On the production of energy and helium in low energy nuclear reactions

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Table of Isotopes (small nuclei)

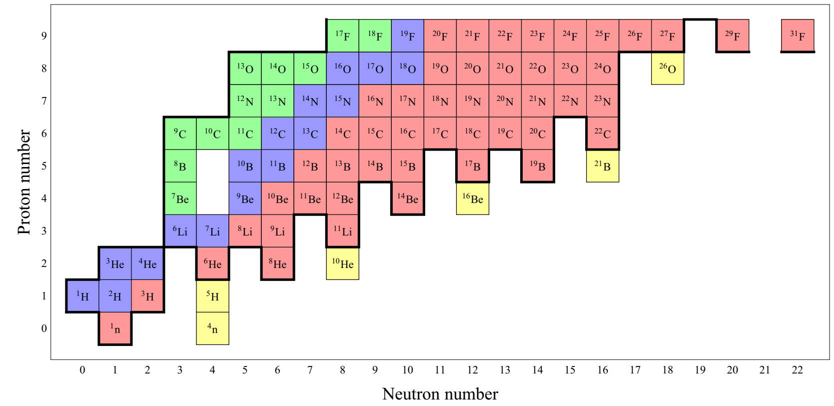
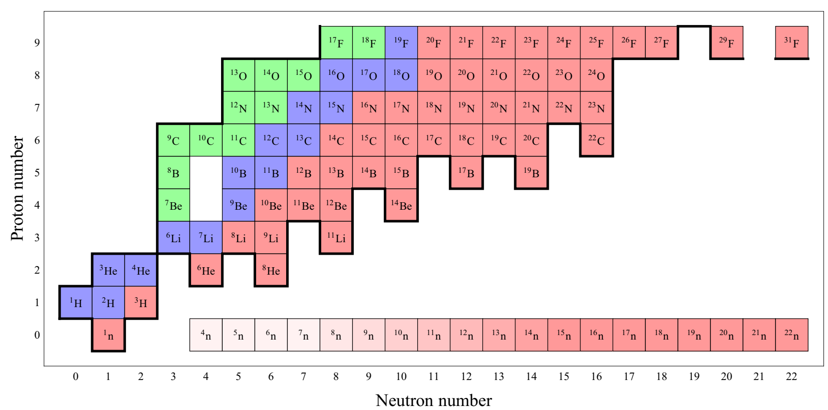
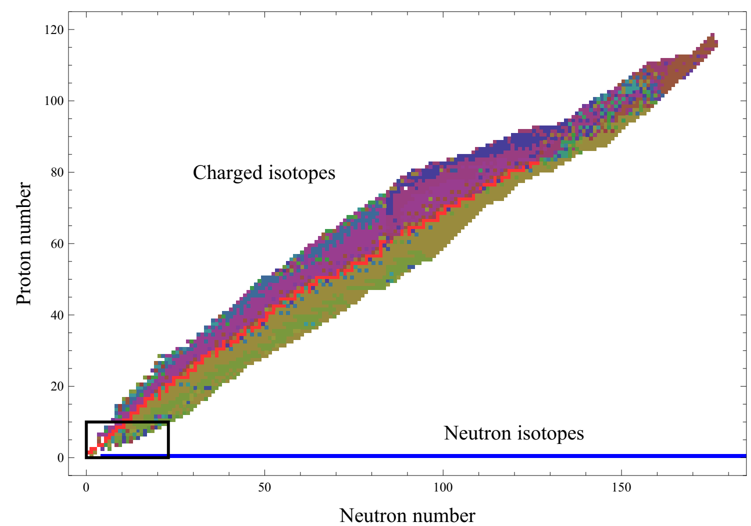


Table of Isotopes (including hypothetical neutron isotopes)



Full table of isotopes



Question: How could you detect neutron isotopes?

