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NUCLEAR STRUCTURE: Neon 21
NEON 21: Nuclear Structure
ENERGY LEVELS: Nuclear structure
THERMAL NEUTRONS: Neon 21
NEON 21: Energy levels
RADIATION DETECTORS: Neon 21
CAPTURE: Thermal neutrons
Q-VALUE: Thermal neutrons
CROSS SECTIONS: Thermal neutrons
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ABSTRACT

Energy levels of ^{21}Ne up to 6.76 MeV have been studied by measuring the thermal neutron capture gamma-rays from natural neon. A coaxial Ge(Li) detector was used. Energies and intensities were measured relative to calibration lines of nitrogen. The Q-value and the cross section of the reaction ^{20}Ne(n, γ)^{21}Ne were calculated. The proposed level scheme is discussed in terms of the Nilsson model, considering the coupling of one particle to the ^{20}Ne core. Coriolis coupling is taken into account for the three positive parity bands with $K^{\pi} = 3/2^+$, $1/2^+$ and $5/2^+$. Measurements were made at the IEAR-1 research reactor of the Instituto de Pesquisas Energéticas e Nucleares, São Paulo.

INTRODUCTION

The nuclei of the 2s-ld shell are known to have stable deformations. Accordingly, many successful attempts(2,3,5,7) have been made to interpret the properties of these nuclei in terms of the Nilsson model(10).

The nucleus ^{21}Ne has a well established prolate deformation and its several excited states up to 5 MeV have been interpreted in terms of rotational bands(14,15) Several investigations have been carried out on this nucleus using different reactions and the Nilsson model has been applied with refinements by every author.

In our experiment, we could not improve very much in relation to previous (n, γ) measurements, but we had better conditions of background (no lines of the reactor structural material were observed) and we used a very good peak analysis(6). Some previously undetected transitions were placed in the level scheme.

In the model calculations, we used some new informations about spins and parity of levels and also tried to improve the parameters of the model.

EXPERIMENTAL PROCEDURE AND ANALYSIS

The experimental facility(Figure 1) is installed in a tangential through channel of the 2 MW research reactor of the Instituto de Pesquisas Energéticas e Nucleares; a detailed description was given previously(11).

The thermal neutron flux at the target position was 3.6×10^{12} n cm^{-2}s^{-1}. A coaxially drifted detector of 42.5 cm^3 volume was utilized; the energy resolution was 2.7 keV at 1332.4 keV and 7.6 keV

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at 7200 keV. The gamma spectra were accumulated in a HEWLETT--PACKARD 8192-channel analyser. Digital stabilization was used to avoid baseline and gain drifs.

We performed two measurements, in the first of which the reactor tube was filled with pure natural neon at 4 atm; in the second we used a mixture of nitrogen (.75 atm) and neon (2.25 atm) in order to have an energy and intensity calibration[18] of the spectrometer. Spectral analysis was carried out by the GAUSS V[6] program which uses a gaussian plus a sloping background. Part of the calibration spectrum is shown in Figure 2. The energy and intensity of the neon lines calculated in relation to nitrogen[1] are presented in Table I.

