The Formation of Elements

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The Early Universe

All the matter in the universe was created in the Big Bang

Initially only hydrogen, helium, and a little bit of lithium was created

95% hydrogen, 5% helium, and a trace amount of lithium

So how did all the other elements get created?

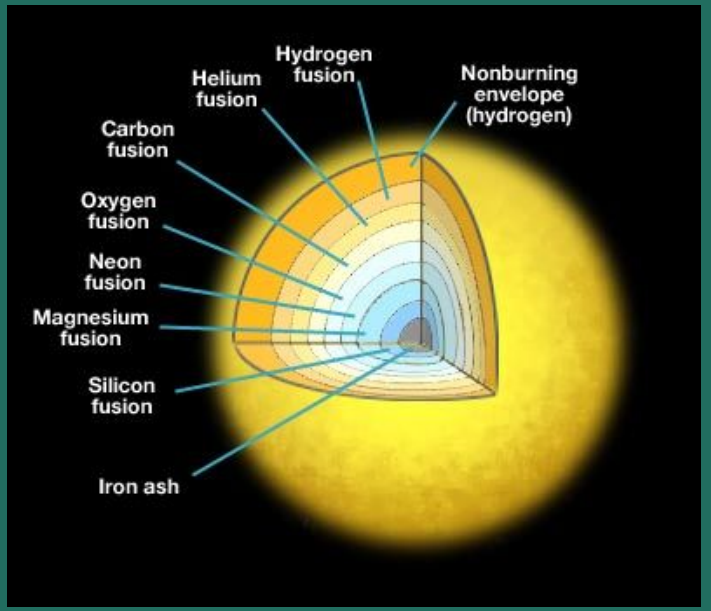
Fusion

Stars burn by fusing elements in their core

Each element requires a certain temperature to fuse

Once one element is exhausted, the next one begins to fuse

Iron fusion takes more energy than it releases



Star Death

Stars die when they can no longer fuse elements in their core

The gravitational pressure from the large mass of the star causes a collapse

Small stars and large stars die in different ways

Star death is the main driving force of heavy element formation

Small Stars ($M < 3M_{Sun}$)



When small stars run out of hydrogen in their core it starts to compress until helium fusion begins

This causes the star to swell until it reaches a new stable size

Helium ash begins to pile up in the core until carbon fusion can begin

Once the star runs out of helium it collapses under gravitational pressure leaving behind a white dwarf

Large Stars ($M > 3M_{Sun}$)



Large stars have much higher internal temperatures which allows for more elements to fuse

Large stars fuse elements up until iron, which requires more energy to fuse than it releases

The star collapses and under its immense mass it creates neutrons

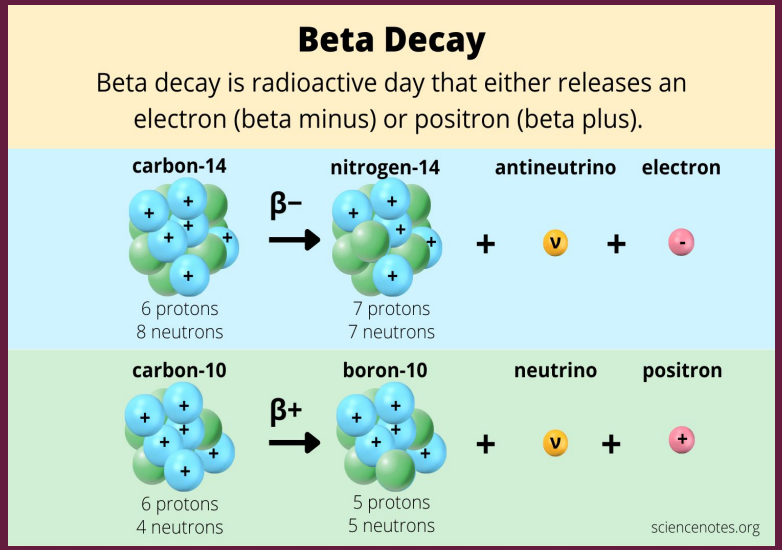
The energy released from the electrons and protons coming together causes a supernova