- From their decay and reaction products
- These depend on how strongly isotopes are bound
- We need a model

Liquid-drop model

- Suppose that neutrons in a neutron isotope are bound about 1/2 as strongly as they are in an ordinary charged isotope.
- The volumetric neutron isotope mass excess then would be

$$\Delta(^{A}n) \approx 8.071A - 7A \approx A$$

- We need also a surface energy proportional to $A^{2/3}$.
  - Hypothesize: $A^{2/3}$.
- Now we have the hypothetical neutron isotope mass excess

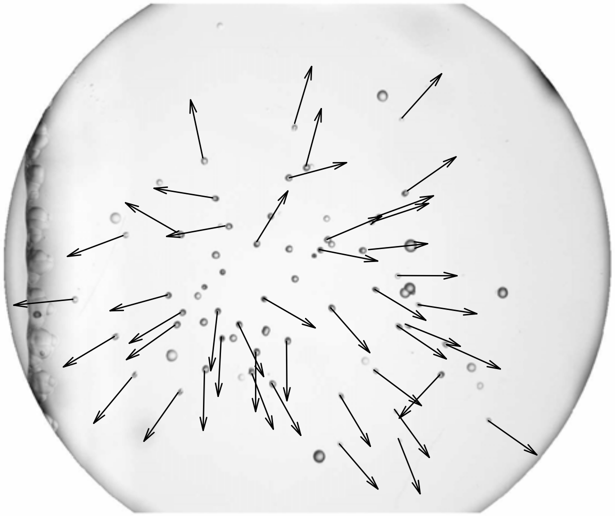
$$\Delta(^{A}n) = A + A^{2/3}$$

Neutron isotope detection by radioactive decay (exothermic $\beta\beta\alpha$)

- $^{200}n \longrightarrow {}^{196}n + {}^{4}He$
- $^{196}n \longrightarrow {}^{192}n + {}^{4}He$
- $^{192}n \longrightarrow {}^{188}n + {}^{4}He$
- And so on. A neutron isotope decays by emitting a series of energetic alpha particles.
- Overall: $^{200}n \longrightarrow 50(^{4}He)$
- We can detect the alpha particles.

Alpha particle shower

Etch pits on a detector chip in air under a nickel cathode (Oriani)

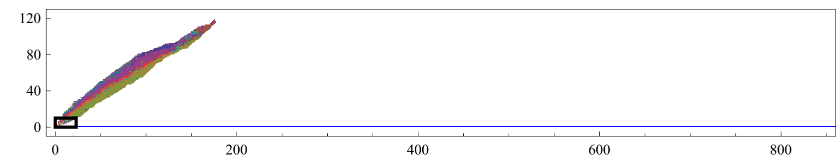


The Oriani shower

- 63 pits
- about 200 alphas in full 4π shower
- about 800 neutrons in parent neutron isotope

- Consistent with decay mode
- Consistent with large neutron isotopes
- Consistent with helium production

Full table of isotopes



Neutron isotope detection by growth reactions

- Isotope growth (deuterium fuel)

$$^{2}\mathrm{H} + {}^{A}\mathrm{n} \longrightarrow {}^{A+1}\mathrm{n} + {}^{1}\mathrm{H}$$
$$^{2}\mathrm{H} + {}^{A+1}\mathrm{n} \longrightarrow {}^{A+2}\mathrm{n} + {}^{1}\mathrm{H}$$
$$^{2}\mathrm{H} + {}^{A+2}\mathrm{n} \longrightarrow {}^{A+3}\mathrm{n} + {}^{1}\mathrm{H}$$
$$^{2}\mathrm{H} + {}^{A+3}\mathrm{n} \longrightarrow {}^{A+4}\mathrm{n} + {}^{1}\mathrm{H}$$

- Neutron isotope growth is accompanied by emission of energetic protons.
- Isotope decay also occurs

$$^{A+4}\mathrm{n} \longrightarrow {}^{A}\mathrm{n} + {}^{4}\mathrm{He}$$

- Overall (steady state)

$$4(^{2}\mathrm{H}) \longrightarrow 4(^{1}\mathrm{H}) + {}^{4}\mathrm{He} + 20\mathrm{MeV}$$

