A NEW ENERGY LEVEL IN ^{20}Ne AT 10·31 MeV

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Summary

Neutron–gamma-ray coincidence measurements have been made in the reaction ^{19}F(d,nγ)^{20}Ne at bombarding energies between 500 and 700 keV. Time-of-flight determination of neutron energy indicates a new energy level in ^{20}Ne at $10\cdot31\pm0\cdot07$ MeV. From angular distributions of the neutrons, and observation of the gamma-decay spectrum of the 10·31 MeV state, spin and parity of 1^+ are inferred for this state.

I. Introduction

Pearson and Spear (1961) have reported a level in ^{20}Ne at 10·27 MeV in their studies of the reaction ^{16}O(α,γ)^{20}Ne. From consideration of angular correlations and partial widths they give this level the assignment 2^+, $T = 1$. Davis, Mehta, and Hunt (1961) have reported a level at 10·30 MeV in their investigation of elastic scattering of alpha-particles by ^{16}O. Angular distribution measurements on the scattered alpha-particles lead them to the assignment 5^- for this level. For both these reactions conservation of angular momentum and parity restrict observations in ^{20}Ne to levels of natural parity, i.e. 0^+, 1^-, 2^+, 3^-, etc.

On the other hand, for excited states in ^{20}Ne between the thresholds for alpha emission to the ground and second excited states of ^{16}O, i.e. between 4·75 and 10·9 MeV, the reaction described here, ^{19}F(d,nγ)^{20}Ne, virtually restricts observations to ^{20}Ne levels of unnatural parity, i.e. 0^-, 1^+, 2^-, 3^+, etc. This is because, for these levels, gamma widths are full widths since alpha emission is forbidden and no other mode of decay is energetically possible, whereas for levels of natural parity the gamma width is only a very small fraction of the full width, the overwhelmingly dominant mode of decay being alpha emission. Hence the level reported here at 10·31 MeV is a different state from either of those reported previously.

It is true that this argument ignores the effects of isotopic spin in inhibiting alpha emission from $T = 1$ levels, but if the $T = 1$ assignment of Pearson and Spear is correct, then the isotopic spin selection rules are not operating strongly at this excitation.

II. Experimental Arrangements and Results

A target consisting of 120 μg/cm^2 of SrF_2 deposited on a copper backing was bombarded by a 650 keV deuteron beam from the Melbourne 1 MeV electrostatic generator, and observations were made on neutrons and gamma-rays emitted.

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(a) *Neutron Energy Measurement*

Neutron energy was measured by a time-of-flight technique using two scintillation counters. The neutron detector consisted of a 3 in. by 2 in. plastic phosphor (Naton 11) mounted on an EMI 9536A photomultiplier and was placed at a measured distance from the target in the 0° direction. The gamma detector consisted of a $1\frac{1}{2}$ in. by 1 in. NaI(Tl) phosphor mounted on an RCA 6342 photomultiplier and was placed close up to the target in the 90° direction. This detector provided the "go" signal for a neutron by recording the gamma-ray emitted in the decay of the ^{20}Ne state which was produced by the emission of the neutron.

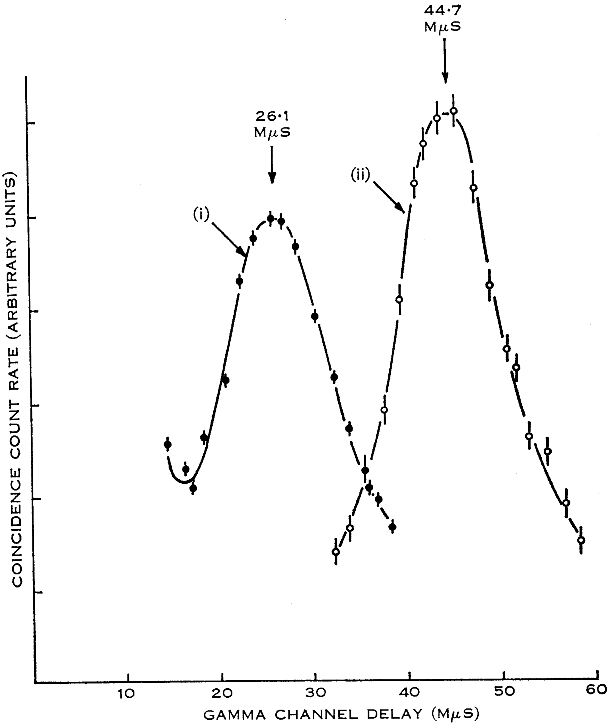

Fig. 1.—The delay distributions. Curve (i) is for a neutron flight path of 24·0 cm and curve (ii) for a flight path of 49·0 cm.

