Teacher notes
Topic E

Iron or nickel?

Despite what many books say, ${}^{62}_{28}\mathrm{Ni}$ has a higher (slightly) binding energy per nucleon than ${}^{58}_{26}\mathrm{Fe}$. The binding energy per nucleon for ${}^{62}_{28}\mathrm{Ni}$ is 8.795 MeV and that for ${}^{58}_{26}\mathrm{Fe}$ is 8.792 MeV.

This begs the question why nuclear fusion reactions in stellar interiors end with the production of iron and not nickel?

It is a good exercise to calculate the binding energies per nucleon for iron and nickel!

We use the version of the mass defect in terms of atomic masses.

For nickel:

$\mu = (ZM_H + Nm_n - M_{atom}) = 28\times1.007825 + (62-28)\times1.008665 - 61.928345115 = 0.58536489$ u.

So the binding energy per nucleon is $\dfrac{0.58536489 \times 931.5}{62} = 8.7946\ \text{MeV}$.

For iron:

$\mu = (ZM_H + Nm_n - M_{atom}) = 26\times1.007825 + (58-26)\times1.008665 - 57.933275558 = 0.54745444$ u.

So the binding energy per nucleon is $\dfrac{0.54745444 \times 931.5}{58} = 8.7923\ \text{MeV}$.

The problem is to find fusion reactions that can take iron (which is produced in the silicon fusion sequence) to nickel.

One possibility is to produce nickel through a triple alpha type of process such as

$${}^{58}_{26}\mathrm{Fe} + {}^{6}_{2}\mathrm{He} \to {}^{62}_{28}\mathrm{Ni} + \gamma$$

Another possibility is to produce nickel through two fusion reactions with ${}^{3}_{1}\mathrm{H}$:

${}^{58}_{26}\mathrm{Fe} + {}^{3}_{1}\mathrm{H} \to {}^{59}_{27}\mathrm{Co} + 2\mathrm{n}$ followed by ${}^{59}_{27}\mathrm{Co} + {}^{3}_{1}\mathrm{H} \to {}^{62}_{28}\mathrm{Ni}$

However, in both cases the required nuclei, ${}^{6}_{2}He$ and ${}^{3}_{1}H$ are unstable and will never be found in large numbers at the end stage of the evolution of a massive star.

So, the conclusion is that despite being the most tightly bound nucleus (highest biding energy per nucleon) there is no available fusion reaction to turn iron into nickel in a star.

See the article by Richard Shurtleff and Edward Derringh in *Am. J. Phys.* 57, 552 (1989).