Neutron isotope detection by lithium-6 reactions

Isotope growth

$$^{6}\mathrm{Li} + {}^{A}\mathrm{n} \longrightarrow {}^{A+1}\mathrm{n} + {}^{5}\mathrm{Li}$$
$$^{6}\mathrm{Li} + {}^{A+1}\mathrm{n} \longrightarrow {}^{A+2}\mathrm{n} + {}^{5}\mathrm{Li}$$
$$^{6}\mathrm{Li} + {}^{A+2}\mathrm{n} \longrightarrow {}^{A+3}\mathrm{n} + {}^{5}\mathrm{Li}$$
$$^{6}\mathrm{Li} + {}^{A+3}\mathrm{n} \longrightarrow {}^{A+4}\mathrm{n} + {}^{5}\mathrm{Li}$$

Isotope decay

$$^{A+4}\mathrm{n} \longrightarrow {}^{A}\mathrm{n} + {}^{4}\mathrm{He}$$

Overall (steady state)

$$4(^{6}\mathrm{Li}) \longrightarrow 4(^{5}\mathrm{Li}) + {}^{4}\mathrm{He}$$
$$\longrightarrow 4(^{1}\mathrm{H}) + 5(^{4}\mathrm{He}) + 14\mathrm{MeV}$$

Neutron isotope detection by lithium-7 reactions

Isotope growth

$$^{7}\mathrm{Li} + {}^{A}\mathrm{n} \longrightarrow {}^{A+2}\mathrm{n} + {}^{5}\mathrm{Li}$$

$$^{7}\mathrm{H} + {}^{A+2}\mathrm{n} \longrightarrow {}^{A+4}\mathrm{n} + {}^{5}\mathrm{Li}$$

Isotope decay

$$^{A+4}\mathrm{n} \longrightarrow {}^{A}\mathrm{n} + {}^{4}\mathrm{He}$$

Overall (steady state)

$$2({}^{7}\mathrm{Li}) \longrightarrow 2({}^{5}\mathrm{Li}) + {}^{4}\mathrm{He}$$
$$\longrightarrow 2({}^{1}\mathrm{H}) + 3({}^{4}\mathrm{He}) + 7\mathrm{MeV}$$

Some useful things to study

- Energetic protons and alphas
  - Explore basic reactions
- Helium and heat
  - Identify and quantify nuclear fuels
- Transmutation (more expensive)
  - Confirm and extend reaction dynamics

Helium and heat

Steady state reactions for selected fuel isotopes

^{2}H:	$4({}^{2}\mathrm{H}) \longrightarrow 4({}^{1}\mathrm{H}) + {}^{4}\mathrm{He} + 20\mathrm{MeV}$
^{6}Li:	$4({}^{6}\mathrm{Li}) \longrightarrow 4({}^{1}\mathrm{H}) + 5({}^{4}\mathrm{He}) + 14\mathrm{MeV}$
^{7}Li:	$2({}^{7}\mathrm{Li}) \longrightarrow 2({}^{1}\mathrm{H}) + 3({}^{4}\mathrm{He}) + 7\mathrm{MeV}$
^{9}Be:	$4({}^{9}\mathrm{Be}) \longrightarrow 9({}^{4}\mathrm{He}) + 23\mathrm{MeV}$
^{13}C:	$4({}^{13}\mathrm{C}) \longrightarrow 4({}^{12}\mathrm{C}) + {}^{4}\mathrm{He} + 9\mathrm{MeV}$
^{17}O:	$4({}^{17}\mathrm{O}) \longrightarrow 4({}^{16}\mathrm{O}) + {}^{4}\mathrm{He} + 12\mathrm{MeV}$
^{18}O:	$2({}^{18}\mathrm{O}) \longrightarrow 2({}^{16}\mathrm{O}) + {}^{4}\mathrm{He} + 5\mathrm{MeV}$
^{232}Th:	Complex, ambiguous,
^{238}U:	not worked out.

Comments on neutron isotopes

- For theoreticians
  - Ordinary nuclear physics with more isotopes
- For experimenters
  - Opportunity for fundamental research
- For entrepreneurs
  - It's risky to ignore lithium and beryllium and other fuels