The outputs of both counters were fed into a Harwell type 1153A fast-slow coincidence unit (resolving time 5 mμs) and the coincidence count rate observed as a function of delay inserted in the gamma channel. Because of uncertainty in the zero of the variable delay the observations were repeated with a different flight path and the neutron energy obtained from the differences in flight paths and flight times.

The two delay distributions are shown in Figure 1. From these data a neutron energy of $0 \cdot 94 \pm 0 \cdot 07$ MeV is obtained, which gives a ^{20}Ne excitation energy of $10 \cdot 31 \pm 0 \cdot 07$ MeV. No other neutron group was observed in the range of neutron energy the experimental arrangement was suited to detect, namely, 0·5–4 MeV.

(b) *Gamma-Ray Energy Measurement*

The spectrum of gamma-rays involved in the decay scheme of the ^{20}Ne excited state was obtained by using the output of the coincidence unit to gate the pulses taken from the seventh dynode of the gamma detector. Thus only pulses from gamma-rays involved in coincidences passed through the gate and were analysed by a TMC 256 channel kicksorter.

The spectrum obtained is shown in Figure 2. The figure shows a clean $4 \cdot 61 \pm 0 \cdot 07$ MeV gamma energy with only the two-quantum escape peak showing out clearly. There are other lower energy gamma-rays also, but these could not be resolved. There was no sign of any gamma-ray of energy greater than $4 \cdot 61$ MeV.

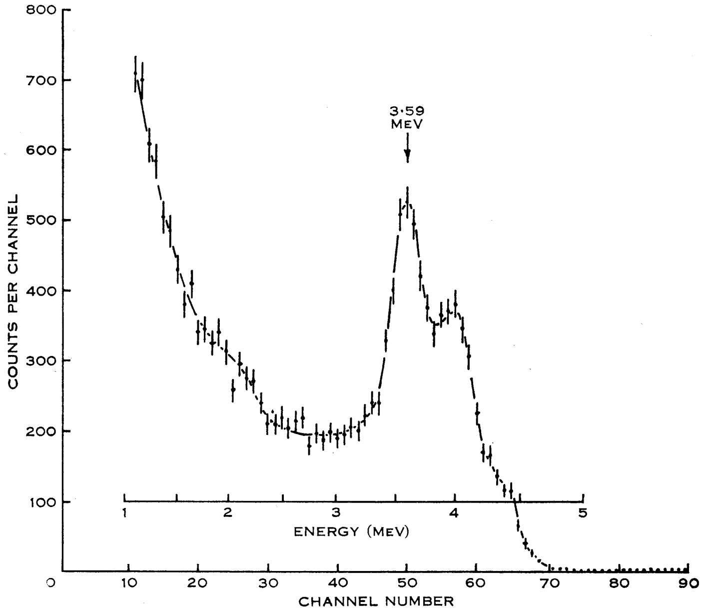

Fig. 2.—Gamma-ray spectrum from the $10 \cdot 31$ MeV state.

Calibration of the energy scale was provided by the $2 \cdot 62$, $4 \cdot 43$, and $6 \cdot 13$ MeV gamma-rays from RdTh, a Po-Be source, and the ^{19}F(p,$\alpha\gamma$)^{16}O reaction respectively.

(c) *Neutron Angular Distributions*

Any angular-dependent measurement made with this experimental arrangement is essentially a triple correlation. However, if the gamma counter is placed directly below the target and close enough to subtend a solid angle of 2π steradians, and the neutron counter is moved around in the horizontal plane, what is obtained is in fact an angular distribution of the neutrons. The ideal of 2π solid angle for the gamma counter could not in fact be realized, but by placing the counter close up to the target it was possible to approach sufficiently close to this ideal to make the measurement essentially an angular distribution.

Angular distributions were measured at incident energies of 500, 550, 600, 650, and 700 keV by working with the gamma-channel delay set at the value appropriate to the centre of the delay distribution peak. The results of these measurements are shown in Figure 3.