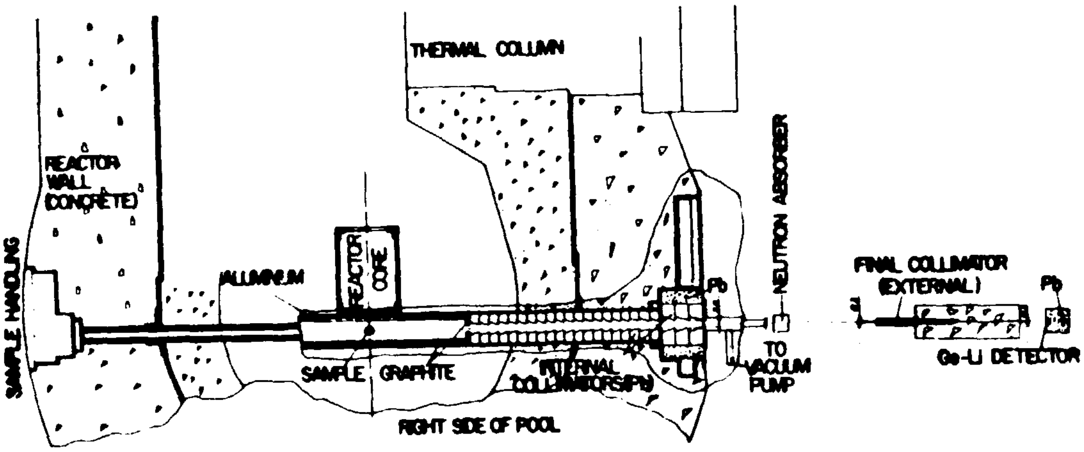

Figure 1 – Experimental Facility.

The level scheme (Figure 3) was established by means of a computer program using our energies and intesities and information from the literature[15,9]. The intensity balance is presented in the Table II; some levels not confirmed by this balance were placed on the basis of previous measurements, because in our experiment, these levels are determined by very weak transitions.

The cross section for thermal neutron capture in ^{20}Ne was determined relatively to the nitrogen value[1] (75 ± 7.5 mb); the obtained result is 41.8 ± 7.6 mb.

The Q-value of the reaction $^{20}Ne(n,\gamma)^{21}Ne$ was determined as the mean value of the sum of the transition energies of several cascades which link the capture level to the ground state. The result is 6760.2 ± 1.7 keV.

These values are in good agreement with previous measurements[1,2].

DISCUSSION

A description of the nucleus ^{21}Ne in terms of the rotational model is more or less established[15]. At least the states below 5 MeV are reasonably well interpreted by this model. Five rotational bands have been identified in this energy region.

In our experiment, the high spin states are very weakly populated because high angular momentum transfer is involved (high spin states can only be populated from a 1/2 capture state by gamma-rays of high multipolarity). For these states we use the available results[9] to illustrate the model performance. A detailed description of the calculations was already given[17].

Table I

