Decay of ^{20}Na to γ-ray emitting states of ^{20}Ne[†]

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^{20}Ne γ rays following ^{20}Na decay identified new branches to states at 9.87, 10.88, and 11.26 MeV, as well as known branches to states at 1.63 and 10.27 MeV. Branching ratios and $\mathfrak{F}t$ values based on these observations are compared to nuclear structure calculations, and the $\beta^{\pm}$ $\mathfrak{F}t$ asymmetry for $A=20$ is discussed.

[RADIOACTIVITY ^{20}Na [from ^{20}Ne(p,n), $E=22.9$ MeV]; measured E_γ, I_γ; deduced β^+ branching ratios, $\mathfrak{F}t$ values, ^{20}Ne levels J^π, mirror β^+ asymmetry; enriched target; Ge(Li) detector.]

I. INTRODUCTION

The positron decay of ^{20}Na to excited states of ^{20}Ne is important for questions of mirror $\beta^{\pm}$-decay symmetry, weak vector current conservation (CVC), isospin purity of the lowest isobaric analog state in ^{20}Ne, and for comparison with nuclear-structure calculations.[1-14] This article reports an experiment on ^{20}Na β^+ delayed ^{20}Ne γ rays following the ^{20}Ne(p,n) ^{20}Na production reaction. The original intent in this experiment was to improve the observational basis of an indirect computation of the ^{20}Na(β^+) ^{20}Ne(1.63 MeV) branching ratio that is of interest for the mirror $\beta^{\pm}$-decay comparison. When the systematic comparison of allowed mirror $\beta^{\pm}$ decays was first made by Wilkinson,[1] it was necessary to reject a β-ray-spectrometer measurement of this branching ratio[15] and to calculate it indirectly,[1,2] using the total decay rate and subtracting the decay to α-emitting 2^+ states, which were normalized to an assumed strength for the superallowed branch. Allowed transitions to 1^+ and 3^+ states were unknown and could not have been discovered by measurements of delayed α emission, which is forbidden by conservation of angular momentum and parity. No branches to γ-ray emitting states other than ^{20}Ne(1.63 MeV) were known, although experimental branching ratio limits of 1–2 %[15,16] still allowed significant new branches and γ-decay competition from known α-emitting states. γ competition of 10% in the isospin-inhibited α decay of ^{20}Ne(10.27 MeV, $T=1$), for example, would change the indirectly computed rate of the important ^{20}Ne(1.63 MeV) branch by an amount comparable to the uncertainty from other sources, but would correspond to a ^{20}Na decay branching ratio of only 0.3% for the 8.64-MeV deexcitation γ ray, well below those experimental limits. Recent experiments,[2-5,7-9] including an observation of this latter transition,[7,8] have greatly clarified matters. Early measurements[15,16] implied a 50% inhibition of the superallowed transition to ^{20}Ne(10.27 MeV, $T=1$), a large violation of isospin symmetry, and a small half-life, but they are contradicted by recent results. The ^{20}Na half-life and the ^{20}Na-^{20}Ne mass difference are now well determined as 445.7 ± 2.9 msec[3,7-9,12] and 13.892 ± 0.007 MeV,[3] respectively. The relative strengths of all α-emitting states and their ratio to the strong 1.63-MeV delayed γ transition are also well determined.[8] Direct measurements now indicate that the superallowed transition has a strength consistent with CVC[7,8] and that the $\mathfrak{F}t$ values of the mirror $\beta^{\pm}$ decays of ^{20}Na and ^{20}F to ^{20}Ne(1.63 MeV) differ by only a few percent.[7,8,12]

Results from the present work on ^{20}Na decay to γ-emitting states allow an improved determination of $\Gamma_\gamma/\Gamma_\alpha$ for ^{20}Ne(10.27 MeV, $T=1$). This has already been used[17] in connection with a study of the ^{16}O(α,γ) ^{20}Ne reaction to limit the isospin impurity in that state, and to predict the weak magnetism strength in the ^{20}Na and ^{20}F decays, which can be used in a test of CVC and in studies of second-class-current effects in β decay. The present work also updates the comparison of the directly and indirectly determined $\mathfrak{F}t$ values for the superallowed and first-excited-state transitions. A preliminary account of this work has been given.[18]

