Adopted Levels

Searches for bound multi-neutron systems are motivated by the discovery of neutron stars and by uncertainty in the multi-nucleon forces. So far, there is no convincing evidence supporting observation of bound di-neutron, tri-neutron or tetra-neutron clusters, see for example (1974Ce06, 1984Un02, 1988Al11, 1990Al11, 1998Al16, 2005Al15). A variety of theoretical works give a mixed bag of results, most often excluding A<4 and favoring A>100 with the addition of gravitational forces (1972Ba45, 1986Be02, 1987Be45, 1989Go18, 1997Sm07, 2003Ti03, 2003Pi09) and (Satpathy and Nayak, J Phys G 4 (1978) L161).

In 2012No11 and 2013No10, two completely separate experiments provide evidence for bound multi-neutron systems. In these works, analysis of fission products from ^{238}U(α,F) suggests the existence of a bound multi-neutron cluster. Discussion within the texts argue that six or more neutrons are bound in the cluster. The argument is based on ^{8}He being more tighly bound than ^{6}He or ^{10}He; this is used to suggest a new N=6 magic number. Hence ^{6}n is suggested for the observed particle bound species.

^{6}n Levels

Cross Reference (XREF) Flags

A	^{14}C(^{7}Li,6n)	D	^{238}U(p,6n)
B	^{48}Ca(^{12}C,6n),^{40}Ca(^{12}C,6n)	E	^{238}U(α,6n)
C	W(p,6n)	F	^{252}Cf SF decay

E(level)	XREF	Comments
0?	E	Decay mode not specified.

$^{14}C(^{7}Li,6n)$ 1990Al40

1990Al40:

Evidence of ^{x}n stable neutron nuclei were searched for in fission products by analyzing samples that were activated in the vicinity of a ^{252}Cf spontaneous fission source. A secondary search for ^{6}n was carried out in this work by activating one of the samples (^{24}Mg) with target ejecta produced in the $^{14}C(^{7}Li,X)$ reaction. It was thought that stable neutron nuclides could be produced in this reaction. No convincing evidence of ^{x}n bound neutron nuclides was observed.

^{48}Ca(^{12}C,6n),^{40}Ca(^{12}C,6n) **1964Br17**

The authors separately bombarded ^{48}Ca and ^{40}Ca targets with 72 MeV ^{12}C ions. Evidence of neutral and stable neutron nuclei was searched for by evaluating events from a 20 cm by 20 cm plastic scintillator that measured the pulse height and time-of-flight of reaction ejectiles. An additional measurement of ^{48}Ca(^{3}He,^{6}n) reactions is discussed in the text.

No evidence for a bound multi-neutron configuration was found. Upper limits on ^{6}n production are given in the text.

W(p,6n) 1977De08

1977De08:

A beam of 24 GeV protons, from the CERN synchrotron, impinged on a 10 cm thick ^{nat}W target. Either 7 mm or 17 mm thick aluminum plates were positioned near the spallation target to stop any charged reaction products that were ejected from the target. An neutral products are believed to freely penetrate the Al plate; after which they could induce (^{A}n,xn) reactions on a natural zinc target (A<70). After roughly 60 hours of irradiation, the zinc activation target was transported to IPN-Orsay for radiochemical analysis in a search for ^{72}Ga activity (daughter of ^{72}Zn decay). The observations suggest roughly 6×10^{6} ^{72}Ga atoms were present. Since prior evidence suggests no bound states exist for ≤5 multi-neutron species, the authors claim evidence for Zn(^{A}n,xn)^{72}Zn reactions where A≥6. Comments are given suggesting that transfer reactions and target target impurities are not responsible for the observation. In 1977Tu03 a private communication from Detraz is cited, which give a plausible explanation for a false positive identification published in this work.