Experimental Results

This Work			Bellmann[1]	
E(keV)	E + Er(keV) *	I(γ/100 capt)	E(keV)	I(γ/100 capt)
350.9 ± 0.6	350.9 ± 0.6	32.1 ± 1.4	350.0 ± 0.4	64.2 ± 3.4
583.4 ± 0.7	583.4 ± 0.7	4.0 ± 0.4	–	–
767.2 ± 1.8	767.2 ± 1.8	3.1 ± 1.6	767.6 ± 1.3	3.2 ± 1.0
935.4	935.4 ± 1.2	1.7 ± 0.5	–	–
1140.1	1140.4 ± 2.7	1.1 ± 0.5	1141.0 ± 1.4	2.1 ± 0.7
1072.4 ± 0.4	1072.4 ± 0.4	10.9 ± 0.8	1070.2 ± 0.5	10.6 ± 1.1
1397.7 ± 2.4	1397.7 ± 2.4	0.6 ± 0.2	1398.2 ± 1.0	4.1 ± 0.8
1740.1 ± 3.2	1740.1 ± 3.2	1.4 ± 0.3	–	–
1930.9 ± 0.2	1930.9 ± 0.2	17.3 ± 0.9	1929.5 ± 0.2	16.1 ± 0.5
2035.3 ± 0.2	2035.7 ± 0.2	77.5 ± 3.6	2034.8 ± 0.4	61.6 ± 1.7
2256.9 ± 1.0	2256.0 ± 0.6	0.9 ± 0.3	2254.8 ± 1.1	2.2 ± 0.3
2437.7 ± 1.1	2437.8 ± 1.1	0.9 ± 0.2	2437.6 ± 0.6	2.7 ± 0.4
2794.1 ± 0.1	2794.3 ± 0.1	26.0 ± 1.2	2793.6 ± 0.4	23.5 ± 0.3
2895.6 ± 0.2	2895.8 ± 0.2	6.8 ± 0.4	2893.9 ± 0.5	5.3 ± 0.4
3095.5 ± 0.6	3095.7 ± 0.6	0.5 ± 0.1	3102.9 ± 1.3	4.4 ± 1.4
3313.0 ± 0.8	3313.3 ± 0.8	0.5 ± 0.1	3320.2 ± 2.4	2.2 ± 1.0
3388.4 ± 1.0	3388.7 ± 1.0	1.0 ± 0.4	–	–
3383.6 ± 1.6	3383.9 ± 1.6	2.4 ± 0.8	–	–
3972.7 ± 0.9	3973.1 ± 0.9	1.3 ± 0.4	3973.7 ± 0.6	3.0 ± 0.3
4373.9 ± 0.1	4374.4 ± 0.1	45.8 ± 2.0	4374.0 ± 0.2	47.3 ± 0.8
4721.5 ± 1.0	4722.1 ± 1.0	1.1 ± 0.2	–	–
4985.4 ± 0.9	4986.1 ± 0.4	0.7 ± 0.3	–	–
5643.1 ± 0.8	5643.9 ± 0.8	1.5 ± 0.3	5642.3 ± 1.9	0.8 ± 0.3
5688.9 ± 0.2	5689.7 ± 0.2	5.4 ± 0.4	5688.7 ± 0.6	4.8 ± 0.4
5994.0 ± 1.5	5994.9 ± 1.5	1.0 ± 0.4	5993.6 ± 4.7	1.2 ± 0.2
6410.3 ± 0.5	6411.4 ± 0.5	0.8 ± 0.2	6415.4 ± 5.5	0.8 ± 0.4
6759.5 ± 0.4	6760.7 ± 0.4	5.4 ± 0.4	6759.9 ± 0.8	5.0 ± 0.3

