EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/ 91.126
13.08.1991

STUDY OF NEUTRON RICH NEON ISOTOPES

O. Tengblad[1], M.J.G. Borge[2], L. Johannsen[3], B. Jonson[4], M. Lindroos[4],
T. Nilsson[4], G. Nyman[4], A. Poves[5], H.L. Ravn[1], J. Retamosa[5], K. Riisager[3],
P. Sona[6], K. Wilhelmsen[4] and the ISOLDE collaboration.

[1] ISOLDE, CERN, Geneva, Switzerland
[2] Instituto de Quimica-Fisica "Rocasolano", Madrid, Spain
[3] Institute of Physics, Univ. of Aarhus, Aarhus, Denmark
[4] Dept. of Physics, Chalmers Univ. of Techn., Göteborg, Sweden
[5] Dept. de Física Teórica, Univ. Autónoma, Madrid, Spain
[6] Dipt. di Fisica, Largo E. Fermi, Firenze, Italy

Abstract

The half-lives and P_n-values of the neutron rich isotopes $^{26\text{-}29}$Ne have been determined. The results are compared to shell-model calculations and good agreement is found except for ^{29}Ne, where the half-life exceeds the predictions by more than an order of magnitude. This unexpectedly long half-life can be explained as due to a fp intruder configuration.

PACS: 27.30.+t ; 21.90.+f ; 23.90.+w

(IS01-31)

(Submitted to: Z. Physik A, August 1991)

1. Introduction

A new type of nuclear structure has been found in the family of nuclei close to the neutron drip-line. The last neutron or neutron pair, being almost unbound, is allowed to move quite far out from the nuclear core thus forming an extensive diffuse neutron skin, called the neutron halo [1]. The experimental evidence has mainly come from high and intermediate energy reactions with radioactive beams, where the large radii of the most exotic projectiles give rise to increased cross-sections [2-4]. Most of the work, experimental as well as theoretical, has so far been concentrated on light drip line nuclei like ^{11}Li. It would clearly be valuable to extend the measurements to heavier nuclei with well developed neutron halos. The isotopes along the neutron drip-line have now been produced and identified up to neon [5-8], mainly due to systematic searches carried out at GANIL. These experiments, however, only prove the existence (i.e. the stability with respect to prompt particle emission) of an isotope. In order to predict in which isotopes neutron halos will be present one must know their neutron separation energies. In dedicated experiments at Los Alamos [9] and GANIL [10-12] most of the atomic masses in this region have been measured.

Several isotopes with a potentially low neutron separation energy are summarized in Table 1, where also extrapolations based on the experimental data [13] are included. These nuclei have in this mass region a tendency to occur in pairs, neighbouring isobars having one-neutron and two-neutron halos, respectively. The elements carbon and neon seem particularly interesting.

Isotope	$S_n$$^{a)}$ (MeV)	$S_{2n}$$^{a)}$ (MeV)
^{11}Li		0.24 ± 0.08
^{11}Be	0.504 ± 0.006	
^{19}B		0.5 ± 0.4
^{19}C	0.17 ± 0.11	
^{22}C		1.3 ± 0.9
^{29}F		-0.2 ± 0.6^{b}
^{29}Ne	1.1 ± 0.5	
^{32}Ne		0.5 ± 1.2^{b}

a) ref. [13].