^{238}U(p,6n) 1977Tu02,1977Tu03

1977Tu02:
A beam of 800 MeV protons impinged on a 90 g/cm^2 ^{238}U target. Roughly 4 kg of special purity ^{208}Pb was shielded from the target with 3/8 inch plates of aluminum that could stop any charged particles that were produced in the bombardment, while any neutral species produced in the uranium should be free to react in the lead material. Following 10 hours of activation, the lead samples were radiochemically analyzed in search of evidence of ^{212}Bi and ^{212}Po that would suggest multi-neutron reactions with the ^{208}Pb. An upper limit of $\sigma<10^{-3}$ μb was established for production of 6n in this reaction.

1977Tu03:
A beam of 400 GeV protons impinged on a 0.42 g/cm^2 uranium target. The target was surrounded by a 1kg sample of specially purified lead that was cylindrically shaped. Multi-neutron species produced in bombardment could interact with the lead cylinder and would lead to production of ^{212}Bi and ^{212}Po. No positive evidence for multi-neutron production was observed, though a high background was observed. References in this article include a private communication from Detraz that give a plausible explanation for a false positive identification published in 1977De08.

^{238}U(α,6n) 2012No11,2013No10

2012No11:

A 160 μm thick ^{238}U target was bombarded with 62 MeV α particles from the Kurchatov Institute cyclotron. Since there is no clear detection method for identifying bound multi-neutron clusters, a secondary target was placed in the scattering chamber. In this case, a powder $SrCO_3$ target, enriched to 99.2% in Sr, was positioned at θ_{lab}=30°. The elastically scattered α particles, as well as charged fission products, were stopped in a 0.1 mm thick Kapton window and 1 mm thick ^{nat}Be foil that were between the ^{238}U target and the $SrCO_3$ target. After sufficient activation, the target was transported to a low-background counting area where the induced activity was characterized.

Within the activity, the an E_γ=1384 keV transition was observed with a lifetime consistent with the known $T_{1/2}$=2.66 hour half-life of ^{92}Sr. This observation implies reactions of the ^{88}Sr(^{x}n,(x-4)n)^{92}Sr type occured. In addition, the ^{x}n species must be effectively particle stable with a lifetime long enough to travel the few cm between the production target and the activation target. The estimated cross section for production of ^{6}n was dσ/dω≈6×10^{-2} mb/sr.

A comparative argument with the binding energies of heavy He is used to suggest x=6 as the most likely case for a bound multi-neutron cluster.

2013No10:

Similar to 2012No11, the authors bombarded a ^{238}U foil with 62 MeV α particles from the Kurchatov Institute cyclotron. In this case a 99.99 chemically pure Al target was positioned at θ_{lab}=20°. The elastically scattered α particles, as well as charged fission products, were stopped in a 0.1 mm thick Kapton window and 1 mm thick ^{nat}Be foil that were between the ^{238}U target and the Al target. After sufficient activation, the target was transported to a low-background counting area where the induced activity was characterized.

Within the activity, the E_γ=1324 and 1779 keV transitions corresponding to ^{28}Mg decay were observed This observation implies reactions of the ^{27}Al(^{x}n,p(x-n)n)^{28}Mg type occured. The estimated total cross section for production of ^{6}n was σ≈0.8 mb.

^{6}n Levels

E(level)
0?

^{252}Cf SF decay 1990Al40

Parent: ^{252}Cf: E=0; $J^{\pi}=0^{+}$; $T_{1/2}$=2.645 y *8*; %SF decay=0.0

The authors expressed caution that all prior searches for stable neutron nuclei had produced results that were either negative, or that were shown to have erronious results that could be otherwise explained.

The authors used a 19 μg ^{252}Cf source that produced roughly 10^{7} fission events/sec to activate ^{19}F, ^{25,26}Mg, ^{103}Rh, ^{110}Pd and ^{208}Pb samples. After exposure, the samples were transported to a low-background counting facility where the induced activity was analyzed for evidence of multi-neutron exchange reactions that could provide evidence for emission of particle stable neutron nuclei in the fission products; i.e. ^{A}Z(^{x}n,(x-k)n)$^{A+k}$Z where x≥6 and k>2 are expected.

No evidence was observed for such fission products.

The article includes reference to (1985AlZH) and other unpublished conference proceeding results.