*E_r – Recoil energy

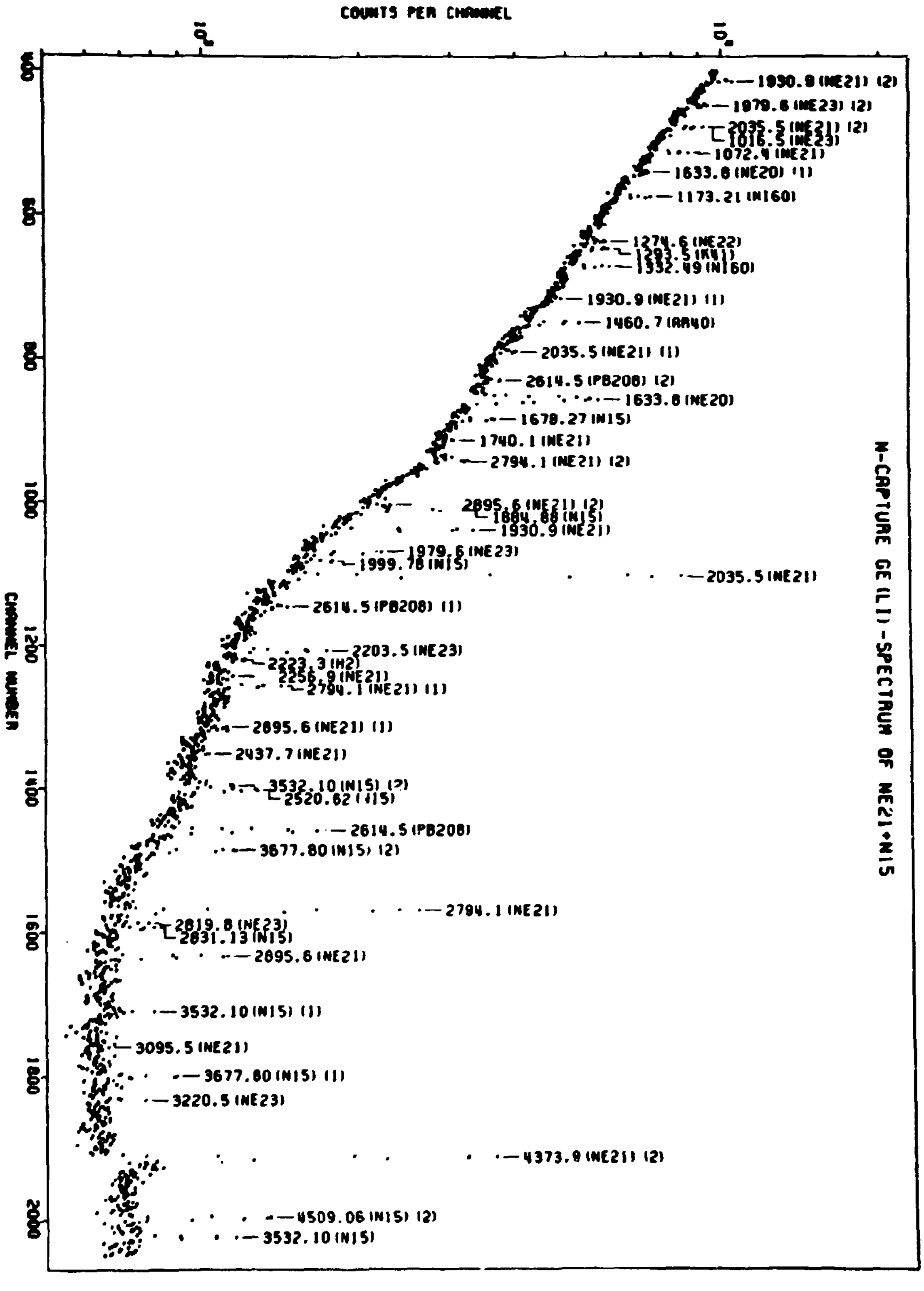

Figure 2a – Part of calibration spectrum from neutron capture in a mixture of Ne and N. Energies are in keV. Lines are identified by the product isotope. Single and double escape lines are denoted by (1) and (2), respectively.

