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A New Measurement of $^{20}Ne(d, \alpha)^{18}F$ Q_0-Value*

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Energy measurements of the most energetic alpha group from $^{20}Ne(d, \alpha)^{18}F$ were made using as reference and calibration points proton and alpha groups from (d, p) and (d, a) reactions in ^{16}O and (d, p) reaction in ^{20}Ne. These reactions where detected simultaneously under the same experimental conditions. Several detection angles were observeci at a fixed bombarding energy using gas targets and a surface barrier detector. The resultant Q-value relative to $Q_0 = 3110.6 \pm 3$ KeV for the $^{16}O(d, \alpha)^{14}N$ reaction is $Q_0 = 2790 \pm 10$ KeV. A comparison is made with previous measurements.

Medidas de energia do grupo de alfas mais energéticas provenientes do $^{20}Ne(d, \alpha)^{18}F$ foram realizadas utilizando-se como linhas de calibração e referência os grupos de protons e alfas de (d, p) e (d, a) com ^{16}O e (d, p) com ^{20}Ne. Essas reações foram detetadas simultâneamente sob as mesmas condições experimentais. Vários ângulos de observação foram empregados a uma energia fixa de bombardeamento usando alvos gasosos e uni detetor de barreira de superfície. O valor-Q resultante, relativo a $Q_0 = 3110.6 \pm 3$ KeV para a reação $^{16}O(d, \alpha)^{14}N$, é $Q_0 = 2790 \pm 10$ KeV. Faz-se uma comparação com medidas anteriores.

1. Introduction

Nuclear reaction Q-values constitute an important type of input data for atomic mass tables[1,2]. In the evaluation of masses for local regions of the periodic table, use is frequently made[1,2] of groups of reactions (called reaction cycles) such that the Q-value for any one of them can be derived from the remaining ones in the cycle. Also, the sum of their Q-values reduces to a few fundamental mass differences thus making possible self-consistent checks of the mass evaluation.

The reaction $^{20}Ne(d, \alpha)^{18}F$ is a member of an important reaction cycle involving nuclei from mass $A = 14$ to $A = 21$ (Ref. 3). The energetics

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of this reaction has been studied twice in the past[3,4]. On both occasions the reaction products were magnetically analysed and detected by photographic plates. C. Mileikowsky[3] at the Nobel Institute measured $Q_0 = 2791 \pm 9$ KeV and López and Almén[4] at the UNAM Physics Institute found $Q_0 = 2766 \pm 20$ KeV. Rytz[5] recalibrated these measurements and changed Mileikowsky's value to $Q_0 = 2795 \pm 9$ KeV.

In view of the conflicting values for the two previous determinations for this reaction Q-value, we decided to carry out a new measurement using a different experimental method. Parts of this work have been reported previously[6].

2. Method

Our method consisted of using a deuteron beam that was momentum analysed by an electrostatic analyser[7] and a gas-target contained in a small scattering chamber[8]. The outgoing lighter particles were detected by a movable solid-state detector arrangement comprising an especially designed collimator.

The incident beam energy was determined within $\pm 0.2\%$ accuracy making use of the electrostatic analyser energy calibration that had been previously determined[9] by the observation of the T(p, n)^{3}He, ^{9}Be(p, n)^{9}B, ^{16}O(d, n)^{17}F and ^{13}C(p, n)^{13}N reaction thresholds, and the ^{27}Al(p, γ)^{28}Si – $E_p = 992$ KeV resonance, employing thin solid targets located at the center of the scattering chamber.

The energy calibration for the outgoing particles was obtained using the reactions ^{20}Ne(d, p)^{21}Ne (1.75 MeV, 2.797 MeV), ^{16}O(d, p)^{17}O (g. s., 1.871 MeV) and ^{16}O(d, α)^{14}N (g. s.). The main reason for using an oxygen-neon mixture is that the experimental Q_0-value for ^{16}O(d, α)^{14}N is accurately known[5] and lies close to the Q_0-value for the reaction under study, and could thus be used as a reference.

3. Experimental Set-Up and Procedure

The experimental arrangement used in this work has already been described in detail elsewhere[8,9]. The continuous beam of the São Paulo 4 MV electrostatic accelerator, after passing through an electrostatic analyser and a set of quadrupole lenses, reached the scattering

chamber. Fig. 1 shows a cut-away view of the scattering chamber in the plane of the reaction. The intersection between the shaded areas in this figure defines the effective target. The target-gas was contained inside the chamber by means of two thin nickel foils placed over two small apertures along the beam trajectory. The pressure inside the chamber was measured by a differential manometer relative to the evacuated collector cup.