Neutron Capture

The main way elements heavier than iron form is through neutron capture

Atoms will capture neutrons and these neutrons will decay into protons through beta decay

Neutron capture has two main processes, one on a long time scale and one on a short one



S-Process

S-Process (slow process) takes 100 to 10000 years for each neutron capture

Occurs when there are relatively few free neutrons available

The long time scales allow enough time for beta decay to occur

The s-process generally occurs with an iron seed nucleus that can then capture neutrons and go up the chain of elements

Since there are few neutrons, the s-process cannot create the heaviest elements

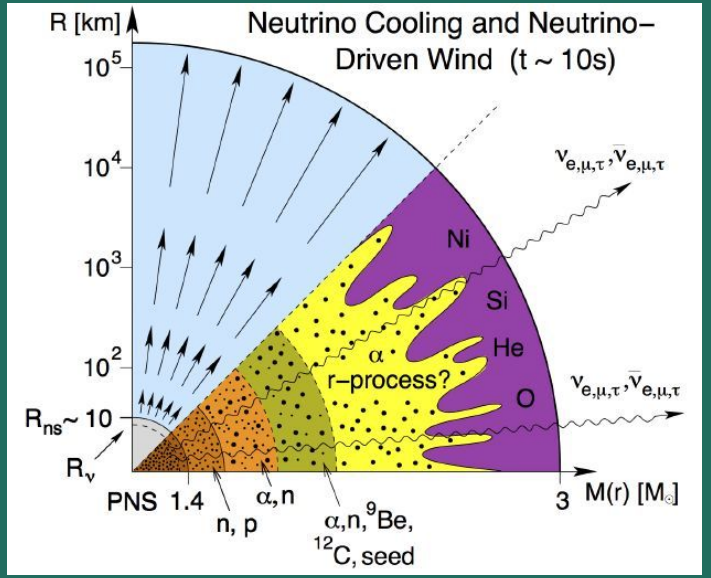
R-Process

R-Process (rapid process) takes between 0.1 - 10 seconds

This process occurs when there is an abundance of free neutrons