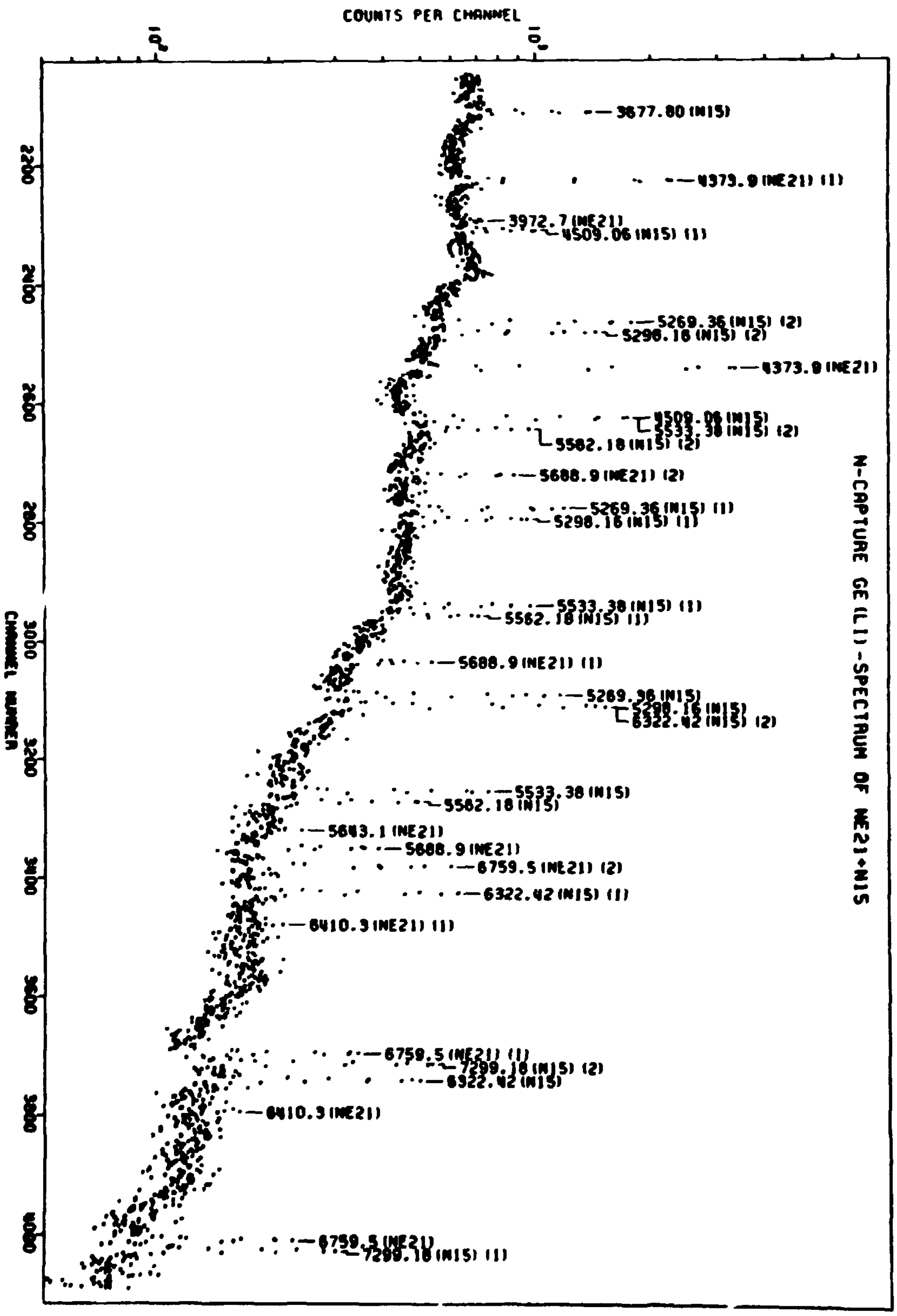

Figure 2b – Part of calibration spectrum from neutron capture in a mixture of Ne and N. Energies are in keV. Lines are identified by the product isotope. Single and double escape lines are denoted by (1) and (2), respectively.

