Eur. Phys. J. A **25**, s01, 333–334 (2005)
DOI: 10.1140/epjad/i2005-06-001-9

EPJ A direct
electronic only

Remarks about the driplines

M. Thoennessen[a]

Department of Physics & Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, USA

Received: 12 September 2004 / Revised version: 3 November 2004 /
Published online: 7 April 2005 – © Società Italiana di Fisica / Springer-Verlag 2005

Abstract. Reaching the limits of nuclear stability has been one of the driving forces of nuclear physics experiments. A few observations and remarks about the current status of the proton and neutron driplines will be presented.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels

1 Proton dripline

The proton dripline itself is not clearly defined. Sometimes it is simply defined by the proton separation energy passing through zero ($S_p = 0$ MeV) [1]. Although this definition is unambiguous due to the Coulomb barrier especially in heavy nuclei, it is not identical with protons "dripping" from the nucleus. With this definition many nuclei "exist" beyond the dripline. An alternative definition of the dripline is to set it equal to the existence of a nucleus which can be defined as limited by the typical nuclear timescale of $\sim 10^{-22}$ s [2]. The dripline and the existence of a nucleus could also be related to the definition of radioactivity with a limit of $\sim 10^{-12}$ s [3]. Most of these discussions of different definitions are semantics. It is, however, important that especially in the interaction of theorists and experimentalist it is understood which definition is used.

Assuming the above definition of the dripline as $S_p = 0$ MeV it is generally accepted that the dripline is relatively well delineated [4]. Compared to the neutron dripline this is certainly true. However, if one looks carefully at the location of the dripline, the exact location is experimentally known for only six elements beyond Mg and below Pb (Cl, K, Sc, Lu, Ta, and Au) [5]. Beyond Pb the dripline is known for the odd isotopes Bi, At, Fr, Ac, and Pa. An interesting possibility exists in the At isotopes, where ^{195}At is unbound by -234 ± 15 keV, while ^{194}At could potentially be bound 117 ± 189 keV [6]. ^{195}At could thus be an island of a proton unbound nucleus surrounded by bound nuclei. This would still only be a curiosity with no practical implications because even though ^{195}At is proton unbound it already has been measured to be an α-emitter [7]. However, if the limit can be pushed to even more proton unstable nuclei islands of proton emitters surrounded by β- and α-emitters could exist.

Although the exact location of the dripline is not well known, the dripline ($S_p = 0$ MeV) has been crossed for most (predominantly for the odd proton) elements. Nevertheless, with the current detection capabilities for the direct observation of isotopes (on the order of nanoseconds) many hundreds of isotopes beyond the dripline are still unknown. The proposed Rare Isotope Accelerator RIA [8] will be able to produce well over 200 new isotopes along the proton dripline [5].

The importance of the dripline for the astrophysical rp-process has been discussed extensively [9]. The exact location of the dripline itself is not really important. The crossing of $S_p = 0$ MeV has no special significance for the lifetimes of waiting point nuclei in stellar environments. These lifetimes have to be determined from the accurate knowledge of the binding energies. Again, because of the Coulomb barrier even unbound nuclei can have significant lifetimes and can have a large influence on the stellar lifetimes [9].

2 Neutron dripline

It is generally accepted that the neutron dripline has been reached for all elements up to oxygen [8]. However, due to the strong odd-even effect of the binding energy, even if an odd isotope has been found to be unstable one still has to check if the next heavier even isotope is also unbound in order to know if the last bound isotope of a given element has been observed. For example, so far no experiments searching for the existence of ^{13}Li or ^{18}Be have been performed. Thus, strictly speaking the dripline is only known up to helium [5].

In order to avoid the odd even staggering of the neutron dripline, it should be handled equivalent to the proton dripline, *i.e.* in terms of isotones instead of isotopes [1,5]. Figure 1 shows the neutron dripline in this presentation.

