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PROPERTIES OF LIGHT NUCLEI VERY FAR FROM BETA STABILITY

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1. INTRODUCTION

This paper will be devoted to underlying the major developments which occured in the study of light nuclei far from the valley of stability since the last International Nuclear Physics Conference in Harrogate (1986) where that field of research was already presented (1). A broader review will appear elsewhere (2). Therefore only some highlights are presented and discussed here. Probably the main development of the field in recent years has to do with a change in its aims and methods. The goal is no longer to search for individual hitherto unobserved nuclear species and to report their existence. It has become to study the major nuclear properties such as binding energy, half life, size, decay modes over broad ranges of neighbouring isotopes extending very far from stability in order to put to a test the current nuclear models based essentially on observations of nuclei near the stability line.

That such an extension has been possible is due to the experimental opportunities open by new accelerator facilities. For the last few years, the fragmentation-like reactions of projectiles at intermediate energy, as performed at GANIL, have increased the yield of exotic nuclei by orders of magnitude. Even if the production process is not as effective as at GeV energies where thicker targets can be used and better zero-degree collection of the fragments can be achieved, the much higher beam intensities available provide for better overall efficiency. The upcoming availability of the SIS/ESR facility at GSI (3) might open new improved opportunities, although the continuous increase of intensities at intermediate-energy accelerators like GANIL will keep the present methods of exotic nuclei production competitive in the years to come (4).

Examples, mostly drawn from recent results obtained at GANIL, will concern spectroscopic studies far from stability (§ 2) where unusual proton and neutron configurations can be used to test nuclear models, binding energy results (§ 3) where theoretical predictions often differ by several MeV far from stability, measurements of matter radii (§ 4), the study of new decay modes (§ 5), and the relevance of exotic nuclei studies to astrophysics (§ 6).

2. SPECTROSCOPIC STUDIES FAR FROM STABILITY

Shell-model calculations remarkably account for nuclear properties when broad enough bases of individual nuclear states can be included. This is true in particular for the p-shell nuclei (5). The fact that detailed spectroscopic information can now be collected for light nuclei with e.g. four neutron less than stable isotopes offers novel opportunity to test and improve the shell model. The β-delayed proton decay of ^{28}S is one example of this new situation (6).

The ^{28}S isotopes were produced by fragmentation of 85 MeV per nucleon ^{36}Ar projectiles from GANIL accelerator onto a nickel target and analyzed through the LISE separator with an energy degrader at the intermediate focal plane. This experimental technique (6, 7) essentially restricts the nuclei transmitted together with ^{28}S through the LISE separator to other N=12 isotones. In the present case only one of these isotones, ^{27}P, is a weak beta-delayed proton precursor with a $\sim 5 \times 10^{-3}$ proton branching ratio (8). Thus the proton energy spectrum (fig. 1) collected during the beam-off time which follows a ^{28}S

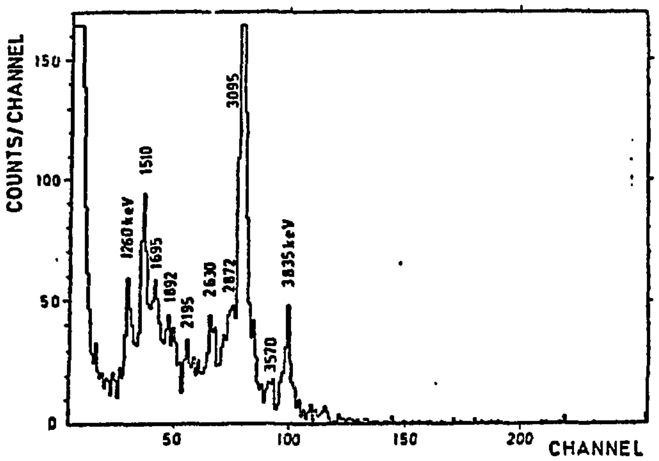

Figure 1 : Energy spectra of β-delayed protons recorder in detector E4 during 250 ms long beam-off period following the implantation of ^{28}Si ion.
The detection of positron is responsible for the events below 1 MeV.

identification is attributable to that isotope only. It allows to draw a detailed table of the decay energies, and the relative and absolute intensities of the β-delayed proton peaks (6). Three of the observed proton transitions can be attributed to proton emission from the 0^+, T=2 ^{28}P level populated by the super-allowed β^+ decay of ^{28}S. This leads to an excitation energy of 5900 ± 21 keV for the T=2 isobaric analog state in ^{28}P.