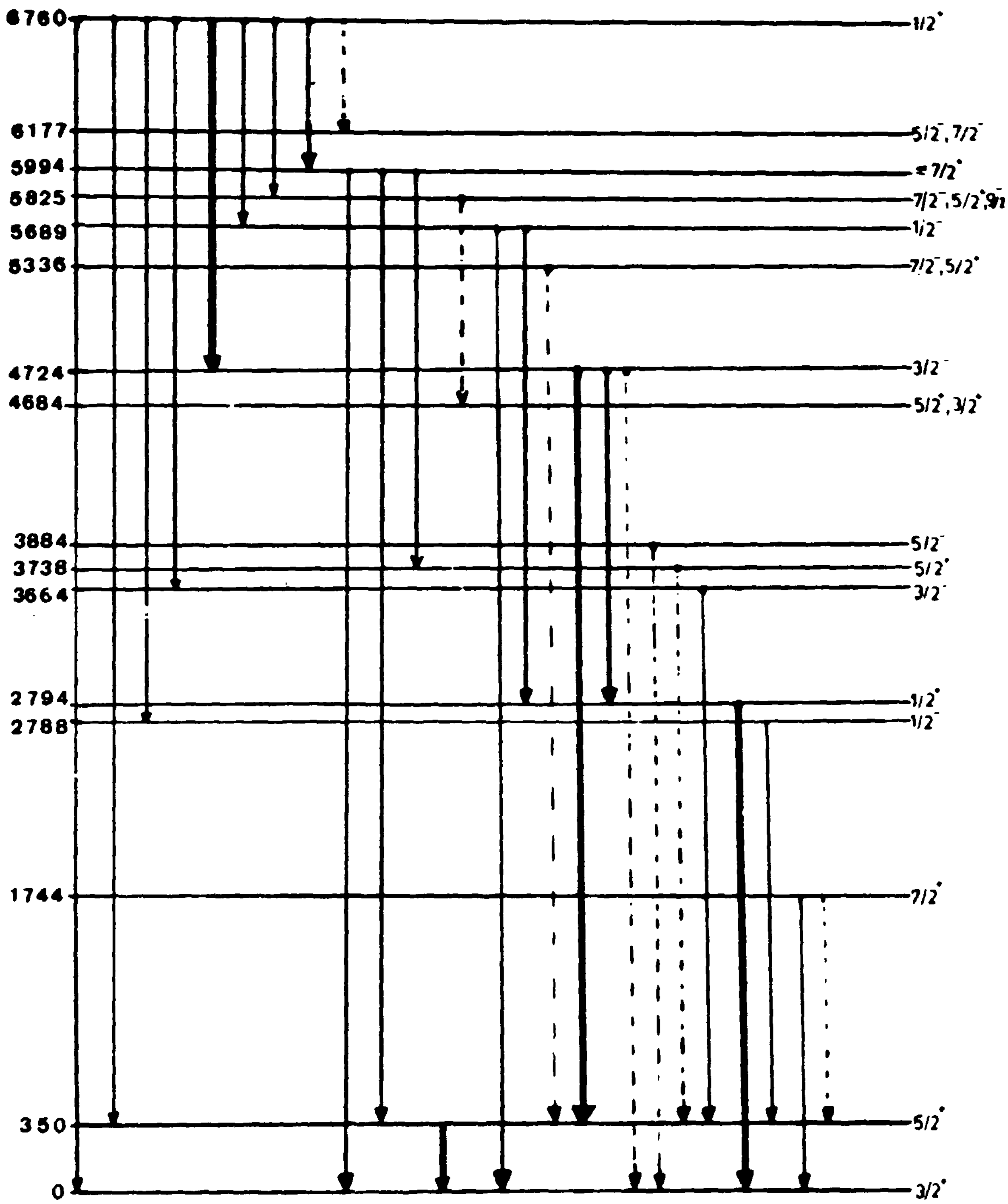

Figure 3 – Level Scheme of ^{21}Ne. Dashed lines indicate the weak transitions. Spins according to Hoffmann et al [11].

Table II

Intensity Balance

E(keV)	I_i/I_0 *
350.3 ± 0.5	55/32
1744.1 ± 4.0	/ 2
2787.5 ± 1.0	1.3/ 0.9
2794.2 ± 0.4	24.1/26
3664.4 ± 1.7	0.5/ 0.5
3735.0 ± 2.9	0.9/ 1.0
3883.6 ± 1.3	/ 2.4
4684.9 ± 2.0	–
4724.1 ± 3.0	77.4/64.2
5336.3 ± 2.0	/ 0.7
5689.8 ± 1.9	10.9/12.2
5994.8 ± 2.9	3.1/ 3.4
6177.3 ± 1.0	4.0/
6760.9 ± 0.3	I_0 = 5.4
5825.4 ± 2.9	1.7/ 1..

*I_i – feeding transitions
I_0 – decaying transitions

POSITIVE PARITY BANDS

The positive parity bands are based on the Nilsson states $3/2^+(211)$, $1/2^+(211)$, $5/2^+(202)$ corresponding to the ground state, 2794 keV and 3738 keV levels respectively. The ground state rotational band is known up to the 11/2 member(4433 keV) and its properties are well known[14]. Some authors[14,15] suggest the 6450 keV level as the $13/2^+$ member of this band, which could be identified with the 6721 keV($13/2^+$) level predicted by the rotational model. The eletromagnetic transition probabilities were calculated for intraband transitions; the comparison with experimental results[13] shows a good agreement. Band mixing influence due to the other two positive parity excited bands was taken into account. Results are shown in the Table III.