The entrance foil thickness was measured by the displacement of the ^{27}Al(p, γ)^{28}Si resonance observed with and without the foil in front of an aluminum target mounted inside the scattering chamber.

Charged particles spectra were obtained using a silicon surface barrier detector and were recorded in a 1024 channel analyser. The differential linearity of the analyser was tested with a precision pulser and was observed to be within $\pm$ 3% for the region that excluded approximately the 100 initial and the 100 final channels.

Four types of gas targets were used: (i) a mixture of natural neon and natural oxygen; (ii) natural oxygen (mostly ^{16}O); (iii) natural neon (90.8% ^{20}Ne, 0.26% ^{21}Ne, 8.9% ^{22}Ne); and (iv) isotopically pure ^{20}Ne. These targets could also have small contaminations of ^{14}N and ^{12}C (in form of CO_2).

Using the mixed gas target (88.75% of neon and 11.25% of oxygen) 1024 channel spectra were obtained for a deuteron incident energy of $E_d = 2100 \pm 4$ KeV at 40, 45, 50, 60, 160 and 168 degrees. The total pressure was 36.3 torr. Also, for almost the same experimental conditions, (same energy, approximate pressures, etc.) two spectra were taken using the isotopically pure neon at $\theta_{lab} = 90$ and 100^0. The purpose of these measurements was to evaluate the distorsion effects of the alpha peaks from the (d, α) reactions with ^{20}Ne by those coming from the ^{22}Ne present in the target of natural neon. Finally, to help in the peak identification, spectra were obtained under similar experimental conditions using the natural oxygen and neon targets.

4. Data Analysis

Only the forward angle data (taken with the gas mixture) were used to calculate the Q_0-values, since the backward angle spectra showed a superposition of peaks. Each spectrum was treated independently

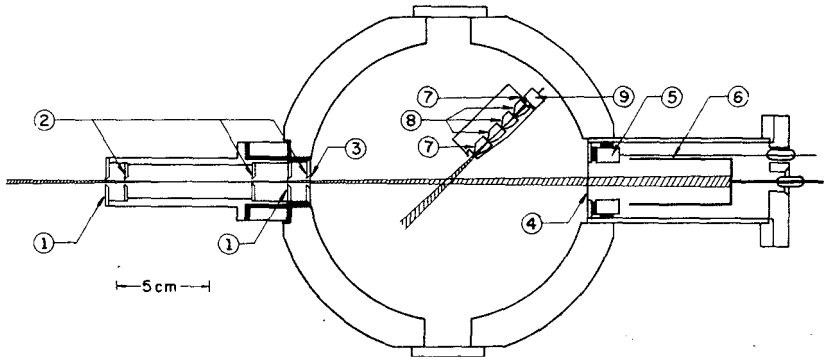

Figure 1 – The scattering chamber used in the measurements. 1) defining slits of the entrance collimator; 2) anti-scattering slits; 3) entrance foil (2500 Å thick Ni); 4) exit foil (5000 Å thick Ni); 5) magnetic and electrostatic suppressor; 6) collector cup; 7) defining slits of the detector collimator; 8) anti-scattering slits; 9) surface barrier detector.

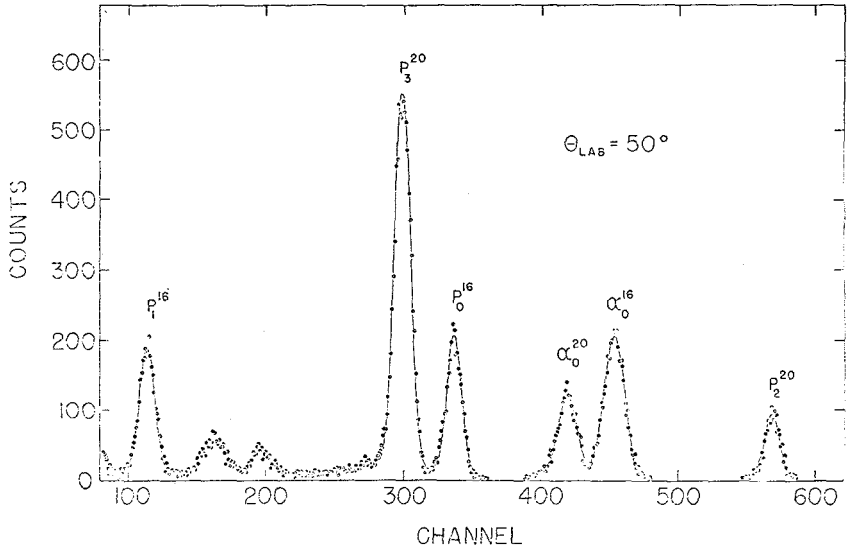

Figure 2 – Spectrum taken at a scattering angle of 50° (lab) with a gas mixture of neon (−89%) and oxigen (−11%) Only the spectrum region of interest is shown here. The full curves are fits through the points as explained in the text.

and their individual results were then combined into an average value. Fig. 2 shows a representative spectrum of the forward angle data. In this figure, the lower index of the peak labels refers to the residual nucleus level (O = ground state, 1 = first excited state, etc.) and the upper index is the mass number of the target nucleus. Following tht: notation of Fig. 3 we describe now the calculation procedure used to get the Q_0-values.