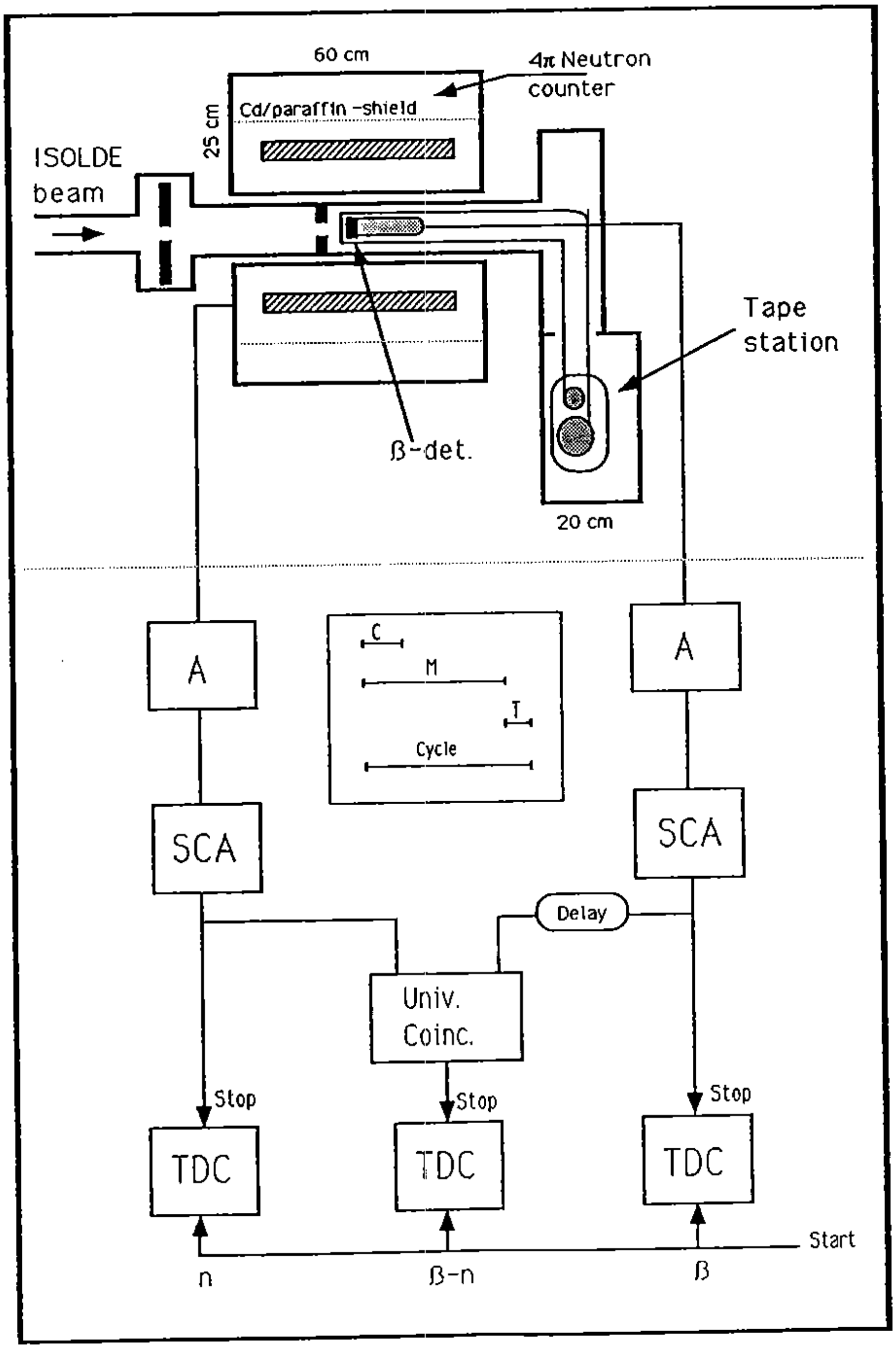
b) ^{29}F and ^{32}Ne are known [7,8] to be particle stable.

We report here on the beta decays of the heavy neon isotopes (A = 26 - 29), a region which has not been studied earlier. The change in structure associated with the neutron halo should also manifest itself in the beta decay, see e.g. refs [14,15]. Although the present experiment is only intended as an exploratory study of the region, the quantities measured, half-lives and neutron emission probabilities, will give a first indication of the structure of these nuclei. The experimental procedures are described in section 2, the results are given in section 3 followed by a discussion and outlook in the last section.

2. Experimental technique

The decay properties of neutron rich Ne-isotopes were investigated at the ISOLDE-facility at CERN. The nuclides were produced in spallation reactions induced by the 910 MeV $^{3}He^{2+}$ beam, of intensity 1.3 μA, from the CERN synchrocyclotron in a 55 g/cm^{2} thick ThC-graphite target connected to a plasma ion-source by a cooled transfer line [16].

Fig 1 shows schematically the experimental set-up. The radioactive neon beam was collected on a tape 2.4 mm in front of an energy-loss ß-detector placed in the center of a 4π neutron counter. Optimized with regard to the isotope under investigation the tape transport system was programmed to perform periodic cycles of Collection/Measurement /Transport. The number of neutrons, beta particles and beta-neutron coincidences (measured in slow coincidence mode) were recorded as function of time using standard NIM electronics and Time to Digital Converters (TDC) connected via CAMAC and Ethernet to a VAX750 computer.