The rotational band $K^\pi = 1/2^+$ has only three identified members. There is some doubt concerning the two upper levels because they could have a reverted order; it seems that experimental results[4] indicate the $5/2^+$ member as the higher energy state. This is supported by the Nilsson model which predicts a decoupling parameter equal to 0.12; this is much less than necessary to explain that possible inversion.

In the $K^\pi = 5/2^+$ band, only the bandhead state and a possible second member[9] are known. Much more study on the high spin states is necessary before a clearly rotational picture can show up. The results of the adiabatic and nonadiabatic(band mixing) calculations are summarized in the Figure 4.

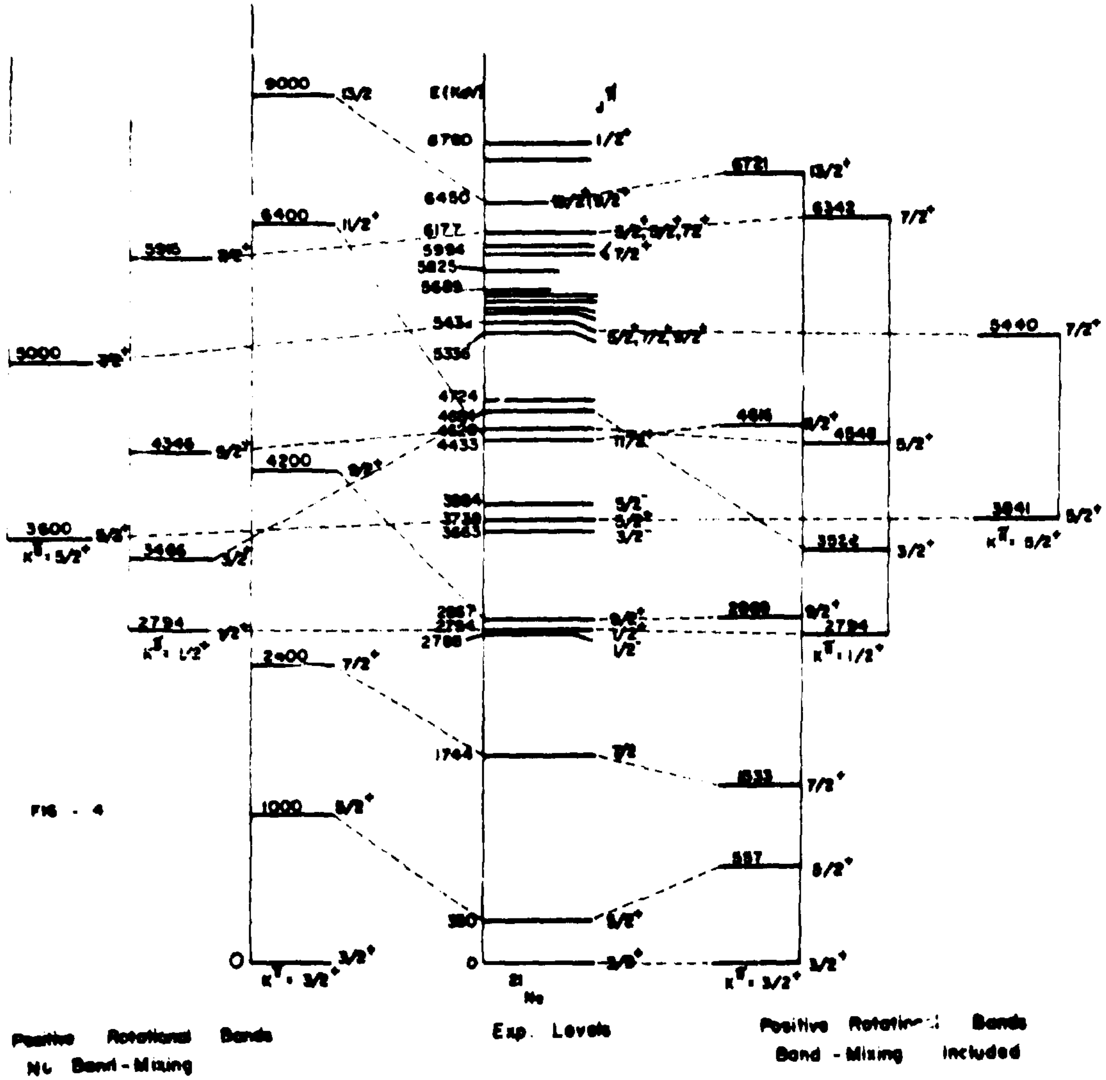

Figure 4 – Positive parity bands summary of adiabatic and nonadiabatic calculations.

Table III

Theoretical and Experimental Ground State Band Transition Probabilities

B(E2) (10^{-2} e^2 b^2)			
I_i	I_f	This work (theoretical)	Pronko et al[15] (exp.)
11/2	9/2	0.19	0.13 ± 0.10
11/2	7/2	0.41	0.43 ± 0.19
9/2	7/2	0.26	0.21 ± 0.14
9/2	5/2	0.33	0.22 ± 0.07
7/2	3/2	0.37	0.24 ± 0.10
7/2	3/2	0.24	0.16 ± 0.06
5/2	3/2	0.52	0.17 ± 0.09
B (M1) (in units of μ_N^2)			
9/2	7/2	0.69	0.22 ± 0.06
7/2	5/2	0.37	0.13 ± 0.04
5/2	3/2	0.09	0.06 ± 0.02

NEGATIVE PARITY BANDS

Two negative parity bands were identified in ^{21}Ne. The $K^\pi = 1/2^-$ band is based on the Nilsson state $1/2^-(101)$ (corresponding to the 2789 keV level) which is obtained by promoting a nucleon from the orbit 4 to the orbit 7. The predicted decoupling parameter is 0.46. The $3/2^-$ and $5/2^-$ members of this band would be the levels at 3664 and 3884 keV respectively. The E2 strengths of the $3/2^- \longrightarrow 1/2^-$ and $5/2^- \longrightarrow 1/2^-$ transitions are considerably enhanced over the single particle rates[12]; this fact supports the interpretation of those states as members of a rotational band.