The identification of this level allows the completion of the T=2, A=28 isospin quintet. As a result the isobaric multiplet mass equation (IMME) can be tested. It is known (9) that the masses of analog states are linked to first order through a quadratic relationship. This holds as long as two-body forces are responsible for charge-dependent effects. Table 1 shows the result of a fit of the mass values of

Table 1 : Coefficients (in keV) and the χ^2 of the different adjustments of the isobaric multiplet mass equation for the A = 28 quintet parametrized as $M = a + b\,T_Z + c\,T_Z^2 + d\,T_Z^3 + e\,T_Z^4$.

a	b	c	d	e	χ^2_ν [a]
-6 268.9 ± 2.4	-4 804.0 ± 4.0	214.4 ± 1.7			0.48
-6 268.1 ± 2.6	-4 799.6 ± 6.4	206.1 ± 9.4	2.9 ± 3.3		0.17
-6 268.2 ± 2.6	-4 797.0 ± 10.0	205.2 ± 12.1		1.4 ± 1.8	0.38
-6 268.2 ± 2.6	-4 807.1 ± 19.1	211.3 ± 15.6	8.5 ± 13.8	-3.1 ± 7.5	

[a] Reduced $\chi^2_\nu = \chi^2/\nu$ where ν is the number of degrees of freedom.

the five T=2, A=28 states. Obviously charge-dependent mixing is insignificant to the present level of experimental accuracy, as observed for neighbouring A=2n quintets, which supports the validity of the quadratic mass equation.

The observation of β-delayed proton lines from ^{28}S also allows to propose a partial decay scheme for this nucleus to be compared with shell-model predictions (6). The calculations provide a good overall account of the data. In particular they correctly predict that the isospin-forbidden proton decay of the 0^+, T=2 isobaric analog ^{28}P state proceeds mainly to the first excited state of ^{27}Si ($½^+$).

These results represent one illustration of the possibility of obtaining detailed spectroscopic information far from stability out of β-delayed particle emission.

Yet β-delayed γ activity can also keep all its effectiveness far from stability, as can be seen in the case of the study of the β decay of ^{22}O (ref. 10). β-coincident γ and γγ events were observed during the beam-off period following the collection of a ^{22}O nucleus in a solid-state telescope at the focus of the LISE separator. Energy spectra were collected while the measurement of the decay with time of γ activity from ^{22}O provided an accurate value of the half life, $T_{½} = 2.25 \pm 0.15$ s, more than three standard deviations away from the only previous measurement. Both the gross theory and the microscopical model predicted shorter half lives, while the shell-model calculations of Wildenthal et al. (11) prove again how effective they are for 1p shell nuclei in predicting a 2.06 s value. As in the case of ^{28}S discussed above, a partial decay scheme of ^{22}O can be drawn from the data which shows that the main features of the shell model predictions for β-branching ratios are indeed observed (10). However specific points of disagreement, such as the strong experimental feeding of the first 1^+ excited state in ^{22}F, at variance with a near-zero theoretical prediction, open the possibility of reassessing the structure of the ^{22}O nucleus wich has such a large neutron excess.

3. BINDING ENERGIES

One of the most obvious criteria to judge the effectiveness of our understanding of nuclei consists in the prediction of which combinations of N- and Z- values make for a bound nucleus. Although the effect of the Coulomb force strongly limits the number of bound neutron-deficient isotopes, all theoretical estimates of nuclear binding energies predict the occurrence of thousands of yet unknown neutron-rich nuclei (12).

By 1980, the proton drip line was established up through Z=11 following the mass measurement of proton-unbound ^{19}Na. Since then, some twenty other neutron-deficient isotopes near or at the proton drip line have been observed through Z=29. The wealth of information which can be derived from their various decay modes is examplified in section 5.

At the time of the Harrogate Conference, the observation of bound ^{22}C and ^{23}N mapped the neutron drip line up to Z=7 only. Since then, the apparently secure predictions of which neutron-rich isotopes would be bound up to Z=10 have been contradicted by experiment.

