Lets look at another example

most scientists you ask will probably agree that some big bang like event is needed to explain the evolution of our universe.

Most scientists though, can't really tell you where all the heavy elements came from.

most likely, from early stars that died & spewed junk into the cosmos.

Given that, we can compare 2 elements created during this epoch & see how long ago it was

$^{235}U \quad t_{1/2} = 7.04\times10^8 y$

$^{238}U \quad t_{1/2} = 4.47\times10^9 y$

$$@\, t=0 \quad \# \frac{^{235}U}{^{238}U} = 1$$

$$\text{now} \quad \# \frac{^{235}U}{^{238}U} = \frac{.7\%}{99.3\%} \sim .007$$

$$= \frac{e^{-\lambda_1 t}}{e^{-\lambda_2 t}}$$

$$\ln(0.007) = -\lambda_1 t - (-\lambda_2 t)$$

$$= (\lambda_2 - \lambda_1)t$$

$$t = \frac{\ln(0.007)}{\lambda_2 - \lambda_1} = \frac{\ln(0.007)}{\frac{0.693}{t_{1/2}} - \frac{0.693}{t_{1/2}}}$$

$$t = \frac{\ln(0.007)}{\frac{0.693}{4.47\times10^9 y} - \frac{0.693}{7.04\times10^8 y}} = 5.98\times10^9 yr$$

pretty old

These 2 elements are actually interesting for another reason.

Where do you suppose all the helium comes from? It shouldn't be in the atomosphere for very long. (at temp $v \sim 600$ m/s $V_{esc} = 11.2$ km/s, collisions give the velocity a distribution. The tail end of the distribution escapes)

Where do you suppose all the heat comes from inside the earth?

(Sun can't supply enough)

Comes from elemente like ^{238}U + ^{235}U decaying (& ^{232}Th too is long lived)

So these decays are an integral part of our lives, but still, where does that energy come from?

Consider the follwing, $^{12}_{6}C$ is defined to weigh 12.00 u

But look at the consituents

6 protons + 6 electrons + 6 neutron

$M_{proton+electron} = 1.007825u$

$M_{neutron} = 1.008665\, u$

so Carbon constituents weigh

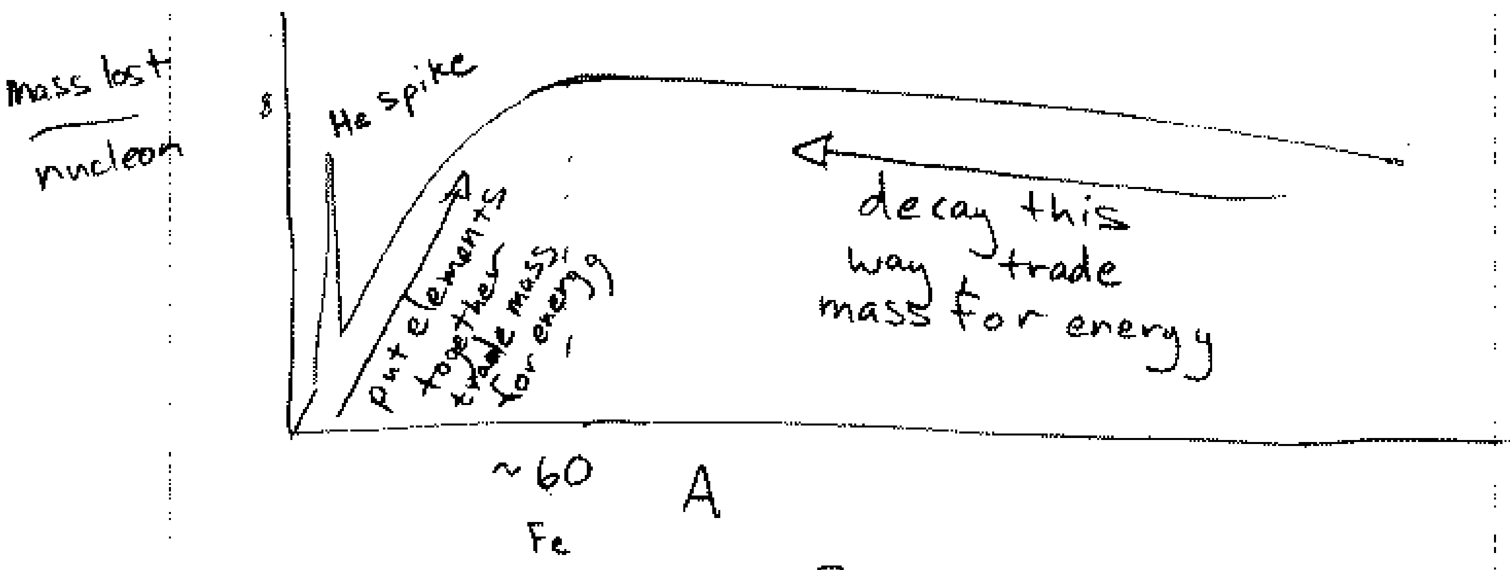
$6M_{pe} + 6M_n = 12.09894\, u$

So apparently, when we make carbon, we lose mass.