The β-detector used was a NE102A plastic scintillator (5 mm diameter, 1 mm thick) glued on to a PM1911 photomultiplier. It was placed in vacuum inside a stainless steal tube connecting the beam line and the tape station. For the calibration of the ß and neutron detectors a beam of ^{9}Li, which has a well established decay scheme, was used. The known decay of ^{9}Li was also used to determine the efficiency of the beta detector. The background in the ß-detector amounted to less than 0.5 counts/s. The 4π neutron counter [17], which has an efficiency of 20%, consists of 12 ^{3}He-gas proportional counters imbedded in paraffin and surounded by a paraffin/cadmium background shield. The background count-rate in the neutron counter was less than 0.3 n/s.

Timing of the measuring cycle, control of beam gate and step motor drive of the tape transport as well as dispatch of the common start signal to the TDC's were controlled by a Sinclair QL computer equipped with a 68008 processer, a specially designed parallel interface and an external high precision clock.

3. Results

A mathematical function describing the decay chain was fitted to the obtained time spectra by the method of minimizing chi-square [18]. The function has 5 free parameters: the direct production of neon and sodium, the half-lives $T_{1/2}$(Ne) and $T_{1/2}$(Na), and the background. In low statistics spectra the sodium parameters were taken from known data and kept fixed. In all cases both ß- and neutron spectra were analysed. The experimental data and the respective fits are shown in figure 2-4. The experimentally determined half-lives and neutron-branching ratios (P_n) are summarized, together with literature values, in Table 2.

Table 2.
Half-lives and P_n-values for the new neutron rich Neon isotopes and their production at ISOLDE

Isotope	Yield	$T_{1/2}$ (ms)			P_n (%)		
	(Atoms/s)	this work	other experiments	theory	this work	other experiments	theory
^{9}Li	$7.4\ 10^{4}$	178 ± 1	178.3 ± 0.3 [a]	—	51 ± 1	50 ± 3 [f]	
^{26}Ne	$3\ 10^{3}$	197 ± 1	230 ± 60 [g]	162 [c]	0.13 ± 0.03	< 8 [b]	0.7 [e]
^{27}Ne	$2\ 10^{2}$	32 ± 2	—	35 [c]	$2.0 \pm .5$	< 12 [b]	9 [e]
^{28}Ne	$2\ 10^{2}$	17 ± 4	14 ± 10 [b]	16.9 [c]	22 ± 3	16 ± 9 [b]	18 [e]
^{29}Ne	> 20	200 ± 100	—	7.4 [c]	—	—	—
^{26}Na	(25 %)	1074 ± 6	1072 ± 9 [c]	—	—	—	—
^{27}Na	(25 %)	—	304 ± 7 [d]	—	—	0.11 ± 0.04 [d]	—
^{28}Na	—	—	30.5 ± 0.4 [d]	—	—	0.83 ± 0.17 [d]	—
^{29}Na	—	—	42.9 ± 1.5 [d]	—	—	21.6 ± 2.6 [d]	—

a D. E. Alburger and D.H. Wilkinson, Phys. Rev. C13 , 835 (1976)
b P.L. Reeder et.al. ref. [31]
c B.H. Wildenthal et.al. ref. [20]
d E. Roeckl et.al. ref. [30], (P_n values rescaled with the corrected value for ^{9}Li from ref. [33])
e deduced as in ref. [27]
f G. Nyman et.al. ref. [19]
g D. Jean; ref [28]

The yields are, especially for the shortlived isotopes, very dependent on the target and ion-source conditions. During the experiment we first took data on mass 26 and 27. As the initial activities of masses 28 and 29 were small, the target and ion-source settings were reoptimized. This explains why the yields given for ^{27}Ne and ^{28}Ne in Table 2 are identical.

Calibration, ^{9}Li: A ^{9}Li beam produced in a Ta-foil target connected to a surface ion-source was used for calibration of the set-up. The well documented decay of ^{9}Li [19] assured that both the equipment and the analysis method worked as expected and that the absolute efficiency of the ß-detector could be determined to be 8.5%.

Mass 26: In the case of mass 26 the high yield allowed us to analyze the measured decay curves of beta and neutron singles as well as the ßn-coincidences. This gave two possible ways of determining the P_n-value; a) by using the ratio between the number of beta-neutron coincidences and the number of betas or neutrons respectively and b) by using the ratio of the number of neutrons to the number of betas. The intensity also allowed for two independent measurements of the neon half-life. All 5 parameters of the fit function could be let free and thus the sodium half-life and the direct production (contamination) of sodium were determined.