II. EXPERIMENT

^{20}Na activity was produced by the ^{20}Ne(p,n)^{20}Na reaction. Isotopically enriched (99.95%) ^{20}Ne target gas[19] was contained in a 1.3-cm long, 0.6-cm-diam. brass-walled target volume between 13-μm Ta foil beam windows. Natural abundance neon, which contains ^{22}Ne, was avoided as target gas to eliminate an 11-sec component in the 1.63-MeV γ ray which would arise from ^{22}Ne(p, ^{3}He)^{20}F(β^-)-

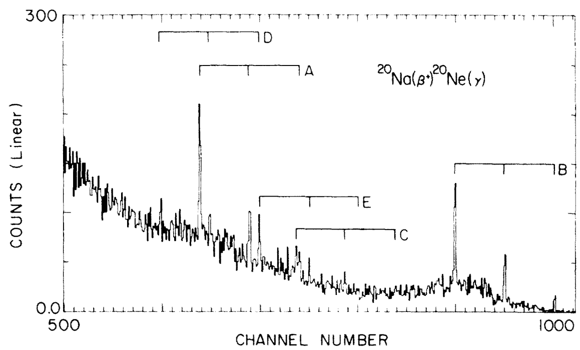

FIG. 1. High-energy portion of the ^{20}Ne γ-ray spectrum from ^{20}Na decay. The labels identifying observed ^{20}Ne transitions are used also in Table I and in the text.

^{20}Ne(1.63 MeV) reactions and which would yield incorrect relative intensity measurements unless separated.[9] After 460-msec bombardments by 22.9-MeV protons from the University of Colorado cyclotron, the target "rabbit" was repeatedly shuttled 6 m to a shielded Ge(Li) γ-ray detector and, starting 400 msec after bombardment, four successive 320-msec, 1024-channel energy spectra were accumulated. A 5.2-sec bombard-count cycle with 3-μA bombardment currents was maintained for 10 h. Besides the strong 1.63-MeV γ ray, several much weaker high-energy γ rays were also observed, and all may be attributed to reactions of protons and ^{20}Ne, as none were present in empty-target experiments. Because of background from activity induced in the Ta foils and brass walls of the target rabbit, this experiment is not sensitive to weak γ rays with energies below 5 MeV. Figure 1 shows the high-energy region of the summed energy spectrum, with markers indicating the observed transitions. Two γ rays were strong enough for meaningful half-life determinations, and these agree with that of the strong 1.63-MeV line. Energies and intensities of the observed γ rays relative to the 1.63-MeV line are given in Table I and are discussed below. The indicated uncertainties arise about equally, for the strongest lines, from the statistics of the γ-ray spectrum and from the uncertainties in the relative detection efficiency for low and high energies. The intensities have been used to determine branching ratios BR and $\mathcal{F}t$ values for transitions to states of ^{20}Ne, as given in Table II, and illustrated in Fig. 2.

A. Detector configuration

γ rays were detected with a commercial closed-end coaxial lithium-drifted germanium [Ge(Li)] detector[20] of approximately 34-cm^3 active volume. During counting periods the distance between the Ge(Li) crystal face and the source center was 13.0 cm. γ rays from the ^{20}Na source passed through a collimator, a 5.1-cm-thick Lucite β-ray absorber, and a 2.4-cm-thick Pb hardener before reaching the detector. The collimator (a 1.9-cm-diam hole in a 2.5-cm-thick Pb plate near the source) reduced the incidence of positron annihilation quanta arising outside the source, without affecting direct radiation from the source. The (low-atomic-number) Lucite absorbed the intense high-energy β rays from the source with minimal production of high-energy bremsstrahlung background. Finally, the Pb hardner preferentially attenuated low-energy γ rays, and allowed the use of higher bombardment currents and higher counting rates for the high-energy γ rays of interest.

TABLE I. ^{20}Ne γ-ray transitions following ^{20}Na decay.