$$(12.09894\,u - 12.00\,u)\,931.494\,\frac{MeV}{c^2} = 92.16\,\frac{MeV}{c^2}$$

or about $7.68\,\frac{MeV}{c^2}$ /nucleon

You can do this same calculation for the other elements too what you find is that theres a curve of how much mass you give up to form a nucleus/nucleon that looks like Robin hoods hat with a feather



what does this mean?

The bound nucleas really does sit at a lower energy & since $E=mc^2$ & E gets lower m gets lower too, bizarre!

With this picture, we can understand

1) Some decays won't happen because there isn't enough Δm to satisfy energy conservation Ie for a decay to occur $\Sigma E_{before} \geq \Sigma E_{after}$

2) If we take 2 atoms with low A and combine them to get Higher, get energy out <u>Fusion</u>

3) <u>If</u> an atom with Z big decays to Z smaller, we can get energy out too <u>fission</u>

Let's go back to our ^{235}U again.

If you bombard ^{235}U with a slow (thermal) neutron $v \sim 2000 m/s$ you get a mess (slide)

You end up turning ^{255}U into

$^{144}Nd + ^{89}Y$

or, something with a binding energy/nucleon (Δm you lose)

of $^{235}U \sim 7.6 \text{ MeV}/c^2$ /nucleon

to $^{144}Nd \sim \frac{8.2 \text{ MeV}/c^2}{\text{nucleon}}$
$^{89}Y \sim \frac{8.7 \text{ MeV}/c^2}{\text{nucleon}}$ } $\sim \frac{8.5 \text{ MeV}/c^2}{\text{nucleon}}$

One [redacted] Fission Reaction

$${}^{1}_{0}n + {}^{235}_{92}U \Rightarrow {}^{236}U^{*}$$ (excited)

$${}^{236}U^{*} \underset{\text{splits}}{\Rightarrow} {}^{144}Ba + {}^{89}Kr + 3\,{}^{1}_{0}n$$ ← can be reused

$${}^{144}Ba \Rightarrow {}^{144}La + \beta^{-}$$
$$\Rightarrow {}^{144}Ce + \beta^{-}$$
$$\Rightarrow {}^{144}Pr + \beta^{-}$$
$$\Rightarrow {}^{144}Nd + \beta^{-}$$

$${}^{89}Kr \Rightarrow {}^{89}Rb + \beta^{-}$$
$$\Rightarrow {}^{89}Sr + \beta^{-}$$
$$\Rightarrow {}^{89}Y + \beta^{-}$$

Fast neutrons like to interact with ${}^{238}U$ and tend to leave quickly in any case (besides ${}^{239}U^{*}$ doesn't "Fission")

Slow (thermal) neutrons interact Best with ${}^{235}U$, so, in a reactor, we try to slow them down so they can react with ${}^{235}U$ ← the key so, we release, something like

$$(8.45 - 7.6) \times 239 \text{ nucleons} \sim 200 \frac{MeV}{c^2}$$

about 200 meV of energy

about 1 meV/nucleon

how do we get this stuff

In the sun, temperatures are (10^7K) so high, particles can move fast enough to overcome the coulomb repulsion

2 of these: $^1_1H + ^1_1H \Rightarrow ^2_1H + \beta^+ + \nu$ $\quad \Delta m \sim 1 \, MeV/c^2$

2 of these: $^1_1H + ^2_1H \rightarrow ^3_2He + \gamma$ $\quad \sim 5.9 \, meV/c^2$

give: $^3_2He + ^3_2He \rightarrow ^4_2He + 2\,^1_1H$ $\quad \sim 12 \, meV/c^2$

total energy released ~ 26 MeV/c^2

since we converted 4 $^1_1$H into one $^4_2$He

this amounts to about 6.5 MeV/c^2/nucleon

of energy released in this reaction.

(at higher temps, even carbon can fuse)

eventually, all the hydrogen is consumed & the star will start to die.

(we've got billions of years yet!)