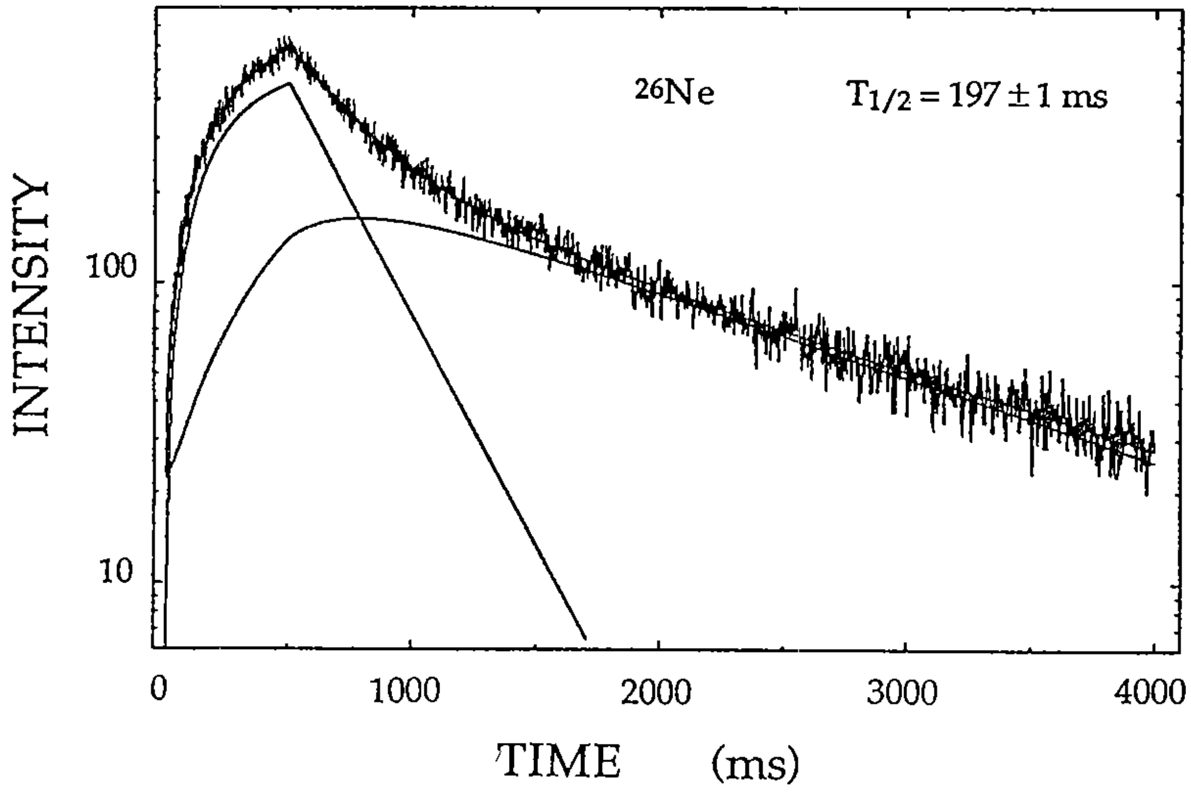


Figure 2 The beta-intensity for mass 26 is shown on a logarithmic scale as a function of time. The activity collected for 500 ms, was allowed to decay for 3500 ms and then transported away. The curve shows the computer fit to the ß-decay curve, and its decomposition into contributions from the ^{26}Ne and ^{26}Na decay.

Mass 27: The statistics obtained in the spectra of this isotope did not allow for all parameters to be let free during the fitting procedure. Instead we used the literature value for the ^{27}Na half-life [30] and assumed the percentage direct production of ^{27}Na to be the same as for the case of mass 26. These two parameters were, in order to obtain the uncertainty, varied by hand in different fits.

