Protons from the Deuteron Bombardment of Separated Neon Isotopes*

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With neon gas enriched either to 93 percent Ne^{22} or to 99 percent Ne^{20} we confirm the observations with less well-concentrated isotopes by Elder, Motz, and Davison on the $Ne^{20}(d,p)Ne^{21}$ and $Ne^{22}(d,p)Ne^{23}$ reactions. Aided by the enrichment factor of 3 for Ne^{21} in the "heavy" neon, we find a long-range proton group from $Ne^{21}(d,p)Ne^{22}$ with a Q of 6.79±0.10 Mev for the reaction. Consideration of these and other reactions involving neon isotopes show that the mass of Ne^{21} is 21.00062±0.00010 and that this new proton group indicates an excited state at 1.37 Mev in the Ne^{22} nucleus.

WITH targets of neon gas containing either 93 percent Ne^{22} or 99 percent Ne^{20} we have repeated the deuteron bombardment experiments most recently carried out in this laboratory by Elder, Motz, and Davison.[1] Our measurements with these better-separated isotopes completely confirm their observations on the $Ne^{20}(d,p)Ne^{21}$ and $Ne^{22}(d,p)Ne^{23}$ reactions. In addition, even though the Ne^{21} content in this "heavy" gas had been enriched to only about 0.75 percent, or a factor of three, we have succeeded in locating a long-range proton group from the reaction $Ne^{21}(d,p)Ne^{22}$ with the Ne^{22} nucleus in an excited state 1.37 Mev above ground.

These isotope enrichments were produced in a multistage thermal diffusion apparatus.[2] The gas pressure in the target box was about 16 cm of Hg for the investigation of the proton groups from the bombardment of Ne^{20} and Ne^{22}, and about 70 cm of Hg in the search for the elusive protons from $Ne^{21}(d,p)Ne^{22}$. In the bombardment region the deuterons had an energy of 2.9 Mev for the first reactions, but an energy of 3.12 Mev for the study of the $Ne^{21}(d,p)Ne^{22}$ reaction since the entrance foil was then thinner. Hot calcium shavings were used to remove any air contamination in the neon. Our failure to detect any trace of the ubiquitous long-range group of protons from $N^{14}(d,p)N^{15}$ indicated that this purification was fairly complete. The emitted protons were counted in all cases only at 90° with the incident beam, by means of a single proportional counter.

TABLE I. Reaction energies and energy levels of the neon isotopes.

	Proton range (cm)	Q(Mev)	Energy level (Mev)
$Ne^{20}(d,p)Ne^{21}$	24.04	1.68±0.07	2.82
	35.26	2.73±0.06	1.77
	53.62	4.19±0.07	0.31
	57.96	4.50±0.09	ground
$Ne^{21}(d,p)Ne^{22}$	103.0	6.79±0.10	1.37
$Ne^{22}(d,p)Ne^{23}$	19.31	1.13±0.10	1.75
	26.73	1.90±0.07	0.98
	37.42	2.88±0.06	ground

The yields of protons of various energies for the Ne^{20} and Ne^{22} bombardments are shown in Fig. 1. Comparison of the two curves shows clearly which proton groups are to be assigned to each isotope. In particular, it is quite evident that both members of the partly resolved double group of longest range belong to $Ne^{20}(d,p)Ne^{21}$, thus fixing with fair precision the ground-state Q-value for this reaction. The extrapolated ranges and calculated Q-values for each of these proton groups are assembled in Table I. Although we find no indication of a still-longer-range proton group from the Ne^{21} bombardment, we conclude from the argument given below that the single low-intensity group with an extrapolated mean range of 103±2 cm does not involve the ground state of the resulting Ne^{22} nucleus.

It is of interest to see whether these and the other reactions depicted in Fig. 2 lead to a consistent set of masses for the neon isotopes. The most accurately known neon mass is that of Ne^{20}. Mattauch and Flammersfeld in their recently published survey[3] give the value 19.99890±0.000047 for this mass. The Q for the reaction $Na^{23}(p,\alpha)Ne^{20}$ is +2.14±0.07 Mev, or 0.00230 atomic mass units.[4] This Q plus the Ne^{20} mass just quoted give 22.99697 for the mass of Na^{23}. The $Na^{23}(d,\alpha)Ne^{21}$ reaction[5] has a Q equivalent to +0.00725 mass units. With 22.99697 for the mass of Na^{23}, this leads to a value 21.00056 for the mass of Ne^{21}. Based on the 19.99890 Ne^{20} mass, our Q of 4.50±0.09 Mev for the $Ne^{20}(d,p)Ne^{21}$ reaction gives 21.00067 for the mass of Ne^{21}. These two values for the mass of Ne^{21} agree well within their probable errors, and they exactly straddle the value 21.00062±0.00009 calculated by Mattauch and Flammersfeld from all available data.