Energy[a] (keV)	Assignment in ^{20}Ne		Label[b]	Relative intensity[c]
1633 ± 2	1633 → 0	$2^+ \to 0^+$		1.000
8240 ± 5 [d]	9873 → 1633	$3^+ \to 2^+$	D	$(2.66 \pm 1.33) \times 10^{-4}$
8641 ± 3	10 274 → 1633	$T=1$ $2^+ \to 2^+$	A	$(1.26 \pm 0.16) \times 10^{-3}$
9251 ± 3 [d]	10 884 → 1633	$T=1$ $3^+ \to 2^+$	E	$(3.80 \pm 1.31) \times 10^{-4}$
9628 ± 5 [d]	11 261 → 1633	$T=1$ $1^+ \to 2^+$	C	$(4.26 \pm 1.50) \times 10^{-4}$
11 261 ± 5	11 261 → 0	$T=1$ $1^+ \to 0^+$	B	$(2.13 \pm 0.28) \times 10^{-3}$

[a] Nuclear energy-level differences are given. Recoil corrections of up to 3.4 keV have been made.

[b] The labels used here are the same as in Fig. 1.

[c] γ-ray intensities are given relative to the intensity of the 1.63-MeV γ ray, which was itself determined to be 79.38 ± 1.58% of ^{20}Na decay, including cascades. (See text).

[d] Too weak for half-life check.

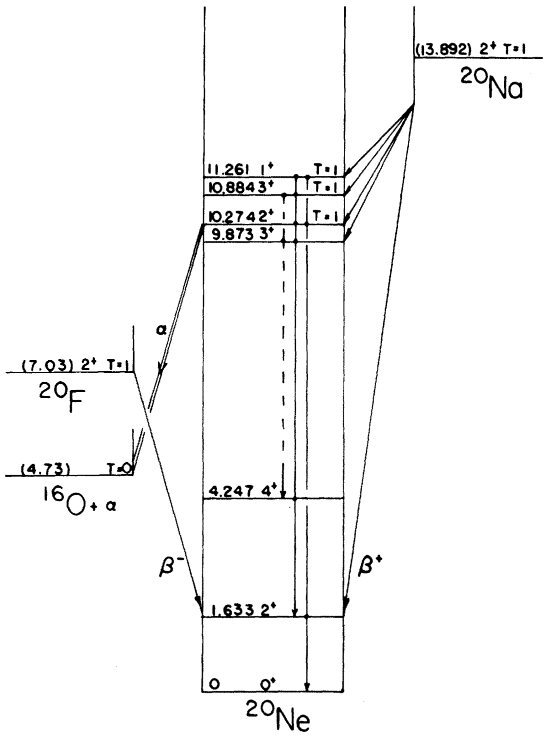

FIG. 2. Decay of ^{20}Na to γ-ray emitting states of ^{20}Ne. The lowest $T=1$ state of ^{20}Ne also emits α particles as shown. Decay to other α-emitting states is not shown. (See Ref. 8.) The dashed line indicates known transitions from the 9.87- and 10.88-MeV states which were too weak to be observed here.

B. γ-ray energy measurements

An energy calibration was established using ^{28}Si γ rays observed in a ^{28}Si$(p, n)^{28}$P$(\beta^+)^{28}$Si(γ) experiment which was conducted immediately following the main ^{20}Ne$(p, n)^{20}$Na$(\beta^+)^{20}$Ne(γ) experiment, using the same experimental configuration. Transition energies, of which the most important were 7933.40 ± 0.40 keV, 7537.22 ± 0.51 keV, 6810.02 ± 0.61 keV, 4497.62 ± 0.22 keV, 3039.60 ± 0.54 keV, 2838.92 ± 0.22 keV, and 1778.88 ± 0.09 keV were taken from the compilation of Endt and van der Leun,[21] and corrections were made for nuclear recoil. Substantial corrections (< 8 keV) for system nonlinearity were made using these calibration energies and pulser data in extrapolating to the highest energies. The possibility of significant electronic drifts between the ^{20}Na and ^{28}P observations was ruled out by checking ^{66}Ga lines[22] (from activated brass) in the ^{20}Na spectra against the energy calibration computed from the ^{28}P spectra. Corrections of up to 3.4 keV for nuclear recoil were made in calculating ^{20}Ne transitions energies from the observed γ-ray energies.

