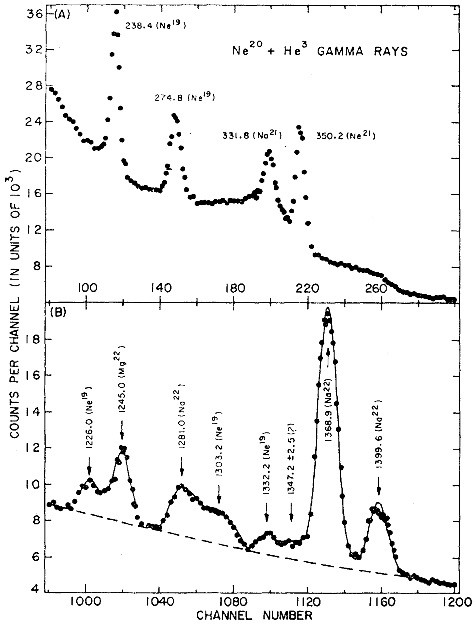

FIG. 1. Partial spectrum, measured with an 8-cc Ge(Li) detector at 90° with respect to the beam direction, of γ rays resulting from the He^3 bombardment of Ne^{20}. The full-energy-loss peaks of the γ rays are labeled by their energies (in keV) and by the nucleus to which they are assigned. The width of the full-energy-loss peak for an unbroadened 1.27-MeV γ ray under the conditions of the present experiment was 5.2-keV full-width-at-half-maximum (FWHM). The γ-ray peaks shown in Fig. 1(b) are all broader than this with peak widths varying from 10-to 16-keV FWHM. This is expected since the reactions leading to these levels are all exothermic and the lifetimes of the initial levels involved are all known or are expected to be shorter than the stopping time for the recoiling heavy ion in the Ne gas ($\sim 10^{-10}$ sec). In Fig. 1(b), the energies were found by fitting Gaussian peaks to the experimental line shapes after first subtracting a straight-line background. The results of this fitting together with the assumed background are shown in the figure.

was digitally stabilized. Sections of this spectrum, which are of particular interest for the present work, are shown in Fig. 1. The energy scale was calibrated by the use of radioactive sources (Na^{22}, Mn^{54}, and Ra-Th) which provided a range of accurately known γ-ray energies[4,5] from 238 to 2614 keV. Further calibration energies were also provided by γ rays resulting from He^3-induced reactions on impurities (chiefly carbon and oxygen) and γ rays resulting from the He^3 bombardment of air which was introduced into the target cell after evacuation of the neon. Accurate values for the energies of these reaction-produced γ rays were obtained from the work of Chasman, Jones, Ristinen, and Alburger.[6]

We ascribe five of the γ rays shown in Fig. 1 to transitions between levels in the Ne^{19} nucleus. Three other γ rays have previously been identified with transitions between excited states of Na^{22}. The three remaining lines are ascribed to γ rays de-exciting the first excited states of the nuclei Ne^{21}, Na^{21}, and Mg^{22}. Thus γ rays arising from all five reactions mentioned in the introduction can be identified with lines in Fig. 1. Table I lists the measured energies of the γ rays discussed above together with previous energy measurements. γ rays ascribed to the decay of the Ne^{19} level at 2.776 MeV and the Na^{22} level at 2.571 MeV are also included along with previous energy determinations for all the γ rays. The agreement between the energies measured in the present work and previous determinations is in all cases good. For those transitions in Ne^{19}, Na^{21}, Ne^{21}, and Mg^{22}, the values obtained in the present work have smaller uncertainties than the results from previous measurements. For Na^{22} they are not as accurate as, but agree well with, the best previous values. Table II gives the energies of the bound states of Ne^{19} which are deduced from the γ-ray energies of Table I, together with the previous values for these energies. For Ne^{19} the major decay modes assigned in Table I were also checked by NaI(Tl)-NaI(Tl) and NaI(Tl)-Ge(Li) γ-γ coincidence experiments. The partial spectra shown in Fig. 2 were obtained from a two-parameter analysis of γ-γ coincidences observed when Ne^{20} was bombarded with 6.1-MeV He^3 particles. The detectors were 3×3-in. and 5×5-in. NaI(Tl) crystals placed opposite each other and at 90° to the beam. Figure 2(a), representing the γ-ray spectrum observed in the 5×5-in. crystal, shows clearly the decays of the 1.54- and 2.78-MeV levels of Ne^{19} to the 0.238-MeV level, while the decays of the 1.50- and 1.61-MeV levels are shown to be in coin-

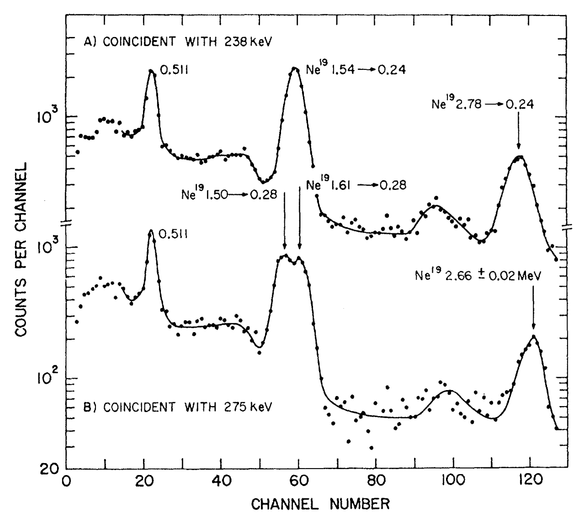

FIG. 2. Partial results of a 2-parameter analysis of γ-γ coincidences resulting from bombardment of a Ne^{20} gas target with a 6.1-MeV He^3 beam. The plots show the γ-ray spectra measured by a 5×5-in. NaI(Tl) detector in coincidence with full-energy-loss peaks of (a) 238-keV γ rays and (b) 275-keV γ rays as seen by a 3×3-in. NaI(Tl) detector. The full-energy-loss peaks of the Ne^{19} γ rays are identified by the energies of the initial and final states between which the transition occurs. The exception is for the peak at 2.66 MeV [in (b)] which is assigned to the Ne^{19} 4.15 → 1.50 transition.