Recent results (13) obtained at GANIL by a Orsay-Dubna-GANIL collaboration shed some new light on the bound character of neutron-rich oxygen and neon isotopes. While the detection method was essentially the same as used in previous LISE experiment, a systematic search for improving the yield of rare neutron-rich projectile fragments was conducted. It is now well established (14) that the so called fragmentation process at intermediate energy is only reminiscent of the clear process observed with projectiles of about 1 GeV per nucleon. In particular the yield of fragments, especially for those further away from stability, strongly depends upon the target. Thus, while clearly the choice of a neutron-rich projectile, in the present case ^{48}Ca, was beneficial, the optimization of target material was investigated. A heavy target (tantalum) was found to provide maximal yield for the most neutron-rich fragments.A two-dimensional display (fig. 2) of the collected nuclei at the focus of LISE confirms the occurrence of isotopes previously observed such as ^{22}C or ^{23}N, and the unbound character of ^{18}B, ^{15}Be or ^{21}C. Most noteworthy are the results

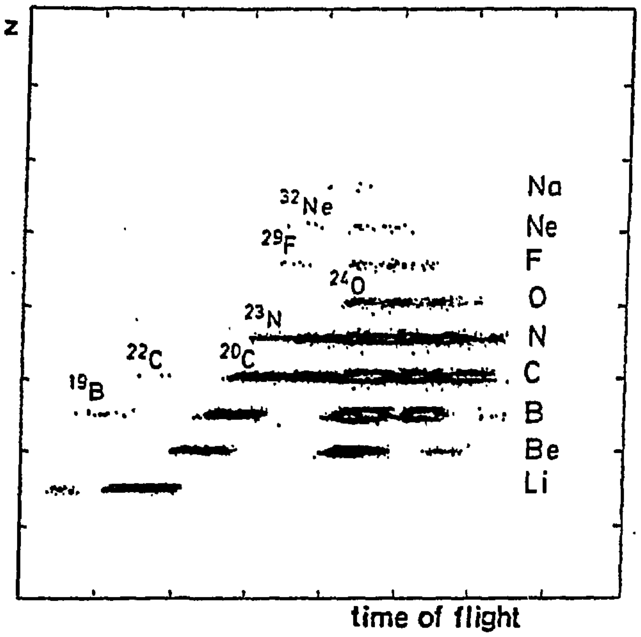

Figure 2 : Two-dimensional plot ΔE versus time of flight obtained in the fragmentation of the ^{48}Ca beam at 44 MeV/n onto a 173 mg/cm2 tantalum target during 40 hours at a magnetic rigidity Bρ = 2.82 Tm of the LISE spectrometer. The new ^{32}Ne isotope is clearly visible (4 counts). A total of 220 events of ^{24}O has been recorded. No counts of ^{26}O are observed. (From ref. 13)

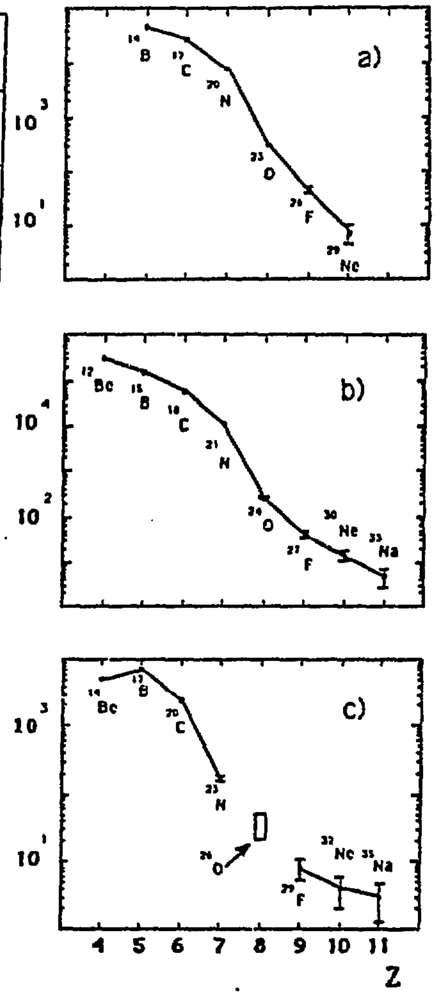

Fig. 3 : Isotopic production along lines with neutron number N = 2Z-1 (a), N = 2Z (b), N = 2Z+2 (c). A smooth monotoneous drop is observed with increasing Z. The ^{26}O yield predicted by interpolation is indicated in c) by a rectangular box. (see text)

concerning the isotopes with Z=8 to 10. In particular, the occurrence of ^{29}F is confirmed while the previously unknown ^{32}Ne is clearly visible (4 events). The unbound character of ^{31}Ne, which is absent from this display, is established.