C. γ-ray intensity measurements

The γ-ray intenstities reported here are based on high-energy double-escape-peak efficiencies measured relative to the full-energy-peak efficiency at 1.63 MeV. The collimator, attenuators, and geometry of the main experiment were used also for the efficiency experiments. At low energies the energy dependence of the full-energy-peak efficiency was determined using the well established intensity ratios of ^{56}Co γ rays.[22] At high energies the double-escape-peak efficiency is based on measurements of γ-ray cascades from ^{23}Na$(p, \gamma)^{24}$Mg resonances. γ rays were observed at 55° with respect to the beam, where the dominant anisotropic term vanishes.[23] The 1318- and 1417-keV resonances give equal-intensity (±2%) cascades,[23] ^{24}Mg(12.957 → 1.369 → 0.0 MeV) and ^{24}Mg(13.052 → 4.123 → 1.369 MeV), respectively, which determine the detection efficiency at 11.59 and 8.93 MeV relative to low energies. The efficiency ratios were obtained from the intensity

TABLE II. Decay of ^{20}Na to γ-ray emitting states of ^{20}Ne.

Energy (keV)	J^π T	BR(EC + β^+) (%)	$\mathfrak{F}t$ [a] (sec)	log$\mathfrak{F}t$
1633	2^+ $T=0$	79.18 ± 1.58 [b]	97 250 ± 2060	4.988 ± 0.009
9873 ± 5	3^+ $T=0$	0.0272 ± 0.0138 [c]	607 000 ± 307 000	5.783 ± 0.178
10 274 ± 3	2^+ $T=1$	2.944 ± 0.224 [d]	2961 ± 228	3.471 ± 0.033
10 884 ± 3	3^+ $T=1$	0.0392 ± 0.0139 [e]	68 900 ± 24 400	4.838 ± 0.132
11 261 ± 5	1^+ $T=1$	0.203 ± 0.026 [f]	5394 ± 696	3.732 ± 0.053

[a] $\mathfrak{F}$ values include radiative, nuclear-size, lepton-wavelength, electronic-screening, and electron-capture corrections.

[b] Based on the 1.63-MeV γ-ray intensity with corrections for cascade contributions from higher states.

[c] 1.29 ± 0.10 times the strength of the observed 9873 → 1633 γ ray, to include other branches.

[d] Includes α emission, the observed 10 274 → 1633 γ ray, and the known 10 274 → 0 γ ray (with $\Gamma_{10.27}/\Gamma_{8.64} = 0.034 \pm 0.009$).

[e] 1.30 ± 0.10 times the strength of the observed 10 884 → 1633 γ ray, to include other branches.

[f] Based on the sum of 11 261 → 0 and 11 261 → 1633 γ-ray intensities.

ratios after small corrections (~2%) for relative attenuation in the target backings.

III. ANALYSIS AND DISCUSSION

A. Assignment of observed γ rays

The observed γ rays and their assignments are given in Table I. The 1.63- and 8.64-MeV transitions have previously been observed in ^{20}Na decay.[7,8,15] The latter, denoted A in Fig. 1, is the first-excited-state transition from the isobaric analog state ^{20}Ne(10.27 MeV, $T=1$). The relative intensity $(1.26\pm0.16)\times10^{-3}$ (or $\approx 1/794$) is consistent with the value $1/(1700\pm1100)$ reported originally.[8] The energy observed here, 8641 ± 3 keV, also agrees with the previous value[8] 8646 ± 4 keV, and with the α energy[24] and γ-ray energy[25] in the ^{16}O(α,γ)^{20}Ne reaction. A 10.27-MeV γ-ray transition $3.4\pm0.9\%$ as strong[24] would not have been observed here. The 11.26- and 9.63-MeV transitions B and C are the ground-state and first-excited-state transitions from a known 1^+ state at 11.26 MeV.[26] The first-excited-state transition C from this state allows an energy calibration check to the highest energies, because its double-escape peak is close to the full-energy peak of the 8.64-MeV transition A. From 8.641 MeV, 1.633 MeV, the 33 ± 5-keV separation of these peaks, and $2m_ec^2=1.022$ MeV, a 1^+ state excitation energy 11.263 MeV is determined, in agreement with the preferred value 11.261 ± 0.005 MeV determined directly from the isolated higher-energy transition B. Transitions D and E correspond to first-excited-state transitions from states at 9.87 and 10.88 MeV which have been observed in the ^{19}F(^{3}He, $d\gamma$)^{20}Ne reaction.[27,28] Accompanying lower-energy γ rays from these states of the reported intensity[27] are beyond the sensitivity of this experiment, as is the ground-state 10.27-MeV transition from ^{20}Ne(10.27 MeV, $T=1$), but their presence is assumed in calculating the branching ratios and $\mathcal{F}t$ values for the decay of ^{20}Na given in Table II.

