Neutron cluster detection

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The abstract remains to be written.

I. INTRODUCTION

In this article I consider the possibility that sufficiently large neutron clusters are bound, and I explore the properties of such clusters including experimental techniques whereby they might be detected. I consider any nucleon cluster to be bound if there exists no exothermic decay channel other than weak decays such as beta decay. I designate a bound neutron cluster containing A neutrons by the symbol $^{\rm A}$Nt, suggesting a neutral nucleus. It denotes an isotope of an element (neutronium or neutrium) whose nucleus contains no protons. It is clearly a nuclear reactive element, although it is not a chemically reactive element because it lacks an orbital electron.

The family of Nt isotopes contains the neutron ^{1}Nt, which is stable except for the beta decay ^{1}Nt→ p + e$^-$+ $\bar{\nu}$. This reaction is often abbreviated ^{1}Nt→^{1}H with the electron attached to the proton and the antineutrino implicit. Experimentally it has been determined that ^{2}Nt is unbound, but exists transiently as a resonance with a positive energy of about 1 MeV. Similarly experiment shows that ^{3}Nt is unbound and that ^{4}Nt may or may not be bound. Here I assume that $^{\rm A}$Nt is bound for A≥4, and explore some of the consequences of this assumption.

Just as a single neutron is unstable with respect to beta decay, so too is $^{\rm A}$Nt unstable. Consider the decay

$$^{\rm A}{\rm Nt} \rightarrow\ ^{\rm A-1}{\rm Nt} +\ ^1{\rm H} + \Delta E \tag{1}$$

where ΔE is the energy released. In terms of mass excesses the energy is

$$\Delta E = \Delta(^{\rm A}{\rm Nt}) - \Delta(^{\rm A-1}{\rm Nt}) - \Delta(^1 H). \tag{2}$$

In this equation the Nt isotope mass difference is

$$\Delta(^{\rm A}{\rm Nt}) - \Delta(^{\rm A-1}{\rm Nt}) = \Delta(^1{\rm Nt}) - B \tag{3}$$

where B is the binding energy per neutron, giving

$$\Delta E = \Delta(^1{\rm Nt}) - \Delta(^1{\rm H}) - B = 0.78 - B \quad {\rm MeV}. \tag{4}$$

If the binding energy is less than 0.78 MeV per neutron, reaction (1) will be exothermic and we can expect a neutron cluster to evaporate in the chain of beta decays

$$\begin{aligned} ^{\rm A}{\rm Nt} &\rightarrow\ ^{\rm A-1}{\rm Nt} +\ ^1{\rm H} \\ ^{\rm A-1}{\rm Nt} &\rightarrow\ ^{\rm A-2}{\rm Nt} +\ ^1{\rm H} \\ ^{\rm A-2}{\rm Nt} &\rightarrow\ ^{\rm A-3}{\rm Nt} +\ ^1{\rm H} \end{aligned} \tag{5}$$

and so on. Recalling that the lifetime of a neutron is about ten minutes, the lifetimes of Nt isotopes are likely to be relatively long.

Now suppose that the binding energy per neutron is greater than 0.78 MeV. Then ΔE is negative and decay reaction (1) is endothermic and cannot occur spontaneously. Beta decay then occurs in the channel

$$^{\rm A}{\rm Nt} \rightarrow\ ^{\rm A}\mathbf{H} \tag{6}$$

in which the isotopic spin $T =$ A/2, the nuclear symmetry, and the nuclear portion of the interaction energy all remain unchanged. I have bold-faced the **H** to emphasize that the neutron cluster $^{\rm A}$Nt and the hydrogen isotope $^{\rm A}\mathbf{H}$

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are members of the same isospin multiplet. Although the hydrogen isotope $^{\mathrm{A}}\mathbf{H}$ is stable against strong decay it can undergo the beta decay

$$^{\mathrm{A}}\mathbf{H} \rightarrow {}^{\mathrm{A}}\mathbf{He} \qquad (7)$$

into the doubly-charged nucleus of the $T = \mathrm{A}/2$ multiplet. This nucleus is unstable with respect to alpha particle emission

$$^{\mathrm{A}}\mathbf{He} \rightarrow {}^{\mathrm{A}-4}\mathrm{Nt} + {}^{4}\mathrm{He} \qquad (8)$$

which is exothermic for any binding energy less than 8.24 MeV.

The $^{\mathrm{A}}\mathbf{He}$ nucleus is unstable with respect to alpha particle emission which is exothermic for any binding energy less than 8.24 MeV