An anergy loss in the entrance foil $\Delta E_d = 33 \pm 2$ KeV for $E_d = 2100$ KeV, was derived from the measured $\Delta E = 34 \pm 2$ KeV at $E = 992$ KeV by means of semi empirical relations for the stopping cross-sections[10]. The energy loss of the deuteron beam in the gas target up to the center of the scattering chamber was calculated and found to be equal to $\Delta E_d = 65.6 \pm 3.3$ KeV, giving a deuteron energy at the medium point of the effective target equal to $E_1 = 2001.4 \pm 5.6$ KeV.

The outgoing energies (E_2) for the various groups of product particles* were calculated using nonrelativistic kinematic relations[11]. The associated errors were computed from the standard error propagation formula taking into account the contributions from E_1, θ and Q. The absolute uncertainty in the detection angle was taken to be 0.25°. The adopted Q-values for the relevant reactions and their respective errors are those listed in Table 1.

Reaction	Q_0(KeV)	Ref.
^{16}O(d, p)^{17}O	1919 ± 3	5
^{16}O(d, α)^{14}N	3110.6 ± 3[(a)]	5
^{20}Ne(d, p)^{21}Ne	4534 ± 6	5
^{20}Ne(d, α)^{18}F	2797	1
^{22}Ne(d, p)^{23}Ne	2970	1
^{22}Ne(d, α)^{20}F	2698	1

Table I -- Adopted Q-values for the reactions of interest in the present measurements.

(a) Using the same imput data as those quoted in Ref. 5 we obtained an average value of $Q_0 = 3112.5 \pm 2.5$ adopting as weights the inverse of the quoted variances.

*For the α_0^{20} group an approximate Q_0-value was used to get E_2 and to further confirm the spectra identification.

The energies $E_2' = E_2 - \Delta E_2$ and their respective errors were then calculated. These values for the four proton groups – p_1^{16}, p_3^{20}, p_0^{16}, p_2^{20} – and the α_0^{16} group enabled us to calibrate the spectra and obtain the unknown energies of the α_0^{20} group, subject to the following approximations. First, we did not consider second order corrections to the multichannel analyser calibration. In fact, as may be seen in Fig. 2, the relevant particle groups are in the region where the differential linearity is good to $\pm 3\%$, as mentioned before. Second, we took, for each particle group, E_3 equal to E_2', that is, we neglected the energy losses suffered by the detected particles in the gold layer that covered the detector surface. This is justifiable since only energy differences for the same type of particles are of interest here.

For the energy calibrations of the spectra, we first determined the position of the centroids of each peak by doing a non-linear least-squares fit[12,13] of the data. The computer program used can fit several peaks simultaneously with the following functional form

$$y(x) = \sum_{j=1}^{J} y_{0j} \exp\{-[(x - x_{0j})^2 2\sqrt{2 \ln 2} / w_{0j}]^2\} \times$$
$$\times [1 + \alpha_{1j}(x - x_{0j})^{m_1} + \alpha_{2j}(x - x_{0j})^{m_2}] + ax + b, \qquad (1)$$

where a, b, y_{0j}, x_{0j}, w_{0j} and α_{ij} are the fitting parameters. Background is approximated by a straight line $ax + b$. Assuming a pure Gaussian peak shape (i. e., using $\alpha_{ij} = 0$) we were able to get reasonably good fits to the data as can be seen from Fig. 2.

For each spectrum, the peak positions (K) of the proton groups and their respective energies E_2' were then used to get the analyser dispersion (in keV/channel) making use of a least squares linear fitting program[14] which takes into account the errors in both variables. The program finds the best line from the minimization of the expression:

$$S = \sum_i [(x_i - X_i)^2/u_i + (a + bx_i - Y_i)^2/v_i], \qquad (2)$$

where (X_i, Y_i) are the calibration points (i = 1, 2, 3, 4); $u_i = X_i$ variances; $v_i = Y_i$ variances; and a, b are the linear fitting parameters.