Elements will capture neutrons faster than they can beta decay

Lots of unstable, neutron-rich isotopes will form, then decay into stability

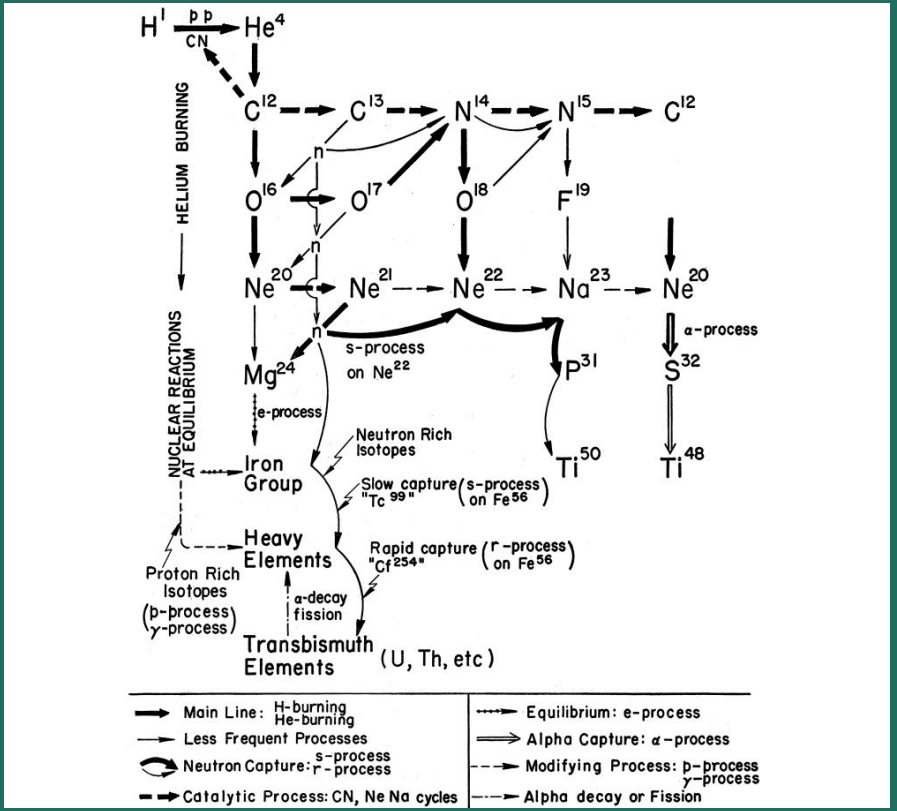


Other processes

P-process results in proton rich isotopes

α-process caused by α particles

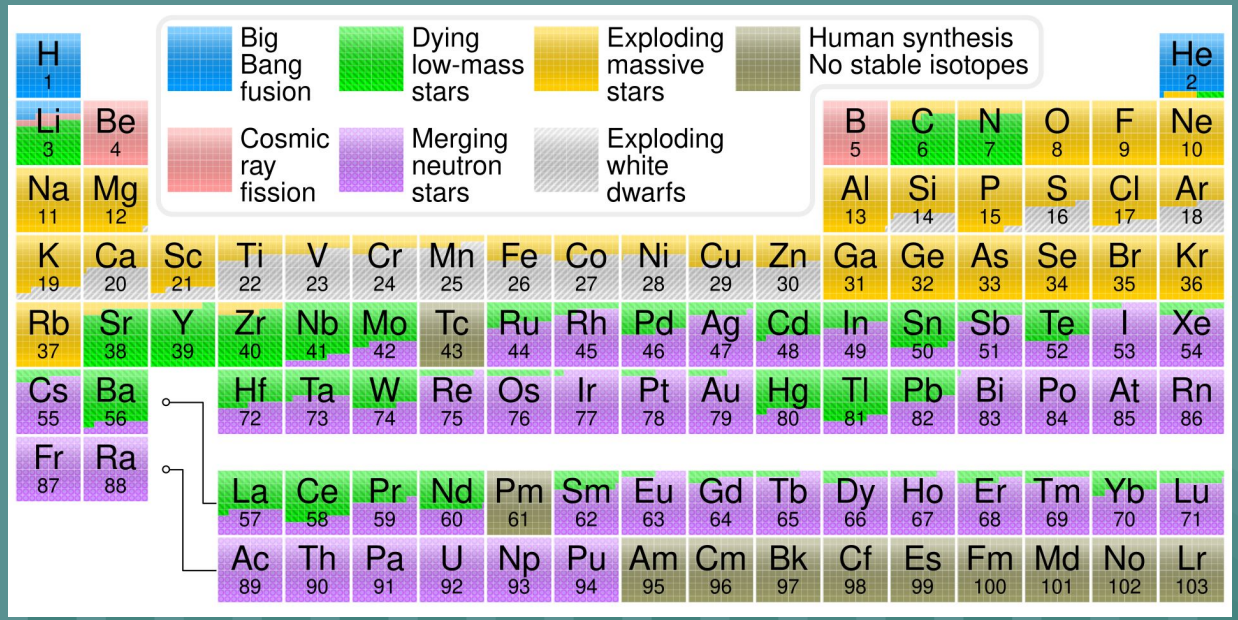
E-process is what happens in large star fusion



Element Abundances

The s-process happens in asymptotic giant branch stars and supernovae

The r-process creates happens in supernovae and merging neutron stars



Conclusion

The big bang created a lot of hydrogen and some helium

Star fusion is able to create elements up to iron

Star death leads to heavier elements through neutron capture

S-process is responsible for medium weight elements

R-process is responsible for heaviest elements



References

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Questions?