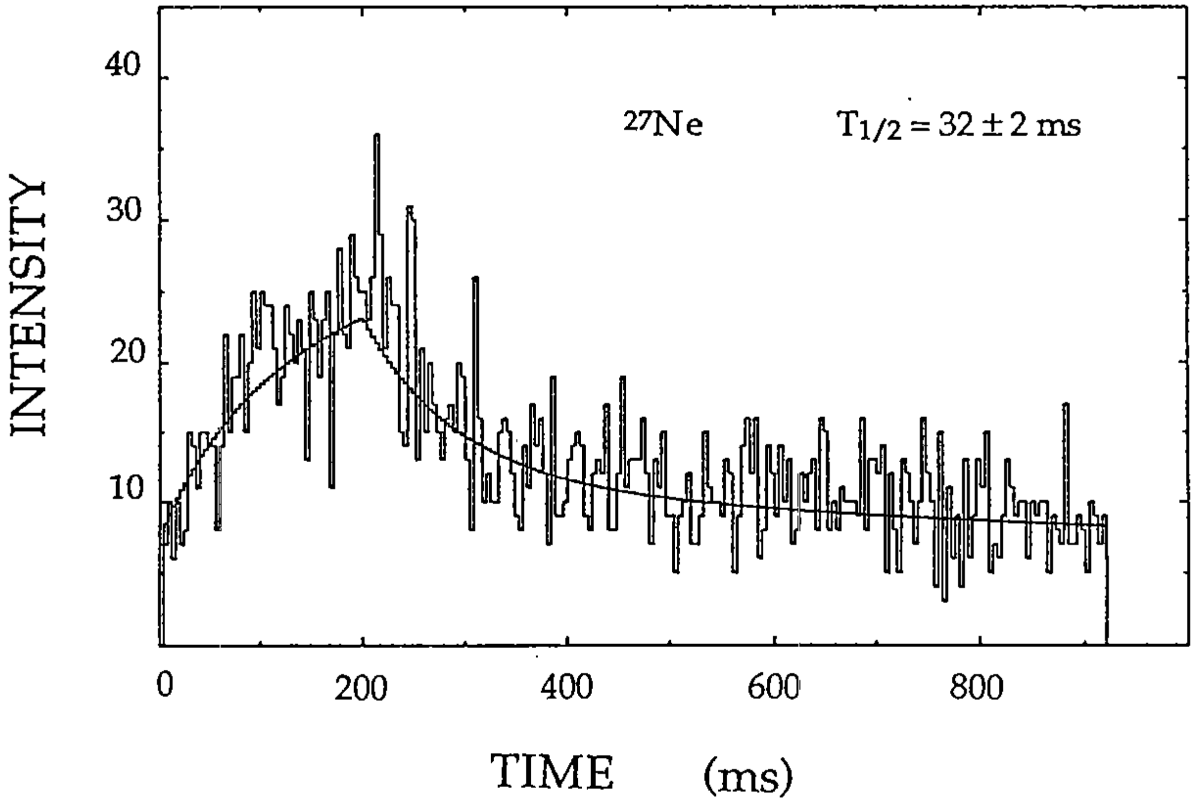


Figure 3 The ß-intensity for mass 27 is shown on a linear scale as a function of time. The activity collected for 200 ms was allowed to decay for 800 ms. The solid curve is a fit to the decay curve.

Mass 28: In the same way as for mass 27 the sodium parameters were kept fixed during the fit but varied by hand in order to obtain the uncertainty. In this case long-lived contaminant activities were present as molecular beams giving rise to a higher but constant ß-background. The beta spectrum could thus not be trusted for the P_n-evaluation. The half-life was obtained from fitting the neutron spectrum.

