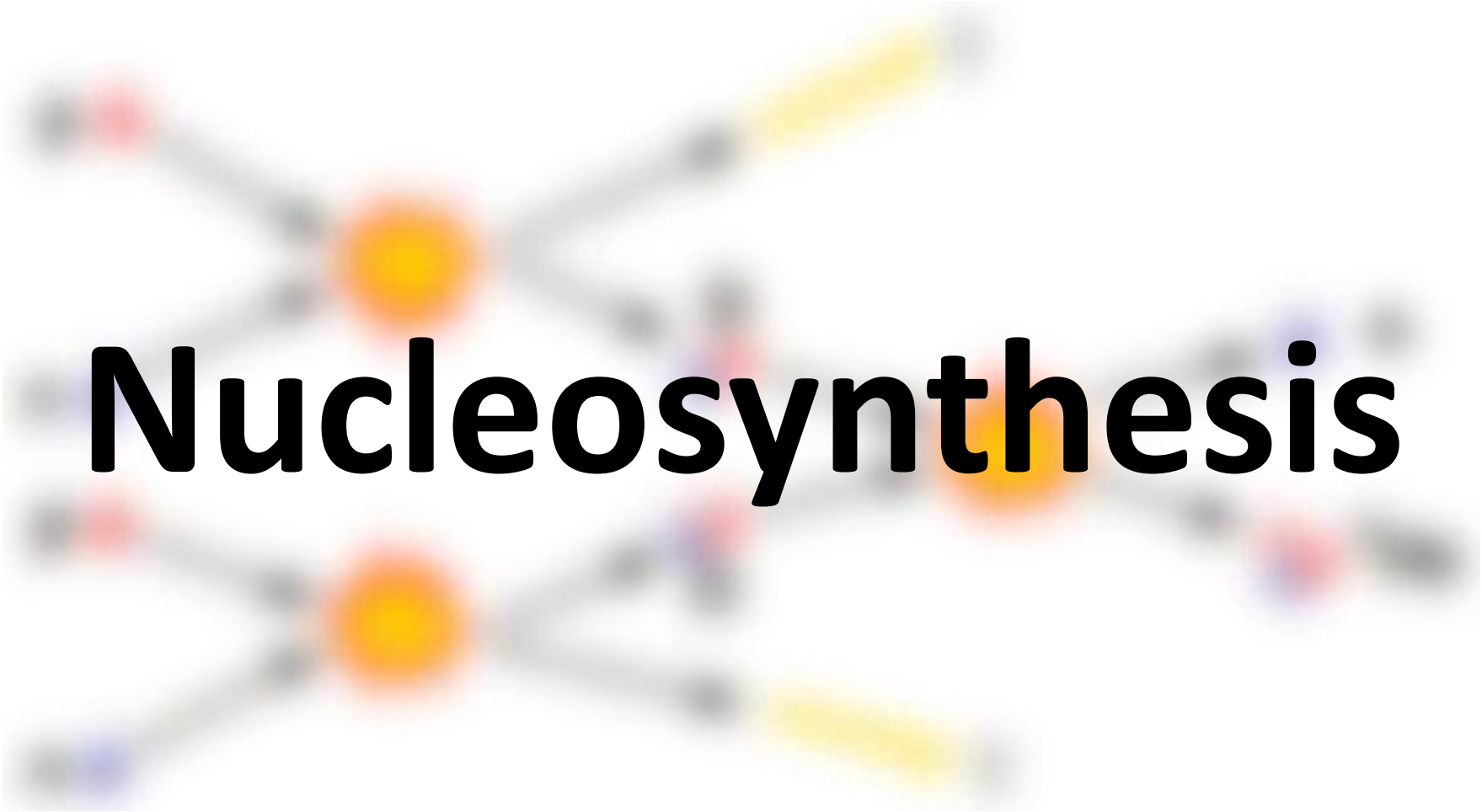

Nucleosynthesis

How were the first Elements in the Universe formed?