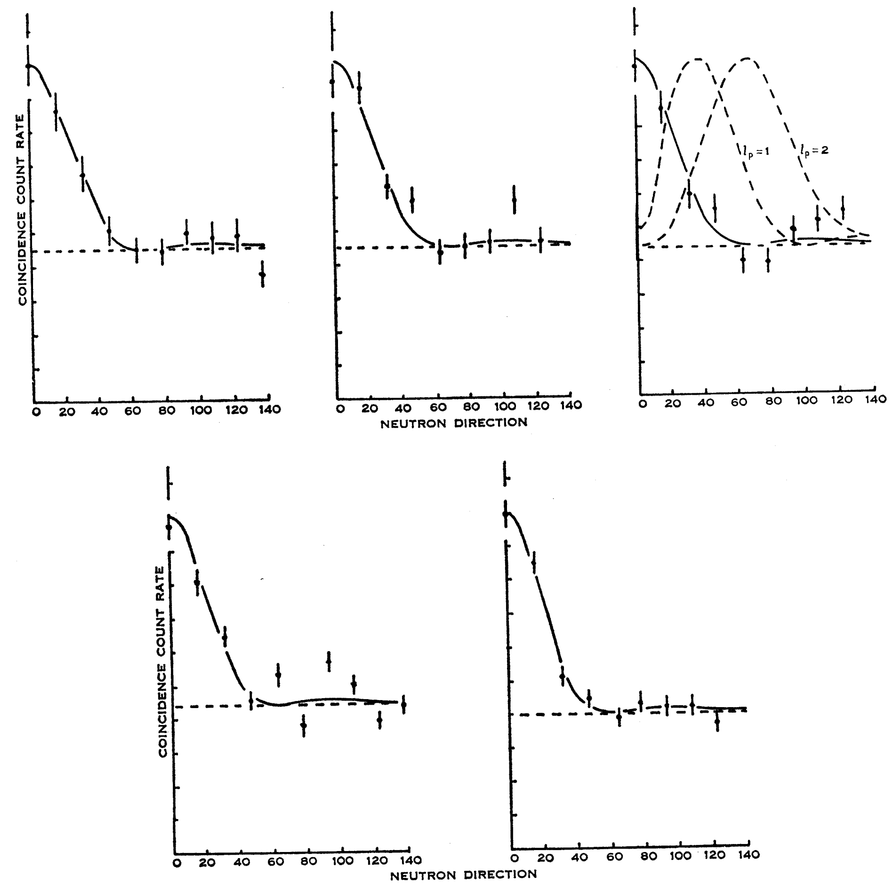

Fig. 3.—Angular distributions of neutrons for incident deuteron energies of 500, 550, 600, 650, and 700 keV. The curves are calculated from Butler stripping theory with $l_p = 0$ unless otherwise labelled.

(*d*) *Excitation Function*

The excitation function, shown in Figure 4, was measured using the same experimental arrangement as for the angular distributions. With the neutron detector in the 0° direction and over a range of incident energies from 500 to 700 keV, covered in steps of 20 keV, no structure is apparent.

III. Discussion

The forward peaking of the angular distributions is strongly suggestive of direct interaction, though a suitable mixture of compound nuclear states could also produce a similar result. However, if the forward peaking were produced by a compound nucleus interaction, it would be expected that the form of the distribution would be very sensitive to changes of bombarding energy, since it would depend criticially on the mixture of compound nuclear states involved. The fact that the form of the distribution is essentially unchanged over the full range of bombarding energies used, and the lack of structure in the excitation function are then strongly indicative of direct interaction.

Since the Q-value of the reaction, $0 \cdot 3$ MeV, is small, it was considered reasonable to analyse the angular distributions by means of Butler stripping theory as proposed

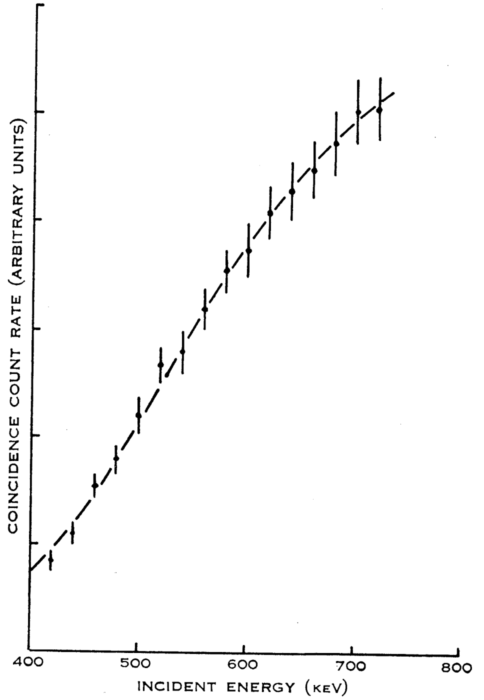

Fig. 4.—The excitation function.

by Wilkinson (1958). If the calculated stripping patterns were stood on an isotropic background of about 40% of the forward intensity, good fits were obtained for $l_p = 0$ and effective nuclear radius $r_0 = 11 \cdot 8$ by 10^{-13} cm in all cases.

If the $l_p = 0$ assignment is accepted for the stripping component of the reaction, the parity of the $10 \cdot 31$ MeV state in ^{20}Ne is fixed as positive and the spin as 0 or 1, since ^{19}F has spin and parity $\frac{1}{2}^+$. Since it is expected that only levels of unnatural parity would be observed in this reaction, the most likely assignment is 1^+.