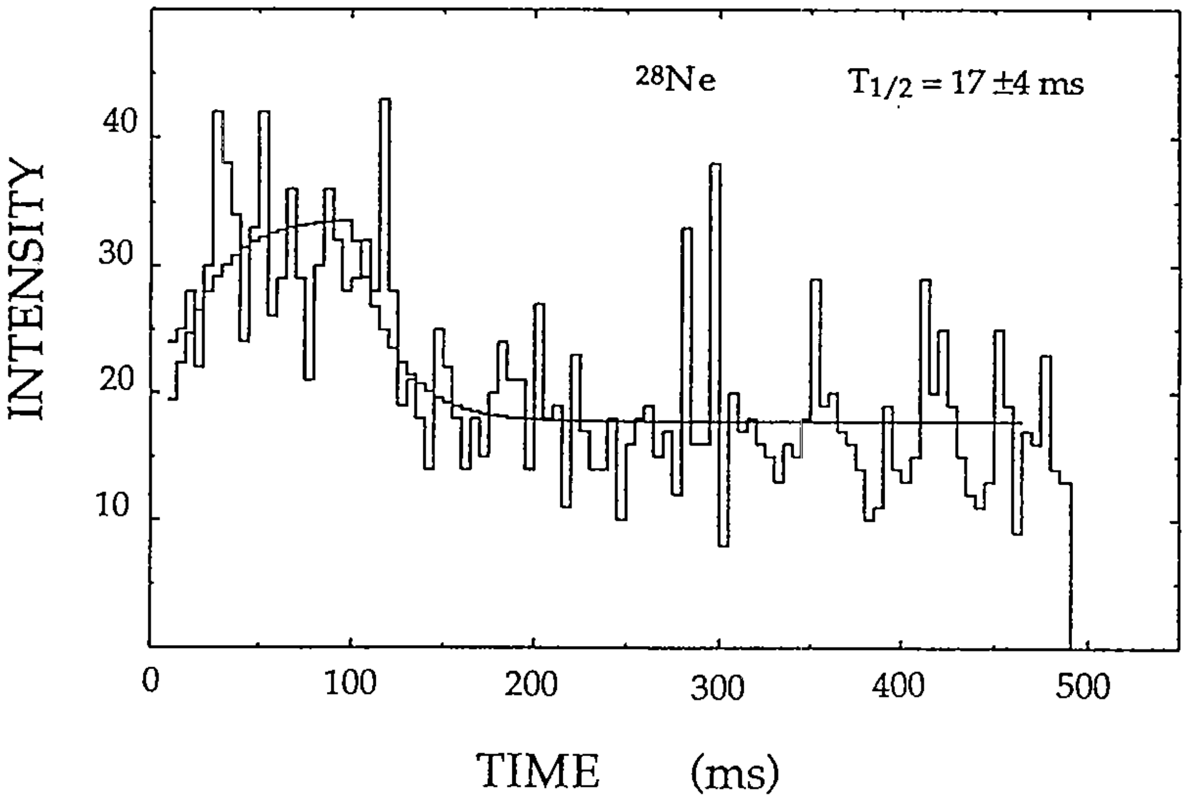


Figure 4 The neutron-intensity for mass 28 shown as a function of time on a linear scale. The activity collected for 100 ms was allowed to decay for 400 ms.The solid curve is a fit to the data, note the background.

Mass 29: The presence of $^{87}Kr^{+++}$ as a contaminant on this mass prohibited any unambiguous analysis of either the ß-spectrum or the coincidence spectrum. However, the ß-spectrum shows an ingrowing activity with a half-life in the order of 350 ms.

The neutron data show an activity amounting to 7500 neutrons above background, equivalent to a yield of at least 20 atoms/s. These neutrons cannot come from the contaminant as there are no neutron emitters following the ^{87}Kr decay and the indicated half-life is too long to be ^{29}Na. The half-life is difficult to fit properly as it turns out to be much longer than expected and thus the choosen cycle periods were not optimal. However, the computer fits of the neutron spectra indicate a half-life of 200 ± 100 ms.

4. Discussion and outlook

Several recent calculations [20-22] exist of ß-decay properties in light neutron-rich nuclei (see [23] and references therein for experimental tests). Table 2 includes the published half-life predictions; these depend critically on the Q-value used in the calculations, but one can note that the shell-model calculations [20] nevertheless give remarkably good predictions up to mass 28. Extrapolations to heavier isotopes cannot be a priori reliable, as the extent of the intruder region [24-26] around ^{31}Na, still is unknown. The P_n-values can be compared to the rough estimate [27]

$$P_n = 0.51 \left(\frac{Q_ß - S_n}{Q_ß - C} \right)^3$$

where $C = 0$ for even neutron number

$C = \frac{13}{\sqrt{A}}$ for odd neutron number

which gives 7 10^{-3}, 0.09 and 0.18 for ^{26}Ne, ^{27}Ne and ^{28}Ne, respectively. The small P_n -value found experimentally for ^{26}Ne is consistent with the strong ß-feeding to states close to the ground state in ^{26}Na [20,28].

The case of ^{29}Ne is of special interest since it is very close to the N=20 region which has been shown to be at the onset of deformation [29]. We have performed 2p2h intruder calculations as described in [29]. Using the single particle energy gap obtained for this region [29], and allowing for 2 neutrons to move over the sd shell closure out to the fp shell we obtain a 97% intruder configuration in the ^{29}Ne ground state. The Gamow Teller decay to ^{29}Na is thus strongly hindered and the half-life is prolonged considerably. By varying the single particle energy gap we change the amount of intruder from true sd (i.e. 0%) to 97% intruder configuration. In this way we can follow the increase in half-life from 7.4 ms (sd) through 18 ms (50% intruder) to 318 ms (97% intruder). Our experimental data clearly point towards a half-life much longer than predicted by a sd calculation, and thus strongly favour the presence of intruder states. An extension of this calculation is done where we follow the fp "di-neutron" component of the GT ß-decay into the highly excited "deuteron" mirror state in the daughter [15].