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TABLE I. γ-ray energies from $Ne^{20}+He^{3}$.

Transition (keV)	Energy (keV) Present	Previous	Reference[a]
Ne^{19} 238 → 0	238.4±0.3	241.2±2.5	b,c,d
Ne^{19} 275 → 0	274.8±0.3	276.1±2.7	b,c,d
Na^{21} 332 → 0	331.8±0.3	342 ±13	e,f
Ne^{21} 350 → 0	350.2±0.3	350.2±0.8	g
Ne^{19} 1501 → 275	1226.0±1.1	(1231 ±5)	h
Mg^{22} 1245 → 0	1245.0±0.6	1240 ±20	i
Na^{22} 1937 → 657	1281.0±1.1	1279.9±0.2	j,k
Ne^{19} 1542 → 238	1303.2±1.1	(1300 ±4)	h
Ne^{19} 1607 → 275	1332.2±1.1	(1337 ±5)	h
Na^{22} 1952 → 583	1368.9±0.3	1368.7±0.3	k
Na^{22} 1984 → 583	1399.6±1.1	1400.4±0.5	k
Ne^{19} 2776 → 238	2537.2±3.4	(2540 ±15)	h
Na^{22} 2573 → 0	2573.0±3.4	2571.2±0.3	k

[a] The previous results are computed as the weighted averages of values given in the cited references.
[b] J. B. Marion, T. W. Bonner, and C. F. Cook, Phys. Rev. **100**, 91 (1965).
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cidence with the 275-keV γ ray corresponding to the $0.275 \rightarrow 0$ transition [Fig. 2(b)]. The γ ray labeled with its energy only is assigned to the decay of the unbound Ne^{19} 4.152-MeV level[7] to the 1.50-MeV level since this γ ray was also observed to be in coincidence with the Ne^{19} $1.50 \rightarrow 0.275$ transition. These γ-γ measurements thus confirm the assignments made on the

TABLE II. Energies of low-lying states of Ne^{19}.

This work (keV)	Previous (keV)
238.4±0.3	241.2±2.5[a]
274.8±0.3	276.1±2.7[a]
1500.8±1.2	1506.0±5.0[b]
1541.6±1.2	1538.0±4.0[b]
1607.1±1.2	1612.0±5.0[b]
2775.8±3.4	2778.0±15.0[c]
4160.0±20.0	4152.0±15.0[c]

[a] See Refs. a–d of Table I.
[b] J. Freeman and D. West, Nucl. Phys. **38**, 89 (1962).
[c] Reference 7.

[7] M. W. Greene and E. B. Nelson, Phys. Rev. **153**, 1068 (1967).

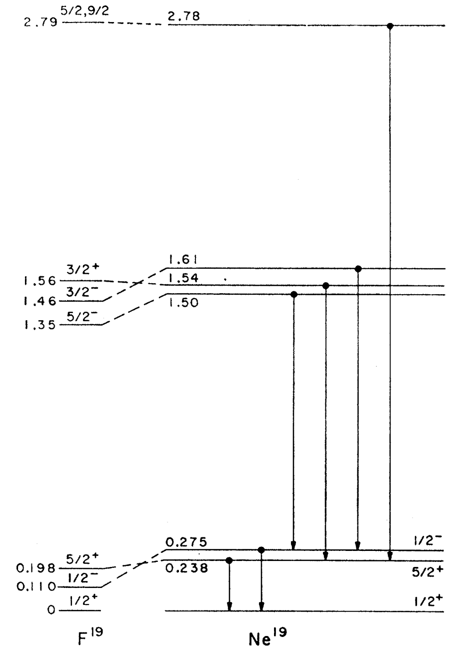

FIG. 3. The energy levels and decay modes of the bound states of Ne^{19}. The energy levels of the mirror nucleus F^{19} are displayed for comparison at the left of the figure. The F^{19} information is from Refs. 2 and 7. The correlation of the mirror levels in the ~1.5-MeV triplet is discussed in the text. All excitation energies are given in MeV.

basis of the singles γ-ray spectra observed in the Ge(Li) detector.

For the triplet of Ne^{19} levels at 1.5 MeV it is expected by comparison with F^{19} that there are minor decay modes which are of the order of 10% for two of the levels. We have not been able to put any meaningful limits on these expected transitions. Figure 3 gives a summary in the form of an energy-level and γ-decay diagram of the results which we have obtained in the present work. It has been known for some time that the ordering of the low-lying $\frac{1}{2}^-$ and $\frac{5}{2}^+$ levels is reversed[2] in going from F^{19} to Ne^{19}. For the triplet of levels at 1.5 MeV, a comparison of the decay modes and energies between F^{19} and Ne^{19} allows the tentative identifications of Fig. 3 to be made. It is thus probable that in Ne^{19} the levels at 1.50, 1.54, and 1.61 MeV are, respectively, $\frac{5}{2}^-$, $\frac{3}{2}^+$, and $\frac{3}{2}^-$. In this case again, in going from F^{19} to Ne^{19}, the even-parity level has moved down with respect to the odd-parity levels.