No event corresponding to ^{26}O is seen. Why this experimental result provides strong evidence for the unbound character of ^{26} O stems from fig. 3. It shows experimental isotopic yields along various series of isotopes. As expected from what is known of the production process, a smooth yield variation is observed in all cases. This behaviour would predict a production of some 30 ^{26}O isotopes, as opposed to the zero-production observed. Yet nuclear stability was predicted for ^{26}O by most theoretical models (table 2). This new experimental evidence (13) represents a strong and novel constraint on all nuclear models of neutron-rich light nuclei. In particular what that implies for the stability of doubly magic ^{28}O which only one model (see table 2) predicted to be bound is of particular interest.

Table 2 : Two-neutron separation energy $S_{2n} = - M(A,Z)+M(A-2,Z)+2M(n)$ in MeV of the neutron-rich isotopes of oxygen predicted by different mass formulae (12) : MN - Möller-Nix, CKZ - Comay-Kelson-Zidon, SM - Satpathy-Nayak, T - Tachibana et al, JM - Jänecke-Masson.

Nuclide	MN S_{2n}	CKZ S_{2n}	SN S_{2n}	T S_{2n}	JM S_{2n}
^{23}O	7.15	9.22	8.0	7.45	9.19
^{24}O	4.91	6.16	6.78	4.20	5.96
^{26}O	0.67	0.87	5.32	1.26	0.96
^{28}O	0.7	-2.08	—	-0.13	-1.61

The results concerning Z=10 isotopes show that ^{31}Ne is unbound while ^{32}Ne is bound. It is worth noting that the persistence of such odd-even effects near the neutron drip line confirms the importance of pairing effects far from stability (15), at variance with some previous extrapolations. Table 3 lists the predicted separation energies for neon isotopes. While the experimental result concerning ^{31}Ne is in agreement with most predictions, some of the calculations obviously underestimate the two-neutron separation energy of ^{32}Ne by at least 1 MeV.

Thus, one is left with a puzzling but stimulating situation. Namely, calculations overestimate, for ^{26}O, and underestimate, for ^{32}Ne, the binding·energy. Obviously, the study of nuclear structure around the double Z=8, N=20 shell closure might bring very interesting results.

Table 3 : One-neutron and two-neutron separation energies (in MeV) of the neutron-rich isotopes of neon as predicted by different mass-formulae (see table 2)

Nuclide	MN		CKZ		SN		T		JM	
	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}	S_{1n}	S_{2n}
^{31}Ne	-1.48	2.80	-2.61	0.17	1.24	6.39	-1.46	2.34	-2.25	0.76
^{32}Ne	1.58	0.10	1.09	-1.52	5.91	7.15	2.35	0.89	1.23	-1.02
^{33}Ne	0.36	1.94	-2.17	-1.08	2.95	8.86	-1.21	1.14	-2.35	-1.12
^{34}Ne	-0.02	0.34	1.20	-0.97	6.15	9.10	2.19	0.98	1.13	-1.22

Over the last three years since the Harrogate Conference, the successful measurement of masses for score of light neutron-rich nuclei certainly constitutes a major breakthrough. The results are reviewed elsewhere in some detail (2). Two programs, at Los Alamos (16) and GANIL (17), account for most of the new results obtained. Both rely on direct mass measurements through precise determinations of parameters such as momentum and time of flight of the exotic nuclear fragments of interest. The ultimate goal of these programs is to lead to a broad understanding of the binding energy of all light neutron-rich nuclei. Fig. 4, taken from ref. 2, shows the present stage of comparison between experimental results and the predictions of the most efficient theoretical model in this mass region, the shell model as developped in recent years by Wildenthal, Brown and coworkers (5, 11, 18). Although the overall agreement is encouraging, obvious departures remain. For instance a strong discrepancy is observed in the region $^{31-33}$Na, where sd-basis and sdpf, 0 $\hbar\omega$-basis both underestimate the binding energy. This is the result of 2 particle - 2 hole excitations into the f 7/2 shell which are explicitly excluded from these calculations, as evidenced by more extended calculations (19, 20). It is clear from fig. 4 that the discrepancy observed for Z=11 is reduced by about half for Z=12 and that good agreement is restored for Z=13. This can be qualitatively understood by refering to the levels occupied by protons in the Nilsson diagram, as indicated by Campi et al. (21) when the Na