With this Na^{23} mass and the maximum β-ray energy of 4.3±0.3 Mev (corrected)[6] reported by Pollard and

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[5] E. B. M. Murrell and C. L. Smith, Proc. Roy. Soc. 173, 410 (1939).
[6] E. Bleuler and W. Zünti, Helv. Phys. Acta, 19, 375 (1946).

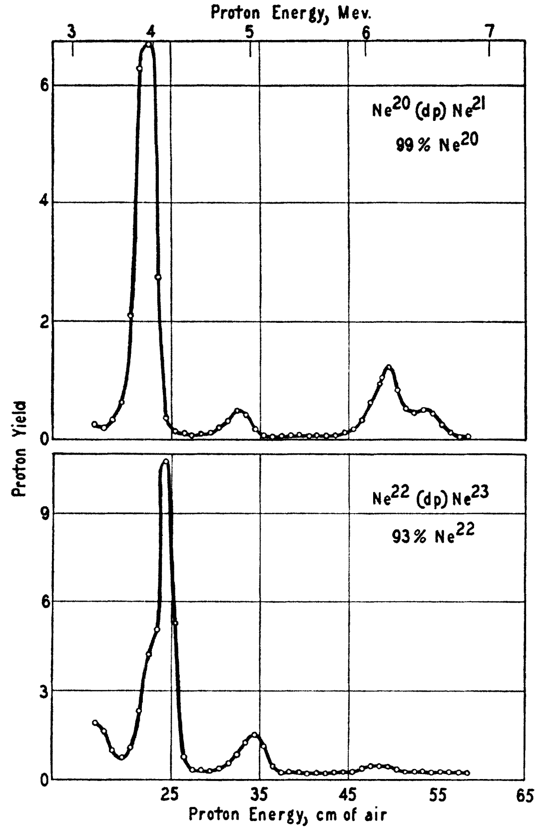

FIG. 1. Yield of protons from the deuteron bombardment of separated neon isotopes with observation at 90° with the incident beam.

Watson[7] for $Ne^{23} \to Na^{23}$, one calculates 23.00160 $\pm$0.00040 for the mass of Ne^{23}. Mattauch and Flammersfeld estimate from all reported evidence that the mass of Ne^{23} is 23.00203$\pm$0.00017. Using this higher value, we calculate from our Q of 2.88$\pm$0.06 Mev for $Ne^{22}(d,p)Ne^{23}$ that Ne^{22} has a mass of 21.99852, in excellent agreement with Mattauch and Flammersfeld's weighted estimate of 21.99850$\pm$0.00015. A better

[7] E. C. Pollard and W. W. Watson, Phys. Rev. 58, 15 (1940).

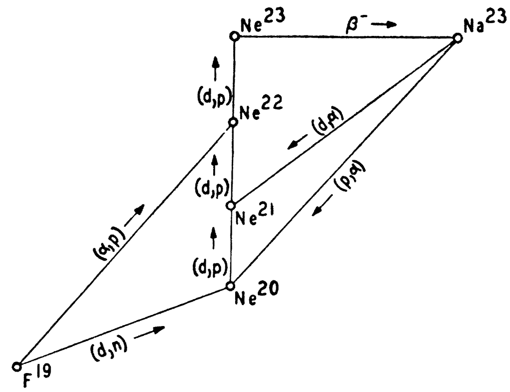

FIG. 2. Nuclear reactions involving neon isotopes.

determination of the mass of Ne^{23} could be made by a more accurate determination of the maximum energy of the electrons emitted by this nucleus.

If the Q of 6.79$\pm$0.10 Mev calculated for our observed $Ne^{21}(d,p)Ne^{22}$ reaction applied to the ground state of Ne^{22}, the 21.99850 value for Ne^{22} would give 20.99919 for the mass of Ne^{21}. The difference between this and the correct mass 21.00062 amounts to 1.37 Mev, indicating that our proton group involves an excited state of this energy in the Ne^{22} nucleus. This is to be compared with the observation by May and Vaidyanathan[8] in their study of the reaction $F^{19}(\alpha,p)Ne^{22}$ that the first excited level of the Ne^{22} nucleus lies at 1.5 Mev above its ground state. Our failure to observe the more energetic protons involving the ground state of Ne^{22} is understandable since (1) our enrichment factor of 3 made detection of these excited state protons barely possible, and (2) from comparison with the proton distributions from Ne^{20} and Ne^{22} bombardment, we might expect the missing longest-range protons to be considerably less numerous than the shorter-range protons from the same reaction.

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[8] A. N. May and R. Vaidyanathan, Proc. Roy. Soc. 155, 519 (1936).