The average production yields during our experiment are listed in Table 2. For comparison, production rates at GANIL reach about 100 s^{-1} for ^{26}Ne [28] and 3 10^{-3} s^{-1} for ^{30}Ne [6]. Our yields are, however, not optimized. The Ne ionization efficiency measured for our ion-source is 0.5 %; one obvious improvement would be to use an ECR ion source whose efficiency for neon is measured to be 31% [32] i.e. a factor 60 better than our plasma ion-source. Furthermore, the ISOLDE installation is at the moment being moved to the PS Booster accelerator, which delivers pulsed proton beams of 1 GeV energy. The higher energy together with the short pulse structure of that beam could lead to 10 times more rapid diffusion out of the target; both factors would increase the yield of the shortlived nuclei close to the neutron dripline. The mass resolution of the separators at the new ISOLDE facility will be higher than at ISOLDE-2, which will help to decrease the problems with contaminants seen here on mass 28 and 29. We therefore expect that the better mass resolution will give a clean ^{29}Ne beam so that the major characteristics of its ß-decay can be definitely determined.

References

1. Hansen, P.G., Jonson, B.: Europhys.Lett. 4, 409 (1987)
2. Tanihata, I., Hamagaki, H., Hashimoto, O., Shida, Y., Yoshikawa, N., Sugimoto, K., Yamakawa, O., Kobayashi, T., Takahashi, N.: Phys.Rev.Lett 55, 2676 (1985)
3. Kobayashi, T., Shimoura, S., Tanihata, I., Katori, K., Matsuda, K., Minamisono, T., Sugimoto, K., Müller, W., Olson, D.L., Symons, T.J.M., Wieman, H.: Phys.Lett. 232B, 51 (1989)
4. Anne, R., Arnell, S.E., Bimbot, R., Emling, H., Guillemaud-Mueller, D., Hansen, P.G., Johannsen, L., Jonson, B., Lewitowicz, M., Mattsson, S., Mueller, A.C., Neugart, R., Nyman, G., Pougheon, F., Richter, A., Riisager, K., Saint-Laurent, M.G., Schrieder, G., Sorlin, O., Wilhelmsen, K.: Phys.Lett. 250B, 19 (1990)
5. Langevin, M., Quiniou, E., Bernas, M., Galin, J., Jacmart, J.C., Naulin, F., Pougheon, F., Anne, R., Détraz, C., Guerreau, D., Guillemaud-Mueller, D., Mueller, A.C.: Phys.Lett. 150B, 71 (1985)
6. Pougheon, F., Guillemaud-Mueller, D., Quiniou, E., Saint Laurent, M.G., Anne, R., Bazin, D., Bernas, M., Guerreau, D., Jacmart, J.C., Hoath, S.D., Mueller, A.C., Détraz, C.: Europhys.Lett. 2, 505 (1986)
7. Guillemaud-Mueller, D., Penionzhkevich, Yu.E., Anne, R., Artukh, A.G., Bazin, D., Borrel, V., Détraz, C., Guerreau, D., Gvozdev, B.A., Jacmart, J.C., Jiang, D.X., Kalinin, A.M., Kamanin, V.V., Kutner, V.B., Lewitowicz, M., Lukyanov, S.M., Mueller, A.C., Hoai Chau, N., Pougheon, F., Richard, A., Saint-Laurent, M.G., Schmidt-Ott, W.D.: Z.Phys. A332, 189 (1989)
8. Guillemaud-Mueller, D., Jacmart, J.C., Kashy, E., Latimier, A., Mueller, A.C., Pougheon, F., Richard, A., Penionzhkevich, Yu.E., Artuhk, A.G., Belozyorov, A.V., Lukyanov, S.M., Anne, R., Bricault, P., Détraz, C., Lewitowicz, M., Zhang, Y., Lyutostansky, Yu.S., Zverev, M.V., Bazin, D., Schmidt-Ott, W.D.: Phys.Rev. C41, 937 (1990)
9. Vieira, D.J., Wouters, J.M., Vaziri, K., Kraus, R.H., Jr., Wollnik, H., Butler, G.W., Wohn, F.K., Wapstra, A.H.: Phys.Rev.Lett. 57, 3253 (1986)
10. Gillibert, A., Bianchi, L., Cunsolo, A., Fernandez, B., Foti, A., Gastebois, J., Gregoire, Ch., Mittig, W., Peghaire, A., Schutz, Y., Stephan, C.: Phys.Lett. 176B, 317 (1986)
11. Gillibert, A., Mittig, W., Bianchi, L., Cunsolo, A., Fernandez, B., Foti, A., Gastebois, J., Grégoire, C., Schutz, Y., Stephan, C.: Phys.Lett. 192B, 39 (1987)
12. Orr, N.A., Mittig, W., Fifield, L.K., Lewitowicz, M., Plagnol, E., Schutz, Y., Zhan Wen Long, Bianchi, L., Gillibert, A., Belozyorov, A.V., Lukyanov, S. M., Penionhkevich, Yu. E., Villari, A.C.C., Gunsolo, A., Foti, A., Audi, G., Stephan, C., Tasson-Got, L. : Phys. Lett. 258B, 29 (1991)
13. Audi, G.: private communication, july 1990
14. Borge, M.J.G., Hansen, P.G., Johannsen, L., Jonson, B., Nilsson, T., Nyman, G., Richter, A., Riisager, K., Tengblad, O., Wilhelmsen, K.: Z. Physik, in press.
15. Poves, A., Retmosa, J., Borge, M.J.G., Tengblad, O.: submitted to Phys. Lett.
16. Bjørnstad, T., Hagebø, E., Hoff, P., Jonsson, O.C., Kugler, E., Ravn, H., Sundell, S., Vosicki, B.: Physica Scripta 34, 578 (1986)
17. Tengblad, O.: MSc Thesis, Inst. of Phys., Chalmers, Gothenburg, Sweden, 1983
18. Bevington, P.A.: Data reduction and error analysis for the physical sciences. New York: McGraw-Hill 1969
19. Nyman, G., Azuma, R.E., Hansen, P.G., Jonson, B., Larsson, P.O., Mattsson, S., Richter, A., Riisager, K., Tengblad, O., Wilhelmsen, K.: Nucl.Phys. A510, 189 (1990)