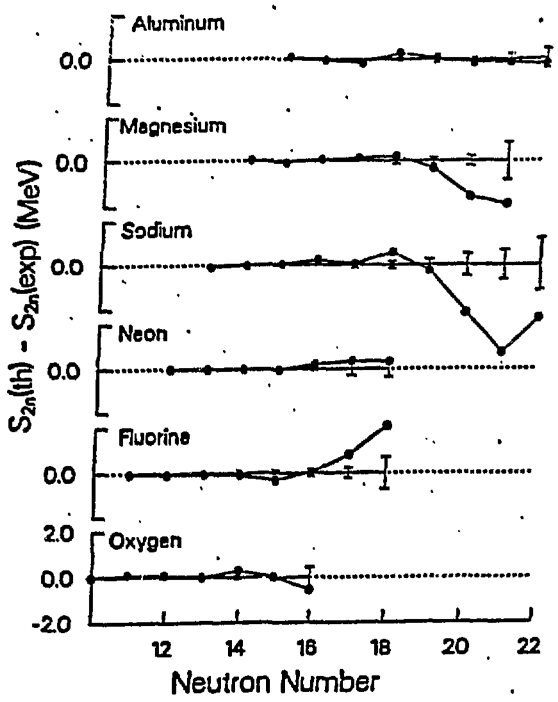

Figure 4 : Difference between the S_{2n} values calculated using the shell model and the experimental S_{2n} values neutron number for oxygen to aluminium isotopes (see ref. 2 for origin of the values). The experimental uncertainties are indicated by error bars.

results were first published. This explanation also leads to the suggestion (2) that ^{29}F, the most neutron-rich bound isotope of fluorine (see fig. 2), would even be more deformed than $^{31-32}Na$. The current improvement of the direct mass measurement techniques as well as increases of beam intensities (4) should put the measurement of the ^{29}F mass shortly within experimental reach.

4. MATTER RADII

Three years ago, the measurement of matter radii had just been initiated (22). Since then, several important results have been obtained. Since the measurement of total reaction cross section, from which the radius parameter is extracted, only requires a small number of interacting nuclei, it can be performed with secondary beams of fragmentation products magnetically separated. The limitations are more a matter of systematic errors than statistical uncertainties.

Three programs have been effectively realized, at Bevalac and GANIL (22, 23, 24, 25). The major result obtained is that the matter radii of light neutron-rich isotopes studied do not always vary as $A^{1/3}$, as observed for stable nuclei. In particular, ^{11}Li, ^{14}Be and ^{17}B exhibit a

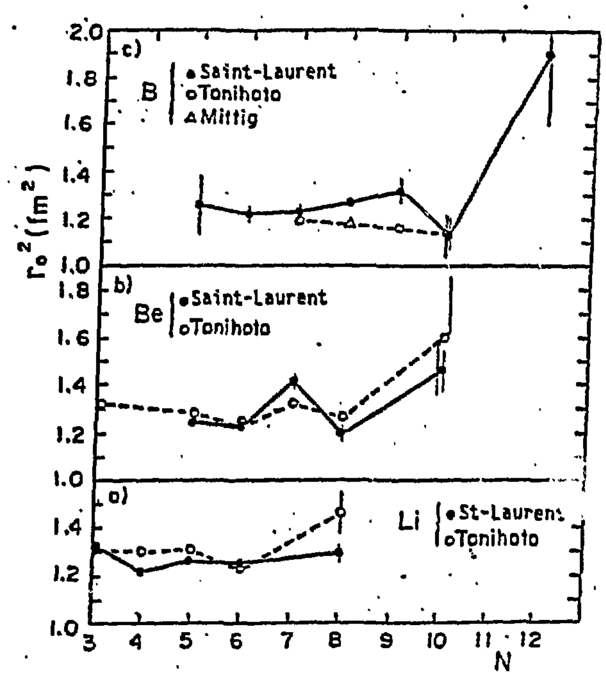

Figure 5 : The reduced strong absorption radius square (r_0^2) for (a) Li, (b)Be, and (c) B isotopes. Full black dots are data points obtained in the work of Saint-Laurent et al (25) ; open circles are from Tanihata et al (22, 23) ; and the triangle is from Mittig et al (24). The lines are only guides for the eye.

striking increase of matter radius over the expected values (fig. 5). The measurements are difficult, and some limited discrepancies exist between data obtained by the different groups through different methods. Yet the overall agreement between the results is well established and ways to account for their differences are proposed (26). The variation of radii with isospin was compared (27) with Hartree-Fock calculations.