B. Branching ratio calculations

The second forbidden $2^+\rightarrow0^+$ ground-state β decay is expected to have negligible strength ($<10^{-7}$), and the experimental limit $<5\times10^{-4}$ agrees with this.[15] The strength of all observed β^+ delayed α groups[8] is 7.198 ± 0.050 times the strength of the group from ^{20}Ne(10.27 MeV, $T=1$), which itself is $(27.94\pm2.66)^{-1}$ times as strong as the 1.63-MeV γ-ray strength,[8] so that α emission is 0.2576 ±0.0246 times the 1.63-MeV γ-ray strength. The known strength of γ-ray-emitting states that is not already included in the 1.63-MeV γ-ray strength (noncascade transitions from the 11.26- and 10.27-MeV states) is 0.0022 ± 0.0003 times the 1.63-MeV γ-ray strength. Combining all of this information gives $79.38\pm1.58\%$ of ^{20}Na decay as the strength of the 1.63-MeV γ ray, including cascades. (This number normalizes the strength of branches to γ-ray emitting states.)

Since 0.25% of the 1.63-MeV γ-ray strength results from cascades of the 11.26-, 10.88-, 10.27-, and 9.87-MeV states (including known unobserved branches),[24,27] decay directly to ^{20}Ne(1.63 MeV) is $79.18\pm1.58\%$ of ^{20}Na decay, only slightly smaller than the value $79.47\pm1.57\%$ used before the present γ-ray observations,[8] and in the direction of a larger $\mathcal{F}t$ value. At the same time, the γ-ray competition in the decay of ^{20}Ne(10.27 MeV, $T=1$) to ^{16}O + α renormalizes the α strength of the analog state [when a given ^{20}Ne(10.27 MeV, $T=1$) $\mathcal{F}t$ value is *assumed*] and of all α-emitting 2^+ states measured relative to it, which increases the indirectly computed branching ratio for the first excited state, decreasing the $\mathcal{F}t$ value. The effect of the present observations is thus to narrow the difference of the direct and indirect $\mathcal{F}t$ calculations for the ^{20}Ne(1.633 MeV) branch, and to reduce the uncertainty in the mirror $\beta^\pm$ $\mathcal{F}t$ asymmetry.

The branching ratios (for positron emission plus electron capture) given in Table II, with the exception of that for the 10.27-MeV state, are based on the observed γ-ray intensities and known unobserved transitions and 79.38% for the intensity of the 1.63-MeV γ ray. For the α-emitting state ^{20}Ne(10.27 MeV, $T=1$), we use the present $\Gamma_{8.64}/\Gamma_{1.63}=(1.26\pm0.16)\times10^{-3}$, $\Gamma_\alpha/\Gamma_{1.63}=(27.94\pm2.66)^{-1}$ of Torgerson *et al.*,[8] and $\Gamma_{10.27}/\Gamma_{8.64}=0.034$ ±0.009 of Pearson and Spear[24] to compute the branching ratios $\Gamma_{8.64}/\Gamma=0.034\pm0.005$ and $\Gamma_\alpha/\Gamma=0.965\pm0.005$. Then the ^{20}Na($\beta^+$)^{20}Ne(10.27 MeV, $T=1$) branching ratio is $(27.94\pm2.66)^{-1}$ (0.0965 $\pm0.005)^{-1}$ times the strength of the 1.63-MeV γ ray, or $2.944\pm0.224\%$ of ^{20}Na decay. The previous value was $2.89\pm0.23\%$.[8] Thus, the higher strength determined in the present work for the 8.64-MeV transition results in a slight increase in the calculated rate of the superallowed transition, and a slightly smaller $\mathcal{F}t$ value.

The observations of Adelberger and Marrs of the ^{19}F(^{3}He, $d\gamma$)^{20}Ne reaction[27] give the relative intensities for γ rays from ^{20}Ne states at 9.87, 10.88, and 11.58 MeV. Ratios of the total decay of those states to the observed transitions to ^{20}Ne(1.63 MeV) were taken as (1.29 ± 0.10), (1.30 $\pm0.10)$, and (1.60 ± 0.20), respectively, in calculating ^{20}Na decay branching ratios or upper limits for these states.