The E_2 energies for the α_0^{20} groups were obtained using the relation

$$E_2(\alpha_0^{20}) = E_2(\alpha_0^{16}) - b.[K(\alpha_0^{16}) - K(\alpha_0^{20})]. \qquad (3)$$

The uncertainty in this energy is given by:

$$\sigma_{E_2^{20}} = [(\sigma_{E_2^{16}})^2 + b^2(\sigma_{\Delta K})^2 + (\Delta K)^2 (\sigma_b)^2]^{1/2}, \qquad (4a)$$

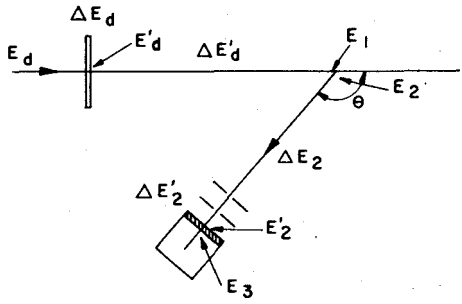

Figure 3 – Energy losses of the reaction particles. The notation is used in the text.

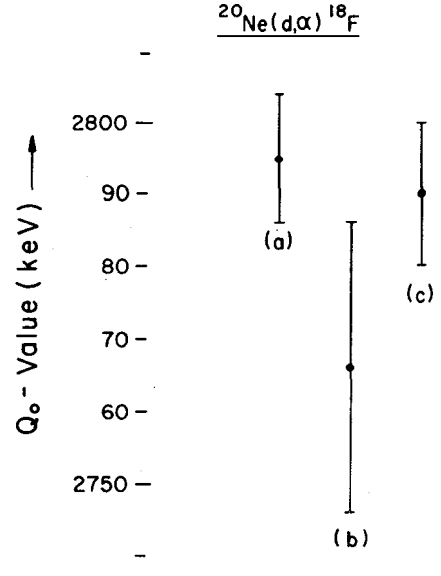

Figure 4 – Comparison among the existing experimental determinations of the ^{20}Ne (d, α)^{18}F Q_0-value: (a) Mileikowsky (Ref. *5)*, (b) López and Almén (Ref. *5)*, (c) This work.

where, in a simplified notation,

$$\Delta K = K_0^{16} - K_0^{20} \text{ and } \sigma_{\Delta K} = [(\sigma_{K_0^{16}})^2 + (\sigma_{K_0^{20}})^2]^{1/2}. \qquad (4b)$$

Finally, knowing the E_2^{20} values, for each spectrum, the Q_0-values were calculated using the nonrelativistic kinematic relations for extracting explicitly the Q dependence on the other variables (E_1, E_2 and θ). The standard procedure for the error propagation was used.

θ_{Lab}	$E_2(\alpha_0^{20})$ (KeV)	Q_0 (KeV)
40^0	4318.4 ± 6.5	2791 ± 10
45^0	4269.7 ± 6.5	2789 ± 10
50^0	4217.6 ± 6.5	2789 ± 10
60^0	4106.0 ± 6.6	2789 ± 10

Table II — Results of this work of Q_0-values for ^{20}Ne(d, α)^{18}F and of E_2 (ai^0).

Since the errors of the four Q_0-values are the same (see Table 2), a simple arithmetic mean was used to calculate an average value. The assignment of an error to this average value however is not so straightforward. The four measurements are not totally independent because they are linked by the systematics of the experimental method used. The only non-systematic component of σ_{Q0} comes from σE_2^{20}, where the major contribution is given by the $(\Delta K)^2\sigma_b^2$ term in (4a). Whereas the assignment of this non-systematic contribution is somewhat dubious, we prefer to quote with the average value an error equal to the error of each individual measurement. This certainly overestimates the experimental uncertainty in the average value.

5. Results and Conclusions

Table 2 lists the results for the experimental Q_0-values obtained in the present work. The average value $Q_0 = 2790 \pm 10$ KeV is compared to the two previous determinations[5] in Fig. 4.

It can be observed that our value is in good agreement with the recalibrated value[5] of Mileikowsky[3]. Good agreement is also observed with the value obtained from the most recent atomic mass table[2].

Our measurements being relative to the Q_0-value of the ^{16}O (d, α)^{14}N reaction, any change in the accepted Q-value for this reaction will correspondly modify our results. However, changes in the Q-values of the (d, p) reactions used in the spectra calibration will not lead to correction of the same order since in this case the E_7^{20} dependence on any individual (d, p) Q-value is small compared to the linear dependence on E_2^{16}. The data presented in tables 1 and 2 should suffice for the determination of recalibrated values.

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