An interesting insight into the physical roots of the observed effect was provided by Hansen and Jonson (15) who related the weak separation energy for two-neutron emission of ^{11}Li or ^{14}Be to the occurrence of an extended di-neutron halo. This picture draws further support from a measurement of the transverse momentum distribution of ^{9}Li and ^{12}Be from nuclear fragmentation of ^{11}Li and ^{14}Be, respectively (23). The distribution exhibits two components. One is remarkably narrow and can be analyzed as the Fourier transform of the halo wave function.

Furthermore, Hansen and Jonson suggest (15) that, due to the loose binding of the halo neutrons, an important amount of E1 strength may remain at low energies and be observable as a soft Coulomb dissociation mode. They estimate that the cross section for such a process in the

^{11}Li + Au collision is around 2 barns, which is in agreement with the first dissociation measurement reported (33).

This topic is certainly one which will be actively studied in the near future since it is clearly a case where exotic nuclei provide us with structural features differing markedly from those encountered near the valley of β-stability.

5. NEW DECAY MODES

The decay of nuclei far from stability draws its interest from the large Q_β values involved which allow for a wide variety of direct or β-delayed particle emissions. One remarkable property of such processes lies in the fact that they relate directly to structural properties of well-identified nuclear states. Indeed, while uncertainties in the details of reaction mechanisms make it difficult for example to extract information on two-proton correlation in nuclei from two-proton transfers, the proton pairs observed through β-delayed two-proton emission directly reflect the magnitude of two-proton correlations inside one well-identified nuclear state, in a way that is free from strong-interaction distorsions.

So far only a few cases of β-delayed two-proton emission had been reported (28), from ^{22}Al, ^{26}P and ^{35}Ca. It appears that the $T_z = -5/2$ series of isotopes observed a few years ago (29) might systematically undergo this radioactive decay. Results from GANIL and Berkeley have shown, although with limited statistics, that such is the case for ^{31}Ar, where a two-proton emission with a total energy of 7-8 MeV is observed from the isobaric analog state in ^{31}Cl, fed by a superallowed β-decay branch (7, 30). The high yields now obtainable at GANIL from ^{36}Ar fragmentation, reaching up to two ^{31}Ar nuclei per second at the focus of the LISE separator, allow to confirm and study in detail the β-delayed 2p decay of ^{31}Ar. The preliminary spectrum (31) of fig. 6 represents a two-fold coincident charged-particle energy spectrum recorded after an ^{31}Ar nucleus has been implanted into a thin ΔE detector in the telescope located at the focus of LISE. In that experiment, the ΔE detector was surrounded by four position-sensitive solid-state detectors. In this way a two-fold coincidence enhances the two-proton detection efficiency and indeed tens of events are observed at 7.62 MeV corresponding to the two-proton decay of the T = 5/2 analog state in ^{31}Cl.

Further analysis of the data is expected to provide the correlation functions, in energy and angle, of the two emitted protons. As explained by Jahn et al. (32), these functions can be used to distinguish between the different emission processes which can account for the two-proton decay.

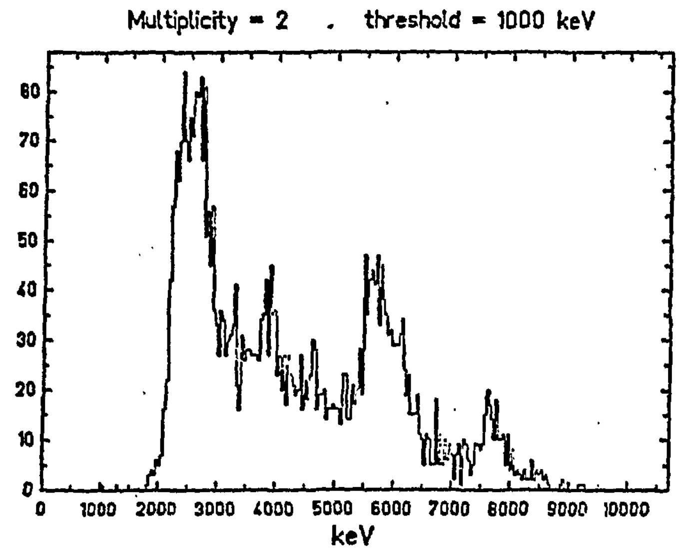

Figure 6 : Total energy spectrum recorded from the β-delayed decay of ^{31}Ar when a triple coincidence is recorded between the decay of the detector where the emitting nucleus is implanted and two of the surrounding detectors. The strong peak at 7.62 MeV corresponds to β-delayed 2p emission from the isobaric analog state in ^{31}Cl.
(from ref. 31)