C. $\mathcal{F}t$-value calculations

Comparative half-lives $\mathcal{F}t$ for the observed ^{20}Na β^+-decay transitions to γ-ray emitting ^{20}Ne states are given in Table II, and are based on the excitation energies and branching ratios BR(EC + β^+)

of Table II, the ^{20}Na-^{20}Ne mass difference 13.892 ±0.007 MeV,[3] and the ^{20}Na half-life $t_{1/2} = 0.4457 \pm 0.0029$ sec.[12] The statistical rate function f^s, including the effect of screening by atomic electrons, was calculated with a code developed by Bahcall and Zimmerman,[29] and additional small corrections were calculated in approximations developed by Wilkinson[30,31] which are accurate to 0.1% for light elements and energetic decays. Corrections have also been made for electron-capture contributions[32] to the decay rates, so that

$$\mathfrak{F}t = f^s(1+\epsilon_{1,2}+\epsilon_3)(1+\delta^R) \times (1+f_0^\epsilon/f_0^{\beta+})\, t_{1/2}/\mathrm{BR}(\mathrm{EC}+\beta^+)\ ,$$

with f^s calculated as in Ref. 29, the nuclear-size and lepton-wavelength correction $(1+\epsilon_{1,2}+\epsilon_3)$ from Ref. 30, the outer radiative correction $(1+\delta^R)$ from Ref. 31, and the electron-capture-to-positron ratio $f_0^\epsilon/f_0^{\beta+}$ from Ref. 32. As a check, similar calculations were made for carefully analyzed $0^+ \to 0^+$ pure Fermi decays of ^{14}O and ^{26m}Al, with results which agreed to ~0.2% with published results based on the same data.[33] Accuracy of this order is important only for the mirror $\beta^\pm$-decay $\mathfrak{F}t$ comparison, and for the discussion of superallowed transitions.

D. Unobserved transitions

Besides the transitions presented in Tables I and II, the marginally too-large single-escape peak of transition D suggests a possible underlying transition of energy 8.74 ±0.02 MeV, and ^{20}Na decay branching ratio $<2\times10^{-4}$. A (1^-) state at 8.74 MeV was reported in early ^{20}Na($\beta^+\alpha$) measurements, but was not observed in a recent high-precision experiment.[8] If a transition to ^{20}Ne(8.74 MeV) exists, it has $\log\mathfrak{F}t > 6.5$, consistent with first-forbidden character.

There is likewise no definite evidence for either the >90% 8.32-MeV γ ray[34] from ^{20}Ne(9.95 MeV) [a suggested (1^+) state][26,34] or the 60% 9.95-MeV γ ray[27] from ^{20}Ne(11.58 MeV). Upper limits for these transitions require $\log\mathfrak{F}t > 6.0$ for ^{20}Ne(9.95 MeV) and $\log\mathfrak{F}t \gtrsim 4.0$ for ^{20}Ne(11.58 MeV). These limits do not rule out allowed transitions to these states.

E. 1^+ state at 11.26 MeV

The allowed $\mathfrak{F}t$ value and the γ decay of the state observed here require $J^\pi = 1^+$ or 3^+. The $\log\mathfrak{F}t$ value 3.732 ±0.053 and excitation energy 11.261 ±0.005 MeV are remarkably close to the values 3.73 and 11.27 MeV, respectively, predicted for a 1^+, $T=1$ state in extended-shell-model calculations of Lanford and Wildenthal.[14] The observed 11.26-MeV γ-ray transiton B corresponds to the giant $M1$ transition exciting a 1^+ state at this energy (nearly exhausting the energy-weighted sum rule) in 180° inelastic electron scattering.[35] The relative strength 0.20 ±0.08 for the transitions C and B to ^{20}Ne(1.63 MeV) and ^{20}Ne(0.0 MeV) (see Table I) corresponds to γ-ray branching ratios 17% and 83%, and to reduced transition probabilities $B(M1)$ in the ratio 0.32 ±0.12. These agree well with the shell-model calculations of Maripuu and Wildenthal,[13] which predicted branching ratios 18% and 82% [$B(M1)$ ratio 0.353]. A brief communication[36] has reported observation of this state in the ^{19}F($d, n\gamma$)^{20}Ne reaction at a slightly lower excitation energy 11.252 ±0.002 MeV and with relative γ-ray intensities corresponding to a $B(M1)$ ratio 0.53 ±0.07 which, however, favored the rotational-model prediction 0.50.