The other band is built on the Nilsson orbit $1/2^-(330)$ which corresponds in our level scheme to the 5689 keV level. The next member would be the 4725 keV level. The reverted order can be explained by the decoupling parameter value which is equal to - 2.73. As experimental information is very limited, band mixing calculations were not performed for these two bands.

MODEL PARAMETERS USED IN THE CALCULATIONS

Nuclear deformation σ = .45

Inertial parameter $\hbar/2I$ = .20 MeV

Oscillator quantum $\hbar\omega_0$ = 41 $A^{-1/3}$MeV

Intrinsic quadrupole moment Q_0 = .52 ± .04 e.b.

Parameters χ and μ of the Nilsson Hamiltonian for different shells:

N = 1 χ = .068 μ = 0

$N = 2 \quad \chi = .068 \quad \mu = .19$

$N = 3 \quad \chi = .068 \quad \mu = .35$

RESUMO

Foi realizado um estudo dos níveis de energia do ^{21}Ne até 6,76 MeV por meio de medidas dos raios gama de captura de nêutrons térmicos em neônio natural utilizando um detector de Ge(Li). Energia e intensidades foram medidas usando como calibração as linhas do nitrogênio. Também foram calculados o valor Q e a secção de choque para a captura de nêutrons térmicos da reação $^{20}Ne(n,\gamma)^{21}Ne$. O esquema de níveis proposto é discutido em termos do modelo de Nilsson, considerando o acoplamento de uma partícula ao caroço formado pelo ^{20}Ne. É levada em conta a interação de Coriolis para as três bandas de paridade positiva com $K^{\pi} = 3/2^+$, $1/2^+$ e $5/2^+$ As medidas foram realizadas no reator de pesquisa IEAR-1 do Instituto de Pesquisas Energéticas e Nucleares, São Paulo.

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