On the neutron-rich side of the chart of nuclides, the catalogue of radioactive decay processes continues to expand as increasing Q values farther and farther from stability open up new decay channels, or make those already observed not as exceptionnal as they were regarded before. The well-documented case of ^{11}Li where up to half a dozen of β-delayed modes were observed, as indicated by review papers (2), is no longer isolated. For instance β-delayed triton emission is now also observed (33) in the decay of ^{8}He. The hitherto unobserved β-delayed deuteron emission was reported (34) at ISOLDE/CERN in the decay of ^{6}He with a branching ratio in the 3 x 10^{-6} range. One interesting feature of this new process is that it can only occur if the β decay of ^{6}He (0^{+}) feeds the tail of a higher-lying 1^{+} state in ^{6}Li. Also virtual decay through the bound 1^+ ground state of ^{6}Li is needed to explain the data. Again such a result shows the specific information which can be derived from rare exotic decay modes.

Another new decay mode was observed in a recent study (40) of β-delayed multi-neutron emission from ^{14}Be, ^{17}B and ^{20}C produced by ^{22}Ne fragmentation. In this work, the telescope where fragments were stopped was surrounded by a neutron detector filled with 500 liters of liquid gadolynium-doped scintillator. The results are presented in table 4.

Table 4 : Half-lives and probabilities of β-delayed multineutron emissions (from ref. 40)

^AZ	$T_{1/2}$ (ms)	P_{0n}	P_{1n}	P_{2n}	P_{3n}	P_{4n}
				(%)		
^{14}Be	4.35 (17)	0.14 (3)	0.81 (4)	0.05 (2)	—	—
^{17}B	5.08 (5)	0.21 (2)	0.63 (1)	0.11 (7)	0.035 (7)	0.004 (3)
^{19}C	49 (4)	0.46 (3)	0.47 (3)	0.07 (3)	—	—

They show relatively large probabilities for β-delayed multineutron emission and even provide evidence for the new β-4n process.

In this review of continuing experimental successes, one much searched for process still eludes us, namely the direct two-proton radioactive mode already discussed at the previous conference (1), where references to predictions of this process were given. It suffices to recall that, at the proton drip line, some even-Z isotopes might be bound against one-proton but unbound against two-proton emission. If the Coulomb barrier hinders the latter decay enough to make it observable by spectroscopic techniques, a new radioactive mode could thus be observed. Obviously barrier penetration is drastically governed by the amount of energy available for the two-proton emission channel. In this respect, binding-energy calculations play a crucial role in predicting which isotopes can be expected to exhibit the new decay mode.

At variance with neutron-rich nuclei where deviations of several MeV exist between theoretical calculations, local mass relations for neutron-rich nuclei agree between themselves and with experimental values within a few hundreds of keV. This only reflects the good accuracy of the assumed charge-independence of nuclear forces. Mass relations have been proposed by Goldanskii (35) and Kelson and Garvey (36). It is possible to show that they are analytically related, so that their predictive capacities are equivalent.

Two nuclei with negative S_{2p} two-proton separation energy values have already been observed at GANIL, i.e. ^{22}Si (ref. 37) and ^{31}Ar (ref. 7). In line with the small $|S_{2p}|$ values predicted, close to 0 and 200 keV, respectively, none of these two isotopes was found to significantly decay by direct 2p emission. Indeed calculations show that barrier penetration is much slower than β decay in such cases. A more promising case appeared to be ^{39}Ti where S_{2p} is predicted to be around -700 keV. In a recent experiment at GANIL (38), about eighty ^{39}Ti fragments were detected at the focus of the LISE separator from the interaction of ^{58}Ni projectiles. The energy spectrum of charged particles emitted after the beam-off period following each ^{39}Ti implantation in the detector is presented in fig. 7. Although analysis is still in progress, it appears that the line which is observed in this spectrum can be associated with the decay of the isobaric analog state in ^{39}Sc. The time correlation between ^{39}Ti implantation and its charged-particle decay was consistent with a radioactive half-life of about 25 ms.