There may be another unnatural-parity state nearby. Excitation energies which range from 11.23 to 11.27 MeV have been reported and are not entirely consistent.[26] Representative values include 11.259 ±0.010 MeV,[37] 11.233 ±0.010 MeV,[26] 11.239 ±0.015 MeV,[28] 11.252 ±0.002 MeV,[36] and the present value 11.261 ±0.005 MeV. Examination of Fig. 1 suggests a possible γ-ray peak approximately 40 keV lower in energy than the double-escape peak of transition C, but this is not definitely established (and is not included in calculating the intensity of C here).

F. 3^+ states at 10.88 and 9.87 MeV

The allowed $\mathfrak{F}t$ values and γ decay of these states again require $J^\pi = 1^+$ or 3^+. Neither state is excited in 180° inelastic electron scattering,[35] but this does not eliminate 1^+ assignments, because theoretical considerations indicate that the $M1$ strength in ^{20}Ne should be concentrated in a single 1^+ state [as is observed[35] for ^{20}Ne(11.26) MeV)], although several 1^+ states may be present.[13,38] For each state the ^{19}F(^{3}He, $d\gamma$)^{20}Ne results of Adelberger and Marrs[27] show that the γ decay proceeds to the 2^+ first-excited state (the transition E and D observed here) and to the 4^+ second-excited state, but not to the 0^+ ground state. This favors a 3^+ assignment for each state. A $T=1$ assignment for ^{20}Ne(10.88 MeV) is favored by the existence of the 3^+ state ^{20}F(0.656 MeV),[26] its probable analog. ^{20}Ne(9.87 MeV) is below the 10.27-MeV analog of the ^{20}F and ^{20}Na ground states, and is assigned $T=0$. Shell-model calculations[14] predicted a 3^+, $T=1$ state at 10.75 MeV with $\log\mathfrak{F}t = 4.89$, in close agreement with $\log\mathfrak{F}t = 4.838 \pm 0.132$ of ^{20}Ne(10.88 MeV). The $\log\mathfrak{F}t = 4.90$ for a predicted 3^+, $T=0$ state at 10.50 MeV does not agree with the $\log\mathfrak{F}t = 5.783 \pm 0.178$ observed here for ^{20}Ne(9.87 MeV).

G. 2^+ lowest $T=1$ state at 10.274 MeV

^{20}Ne(10.27 MeV) was identified as the lowest $T=1$ state, isobaric analog of ^{20}Na and ^{20}F, from measurements of the isospin-forbidden ^{16}O$(\alpha,\gamma)^{20}$Ne reaction.[24] The excitation energy 10.274 ± 0.003 MeV determined here agrees with 10.279 ± 0.004 MeV determined originally from the β^+ delayed γ-ray energy,[8] with 10.278 ± 0.005 MeV from the β^+ delayed α energy,[8] with 10.272 ± 0.009 MeV from the ^{16}O$(\alpha,\gamma)^{20}$Ne resonance energy ($E_\alpha=6.930\pm0.010$ MeV),[24] and with 10.271 ± 0.003 MeV from the ^{16}O$(\alpha,\gamma)^{20}$Ne γ-ray energy.[25] The $M1$ strength of the 8.64-MeV γ-ray transition from this state shows this transition to be predominantly orbital, being approximately 4.5 times the strength computed for the spin part from the analogous $\beta^\pm$ decays.[17,24] This large Γ_γ value[17] is well approximated by extended-shell-model calculations,[39] as are the $\beta^\pm$ decays to the same state.[14] From the small α-decay width[17] $\Gamma_\alpha=116\pm20$ eV for ^{20}Ne(10.27 MeV, $T=1$) $\rightarrow$ ^{16}O$+\alpha$, 100 times smaller than Γ_α for nearby states of the same spin and parity, an isospin impurity limit of about 1% may be determined.[17] These matters were discussed in greater detail in connection with the ^{16}O$(\alpha,\gamma)^{20}$Ne reaction.[17]