[a] e-mail: thoennessen@nscl.msu.edu

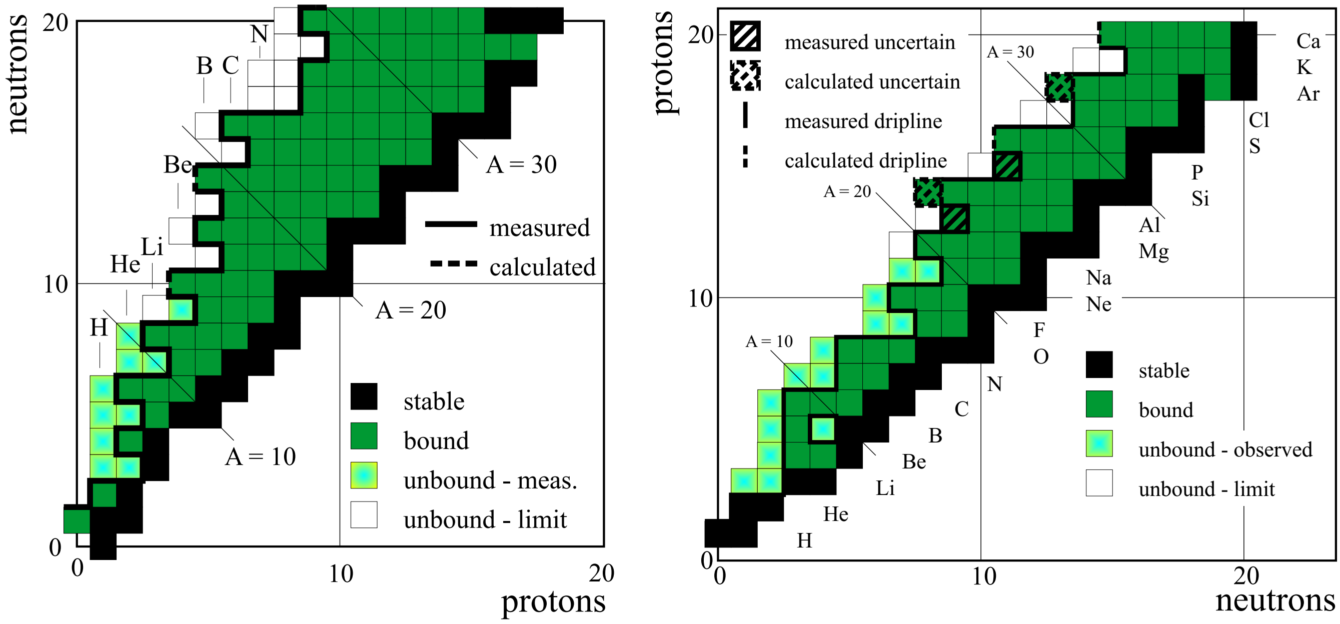

Fig. 1. Light mass region of the chart of nuclei. Left: The neutron dripline presented in terms of isotones, *i.e.* the neutron numbers are plotted *vs.* the proton numbers. Right: The proton dripline for comparison in the normal presentation of proton numbers *vs.* neutron numbers. See text for more details about the notations.

The number of neutrons are plotted *vs.* the number of protons (left). The right side of the figure shows the proton dripline for comparison in the normal presentation, *i.e.* protons *vs.* neutrons. The figure indicates stable, bound and unbound isotopes. Unbound isotopes which have not been observed but where lifetime limits were established are also included (unbound - limit). In addition, the measured (solid lines) and calculated (dashed lines) driplines are shown. At the proton dripline, isotopes where the uncertainty for the binding energies includes $S_p = 0$ MeV are shown as solid hashed (measured uncertainty) and dashed hashed (calculated uncertainty) squares.

In the isotone presentation, the dripline is known up to $N = 9$. It is unlikely that ^{13}Li, ^{18}Be or ^{30}O are bound, so effectively, the dripline is known up to $N = 23$ (^{34}Na) [10,11,12].

The location of the dripline is typically calculated with a variety of mass models. It is often pointed out that these calculations deviate from each other significantly for extrapolations towards the driplines [13]. This is especially true for the neutron dripline. While the deviations of the proton dripline of the empirical model based on p-n interaction by Tachibana *et al.* [14], the finite-range droplet model [15], and the Hartree-Fock-Bogolyubov model (HFB-2) [16] from the extrapolated masses of the AME2003 atomic mass evaluation [6] are on the order of 3-4 isotopes, the neutron dripline (defined as the occurrence of the first unbound isotope) differs just among the three calculations by up to 15 isotopes [5]. However, if the differences are displayed in terms of isotones the deviations of the models are not as large. Again, this representation avoids the difficulty to determine the dripline due to the odd-even staggering. The differences between the models of about 3-4 isotones are comparable to the deviations along the proton dripline [5].

This work has been supported by the National Science Foundation grant number PHY01-10253.

References

1. P.G. Hansen, J.A. Tostevin, Annu. Rev. Nucl. Part. Sci. **53**, 219 (2003).
2. A.C. Mueller, B.M. Sherrill, Annu. Rev. Nucl. Part. Sci. **43**, 529 (1993).
3. J. Cerny, J.C. Hardy, Annu. Rev. Nucl. Part. Sci. **27**, 323 (1977).
4. *RIA Physics White Paper* (2000), `http://www.orau.org/ria/ria-whitepaper-2000.pdf`.
5. M. Thoennessen, Rep. Prog. Phys. **67**, 1187 (2004).
6. G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A **729**, 337 (2003).
7. M. Leino *et al.*, Act. Phys. Pol. B **26**, 309 (1995).
8. *ISOL Task Force to NSAC* (1999), `http://www.orau.org/ria/ISOLTaskForceReport.pdf`.
9. H. Schatz *et al.*, Phys. Rep. **294**, 167 (1998).
10. H. Sakurai *et al.*, Phys. Lett. B **448**, 180 (1999).
11. M. Notani *et al.*, Phys. Lett. B **542**, 49 (2002).
12. S.M. Lukyanov *et al.*, J. Phys. G **28**, L41 (2002).
13. *Scientific Opportunities with Fast Fragmentation Beams from RIA*, Michigan State University (2000), `http://www.orau.org/ria/opportunitiesffbeam.pdf`.
14. T. Tachibana, M. Uno, M. Yamada, S. Yamada, At. Data Nucl. Data Tables **39**, 251 (1988).
15. P. Möller, J.R. Nix, W.J. Swiatecki, At. Data Nucl. Data Tables **59**, 185 (1995).
16. S. Goriely, M. Samyn, P.H. Heenen, J.M. Pearson, F. Tondeur, Phys. Rev. C **66**, 024326 (2002).