As there is no evidence in the gamma spectrum for the decay scheme of any of the ^{20}Ne states below the $5 \cdot 63$ MeV level, with intensity comparable to that of the $4 \cdot 61$ MeV gamma-ray observed, it is concluded that this gamma-ray cannot be the second part of a gamma-gamma cascade, but is in fact a direct transition to either the $5 \cdot 63$ or $5 \cdot 80$ MeV level. Both these levels are of natural parity and, since they lie above the threshold for alpha emission, their decay would not be expected to contribute significantly to the observed gamma spectrum. The possibility that the transition is to the 5·63 MeV state may be ruled out, since this is a 3^- state whereas the 5·80 MeV state is 1^-. Thus the transition is identified as $E1$ rather than $M2$.

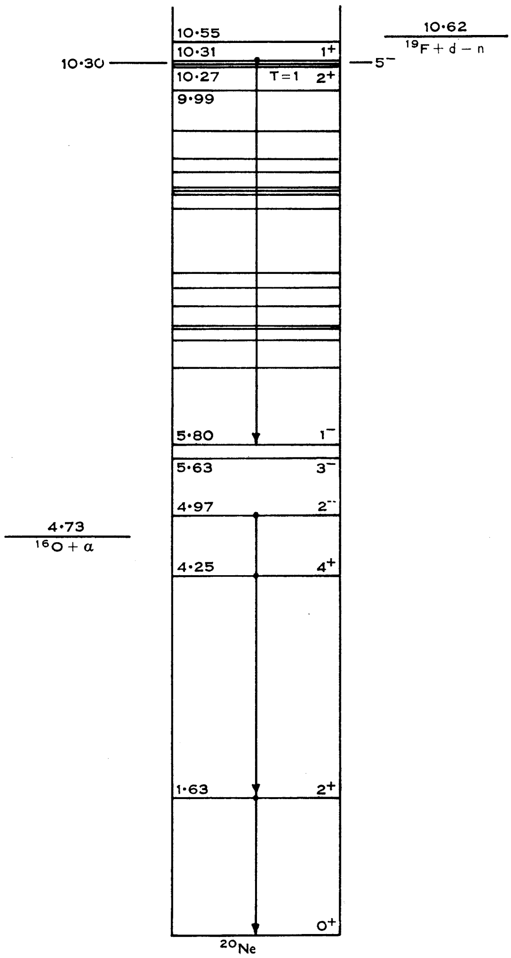

Fig. 5.—Energy-level diagram of ^{20}Ne, showing the decay scheme of the low-lying levels and the identification of the observed 4·61 MeV gamma-ray.

Furthermore, it is necessary to account for the fact that no decay is seen to the 4·97 MeV 2^- state. This level is placed in the same rotational band as the 5·63 MeV level by Litherland *et al.* (1960), so it may be expected to have the same intrinsic structure as the 5·63 MeV level. Hence, if the observed transition were to the 5·63 MeV level, the absence of the higher energy transition could be accounted for only by assuming a spin of at least 4 for the 10·31 MeV state, and this may be ruled out, since it would call for an angular momentum transfer of at least 3 in the direct interaction.

On the assumption that the $10 \cdot 31$ MeV state is 1^+ and the observed gamma transition is $E1$ to the $5 \cdot 80$ MeV 1^- level, the absence of the $E1$ transition to the $4 \cdot 97$ MeV 2^- level may be understood, since the $4 \cdot 97$ and $5 \cdot 80$ MeV states are in different rotational bands and may have very different intrinsic structures. The same explanation may be given for the absence of the $M1$ ground state transition. The relevant portion of the ^{20}Ne energy level diagram is shown in Figure 5.

It might at first be thought that $E1$ transitions would be strongly inhibited, since ^{20}Ne is a self-conjugate nucleus, and there is no reason to suggest $T = 1$ for the $10 \cdot 31$ MeV state. However, these transitions are forbidden only in so far as isotopic spin is a good quantum number, and the results of Pearson and Spear (1961) would indicate that, at least at these energies, this is not so. It is therefore likely that $E1$ transitions will proceed quite readily.

The evidence then is wholly consistent with spin and parity of 1^+ for the $10 \cdot 31$ MeV level, the only unnatural parity assignment consistent with the stripping interpretation of the angular distributions.

Finally, it should be pointed out that although Kruse, Bent, and Lidofsky (1960) and Rabson *et al.* (1960), by observing gamma-rays following deuteron bombardment of ^{19}F, also see only levels of unnatural parity ^{20}Ne, the fact that they do not find the level reported here is readily explained. They were detecting gamma-rays alone and, since this level does not decay by ground state radiation, its identification would have been virtually impossible.

IV. Acknowledgments

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