H. State at 1.63 MeV—mirror $\mathfrak{F}t$ comparison for ^{20}Na(β^+) and ^{20}F(β^-) decays

For ^{20}Na$(\beta^+)^{20}$Ne(1.633 MeV), the experimental branching ratio 79.18 ± 1.58% and $\mathfrak{F}t$ value 97250 ± 2060 sec were given in Table II. An alternate, indirect computation of these quantities starting from a theoretical value for the superallowed transition is also of interest,[1-3,12] and is justified by the extremely well known normal Fermi decay strength,[33] and by the high isospin purity of the analog state (deduced from its small α-particle decay width).[17] The $\mathfrak{F}t$ value 2800 ± 80 sec assumed for the superallowed transition is a revision of a previous value 2780 ± 80 sec[3] reflecting the increased precision in the normal Fermi strength.[33] This value was obtained by combining the Fermi strength with a range of possible values for the small Gamow-Teller component.[3] The assumed $\mathfrak{F}t$ value for the ^{20}Ne(10.27 MeV, $T=1$) branch agrees with direct knowledge (Table II), so the indirect $\mathfrak{F}t$ value for the ^{20}Ne(1.633 MeV) branch which results from it will also agree. The expected uncertainty in the superallowed transition strength is smaller for the theoretical value, however, so that the indirect computation may well give the best $\mathfrak{F}t$ value for ^{20}Na$(\beta^+)^{20}$Ne(1.633 MeV). Shell-model calculations[14] gave $\log\mathfrak{F}t=4.98$, very close to both the direct and indirect calculations for the ^{20}Ne(1.63 MeV) branch.

Assuming $\mathfrak{F}t=2800\pm80$ sec and using $\Gamma_\alpha/\Gamma=0.965\pm0.005$[17] for ^{20}Ne($10.274\pm0.003$ MeV, $T=1$), and using the relative α intensities of Torgerson *et al.*,[8] β^+ delayed α groups amount to 21.63 ± 0.72% of ^{20}Na decay. Decay to γ rays amounts to an additional 0.37%. Thus the indirectly computed branching ratio for ^{20}Na$(\beta^+)^{20}$Ne(1.633 MeV) is 78.00 ± 0.72%, about 1.5% smaller than the direct experimental value 79.18 ± 1.58%. The corresponding (larger) indirect ^{20}Na $\mathfrak{F}t$ value is 98728 ± 1154 sec. For the ^{20}F side of the mirror the $\mathfrak{F}t$ value is 94134 ± 174 sec, based on maximum β^- energy, 5.3959 ± 0.0008 MeV[12] and branching ratio 99.983 ± 0.003%[12] for ^{20}F$(\beta^-)^{20}$Ne(1.633 MeV), and ^{20}F half-life 10.999 ± 0.019 sec (a weighted average of 11.03 ± 0.06 sec[2] and 10.996 ± 0.020 sec[40]). The $A=20$ mirror asymmetry $\delta=[\mathfrak{F}t(\beta^+)/\mathfrak{F}t(\beta^-)]-1$ is thus 0.033 ± 0.022 computed directly, and 0.049 ± 0.013 computed indirectly starting from the assumed strength of the superallowed transition.

Since 1970 when the comparison of allowed mirror $\beta^\pm$ decays underwent renewed scrutiny[1] in connection with the possibility of second-class weak currents, the δ values computed for $A=20$ have changed considerably. With successive experimental improvements the best value of δ has passed through the values -0.067 ± 0.032,[2] $+0.062\pm0.037$,[2] $+0.054\pm0.023$,[3] and $+0.026\pm0.023$,[8] to the present direct and indirect results $+0.033\pm0.022$ and $+0.049\pm0.013$, respectively. Many improvements have been made for other mirror pairs as well.[12] Simultaneously a better understanding of nuclear-structure effects has developed, so that the binding-energy-induced wave function differences between the nominal mirror nuclei are now thought to account for most of the experimentally observed $\beta^\pm$-decay $\mathfrak{F}t$ asymmetry.[12] For the ^{20}Na-^{20}F comparison, the experimental asymmetry δ is indistinguishable from $\delta^{\text{bind}}=0.029\pm0.025$ calculated in a recent survey.[12]

Interest in the possibility of second-class currents continues, but it now seems likely that searches using phenomena less sensitive to nuclear structure effects will prove more definitive.[41]

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