20. Wildenthal, B.H., Curtin, M.S., Brown, B.A.: Phys.Rev. C28, 1343 (1983);
Brown, B.A., Wildenthal, B.H.: At. Data Nucl. Data Tables 33, 347 (1985)
21. Staudt, A., Bender, E., Muto, K., Klapdor, H.V.: Z.Phys. A334,47 (1989);
Staudt, A., Bender, E., Muto, K., Klapdor-Kleingrothaus, H.V.:
At. Data Nucl. Data Tables 44,79 (1990)
22. Tachibana, T., Yamada, M., Yoshida, Y.: Prog.Theor.Phys. 84,641 (1990)
23. Mueller, A.C., Guillemaud-Mueller, D., Jacmart, J.C., Kashy, E., Pougheon, F., Richard, A., Staudt, A., Klapdor-Kleingrothaus, H.V., Lewitowicz, M., Anne, R., Bricault, P., Détraz, C., Penionzhkevich, Yu.E., Artukh, A.G., Belozyorov, A.V., Lukyanov, S.M., Bazin, D., Schmidt-Ott, W.D.: Nucl.Phys. A513, 1 (1990)
24. Thibault, C., Klapisch, R., Rigaud, C., Poskanzer, A.M., Prieels, R., Lessard, L., Reisdorf, W.: Phys.Rev. C12, 644 (1975)
25. Baumann, P., Dessagne, Ph., Huck, A., Klotz, G., Knipper, A., Marguier, G., Miehé, C., Ramdane, M., Richard-Serre, C., Walter, G., Wildenthal, B.H.: Phys.Rev. C36, 765 (1987)
26. Baumann, P., Dessagne, Ph., Gabelmann, H., Huck, A., Klotz, G., Knipper, A., Marguier, G., Miehé, Ch., Poves, A., Ramdane, M., Richard-Serre, C., Schlösser, K., Walter, G.: Phys.Rev. C39, 626 (1989)
27. Kratz, K.-L., Herrmann, G.: Z.Phys. A263, 435 (1973)
28. Jean, D.: Thesis, University Bordeaux I 1987
29. Poves, A., Retamosa, J., " Theoretical study of the very neutron rich nuclei around N=20": submitted to Nucl. Phys.
30. Roeckl, E., Dittner, P.F., Détraz, C., Klapisch, R., Thibault, C., Rigaud, C.: Phys.Rev. C10, 1181 (1974).
31. Reeder, P.L., Warner, R.A., Hensley, W.K., Vieira, D.J., Wouters, J.M.: submitted to Phys. Lett.
32. Bechtold, V., Dohrmann, H., Sheikh, S.H.: Proc. 7:th Workshop on ECR Ion-sources. Jül-Conf-57, Jülich Germany, July 1986
33. Bjørnstad, T., Gustafsson, H. Å., Hansen, P.G., Jonson, B., Lindfors, V., Mattsson, S., Poskanzer, A.M., Ravn, H.L.: Nucl. Phys. A359, 1 (1981)

Imprimé au CERN. Prix : 0.50 Fr.