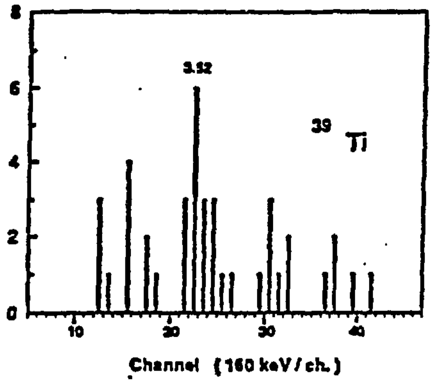

Figure 7 : Energy-spectrum of β-delayed charged particles emitted from ^{39}Ti.

Thus it appears that a S_{2p} = -700 keV value is not negative enough to make 2p emission faster than β decay. Several explanations can be suggested. One of them would stress that out of the whole phase space occupied by the two protons in the emitting nucleus only a restricted portion contributes to a process where the two protons are emitted with equal energies in a relative 1s state. Another one calls for a systematic overestimation of the energy available for two-proton emission. This might come from the accidental failure of one of the two assumptions which justify the success of local mass relationships, i.e. the independent-particle behaviour, and charge symmetry of nuclear forces. Clearly the first one might become invalid at the proton drip line where a single-proton state becomes unbound, which modifies its wave function from what it was in the bound charge-symmetric state. The resulting effect, refered to as the Thomas-Ehrmann effect, has been examined by Comay et al. (39). They found that the decrease of Coulomb repulsion at the proton drip line systematically results in higher-than-predicted binding energies. From the parameter-free systematics collected by Comay et al. (39) it seems that the available energy available for two-proton decay from ^{39}Ti, predicted as some 800 keV, might be reduced by an amount of 400 to 600 keV. This would explain why ^{39}Ti, like ^{22}Si and ^{31}Ar, although unbound, decays rather by weak interaction.

Accordingly, the best candidates for 2p radioactivity in the same mass range should have predicted two-proton decay energies in the 1.0 to 1.2 MeV range. Such is the case for ^{45}Fe or ^{48}Ni which might come within reach of experiments using current energy and intensity upgrades at GANIL (4), or the new SIS/ESR at Darmstadt (3).

6. EXOTIC NUCLEI OF ASTROPHYSICAL INTEREST

The very neutron-rich isotopes painfully synthesized in the laboratory can be very abundant in those astrophysical circumstances where high neutron fluxes are expected. This is the case for the nuclei involved in the r-process of nucleosynthesis. One major and promising development is that these very exotic nuclei can now be studied directly. The r-process path, where neutron absorption competes with β decay, should roughly follow the line where S_n is about 2 MeV. It is still out of reach of experiment for heavier elements but one instance where it could be successfully studied for Z below 20 was recently reported (41). Measurements of half-lives and neutron-emission probabilities were obtained for ^{20}C, $^{40-42}P$ and $^{43-44}S$ produced by fragmentation of ^{48}Ca projectiles at GANIL. The half life of the last isotope studied, ^{44}S, has been shown by Kratz et al. (42) to strongly influence the ratio of ^{46}Ca and ^{48}Ca which can be synthesized in the flux of neutrons expected to be responsible for the r-process. Conversely, the observed solar $^{46}Ca/^{48}Ca$ ratio, and the newly measured ^{44}S half-life constrain the flux of neutrons and the duration of the irradiation. The fact that the measured ^{44}S half-life, around 200 ms, is shorter than predicted leads to even higher fluxes than considered so far.

It is forseeable that at least some of the extended network calculations used in simulating stellar nucleosynthesis might rely increasingly on experimental rather than theoretical values for neutron-rich nuclei.

7. CONCLUSION

The history of nuclei far from stability is closely linked to the improvement of accelerators and experimental equipment. Over the last 3 years since the Harrogate International Conference major change has occured. The results presented here as examples indicate that the main parameters of nuclei are now available along long series of isotopes. Besides specific spectroscopic studies, systematic variations in half lives, radii or binding energies can now be compared to model predictions. New techniques of study become available, as examplified by the spin polarization results presented at this conference (43), and new decay modes shed more light on nuclear structure properties. At last, the breadth of isotopes studied becomes large enough to encompass those responsible for fundamental stellar processes.

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