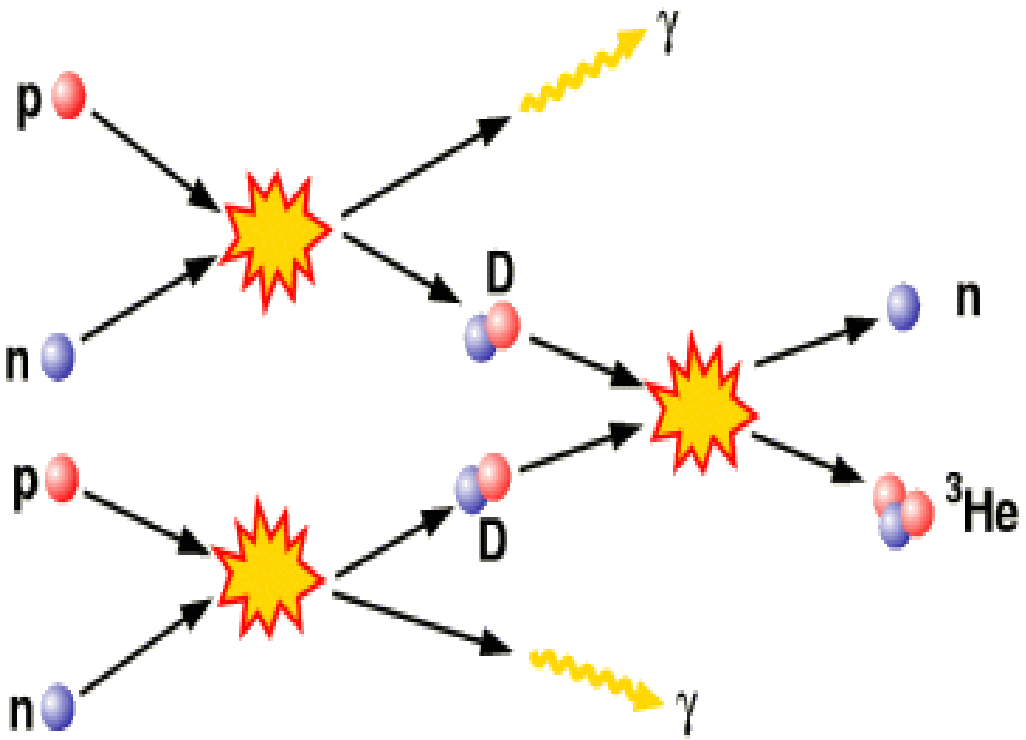
- A few seconds after the big bang, protons, neutrons, and electrons consisted the universe.
- At present, the universe consists of mostly hydrogen and helium.
- The elements of the present universe were formed in a process known as **nucleosynthesis.**

Definition of Terms:

1) **Nucleus (plural: nuclei)** – the central part of the atoms which contains the nucleons.
2) **Nucleons** – subatomic particles found in the nucleus. (proton and neutron)

Nucleosynthesis

Process that creates new atomic nuclei from nucleons.



Nucleosynthesis

1. Building up of complex atoms through the formation of deuterium nuclei or deuterons. ***Deuterons*** are a combination of a proton and a neutron.

$$n + p \longrightarrow d + \gamma$$

To break up a deuteron nuclei apart into its components - proton and neutron; the reverse reaction process must occur.

$$d + \gamma \longrightarrow n + p$$

- The two reactions will take place at the same rate if the universe were filled with energetic photons, which means that the **deuterium will dissociate as quickly as it is formed**.
- But if the universe were adequately old enough, the energy of the photons would not be sufficient to accomplish the dissociation reaction and the deuterium would start to build up.

- Since deuterons are less abundant than protons and neutrons, **deuterons will readily react with them** according to the following reaction equations:

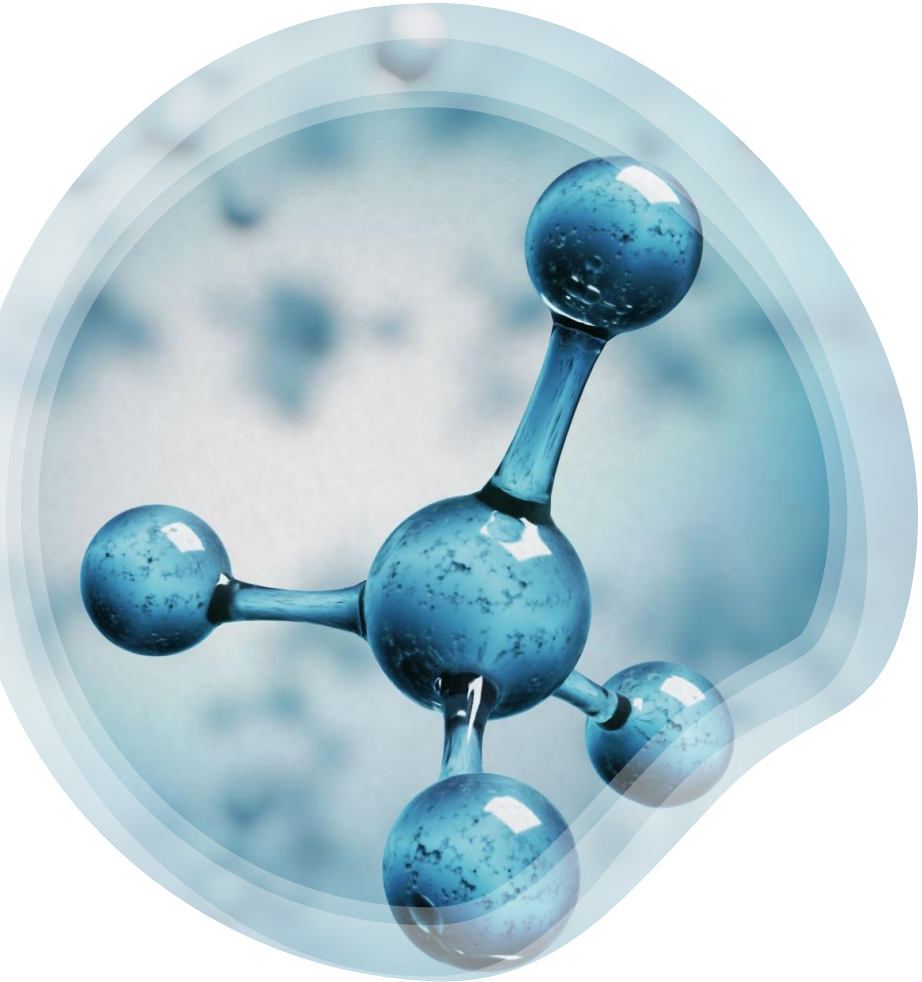
$$d + n \longrightarrow {}^{3}H + \gamma \quad \text{and}$$

$$d + p \longrightarrow {}^{3}He + \gamma$$

- ^{3}H and ^{3}He will also react with p and n :

$$^{3}H + p \longrightarrow {}^{4}He + \gamma$$

$$^{3}He + n \longrightarrow {}^{4}He + \gamma$$



- The last step in the formation of matter in the big bang, was the **production of neutral atoms of H and He**. This happened when proton and ^{4}He nuclei combined with electrons.
- With the formation of neutral atoms, there were essentially no free charged particles left in the universe.

Simple Helium Fusion

$^{4}He + {}^{4}He \longrightarrow {}^{8}Be$

- ^{8}Be is unstable and breaks apart as rapidly as it forms.
- A third ^{4}He is required to participate in the reaction.

$$^{4}He + {}^{4}He + {}^{4}He \longrightarrow {}^{12}C + \gamma$$

$$^{12}C + {}^{4}He \longrightarrow {}^{16}O + \gamma$$

$$^{16}O + {}^{4}He \longrightarrow {}^{20}Ne + \gamma$$

$$^{20}Ne + {}^{4}He \longrightarrow {}^{24}Mg + \gamma$$ and so on.

When the fuel is exhausted, contraction sets in again increasing the temperature so that other reactions can occur, such as **Carbon burning**.

$$^{12}C + {}^{12}C \longrightarrow {}^{24}Mg + \gamma$$

•The elements beyond A = 56 cannot be produced through fusion. These are produced through the process called the **neutron-capture process**.

Neutron-Capture Process

Neutrons are captured by the nucleus in the interior of a star until the amount of neutron excess is sufficient to convert extra neutron to a proton in a beta decay:

$$n \longrightarrow p + e + \gamma$$

This increases the number of protons by one.

$$^{56}Fe + n \longrightarrow {}^{57}Fe + \gamma$$

$$^{57}Fe + n \longrightarrow {}^{58}Fe + \gamma$$

$$^{58}Fe + n \longrightarrow {}^{59}Fe + \gamma$$

^{58}Fe and ^{57}Fe are stable, but ^{59}Fe is not – it is radioactive. It undergoes beta decay to ^{59}Co.

^{59}Co can capture a neutron to become ^{60}Co, which is radioactive, and beta decays to ^{60} Ni.

3 types of Nucleosynthesis:

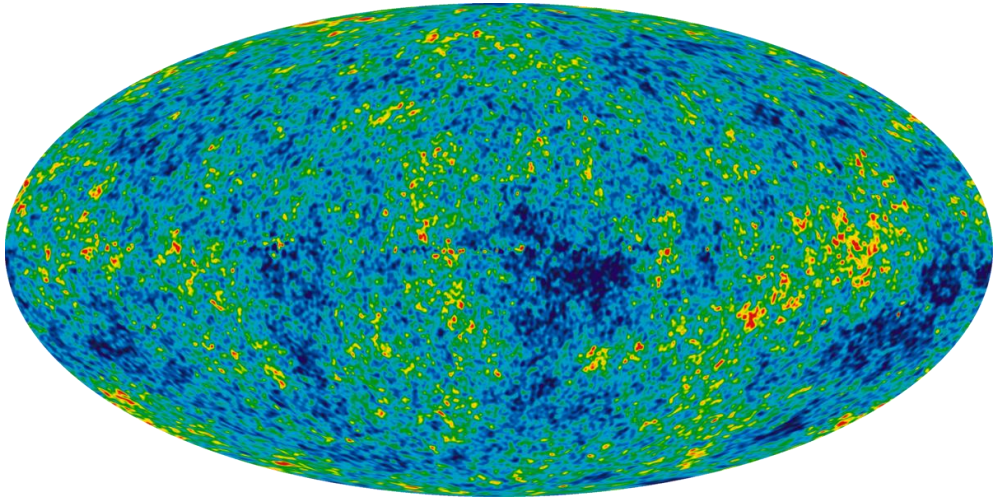
Big Bang Nucleosynthesis

Stellar Nucleosynthesis

Supernova Nucleosynthesis

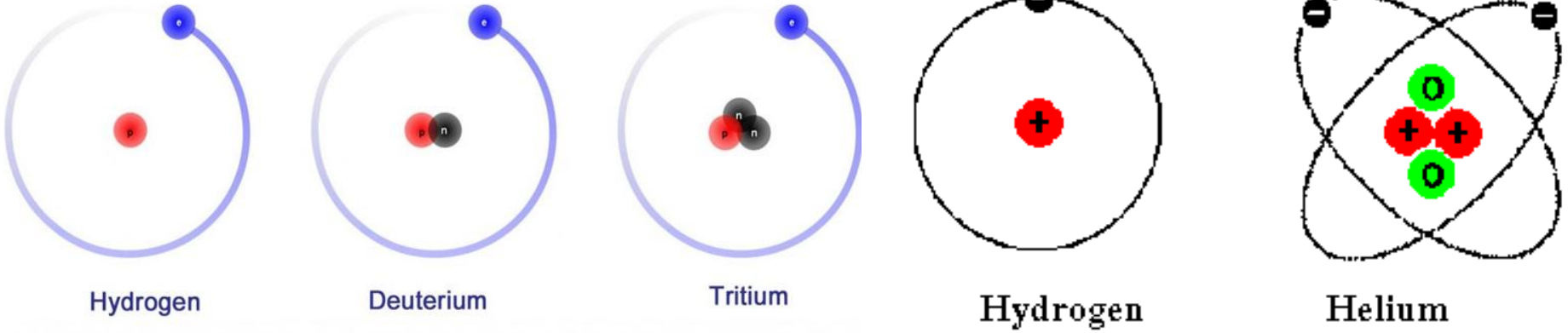
Big Bang Nucleosynthesis

After the expansion and cooling of the universe, nuclei started to form



Big Bang Nucleosynthesis

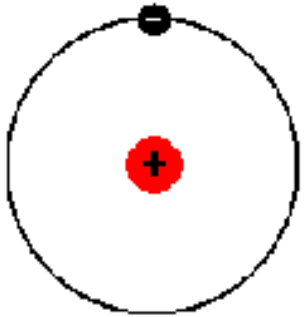
About 3 minutes after the Big Bang, the nucleus of Hydrogen and Helium formed



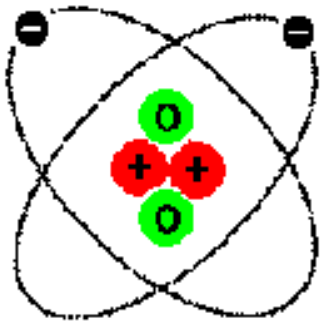
Big Bang Nucleosynthesis

After more cooling, nuclei started to attract electrons forming atoms.

This happened 300, 000 years after the big bang.



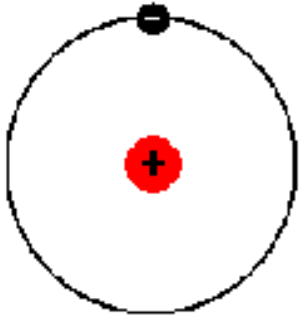
Hydrogen



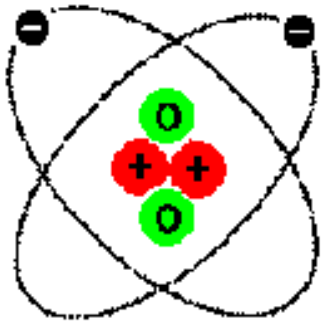
Helium

Evidence of the Big Bang:

All the Hydrogen and Helium we have in the universe came from the big bang.



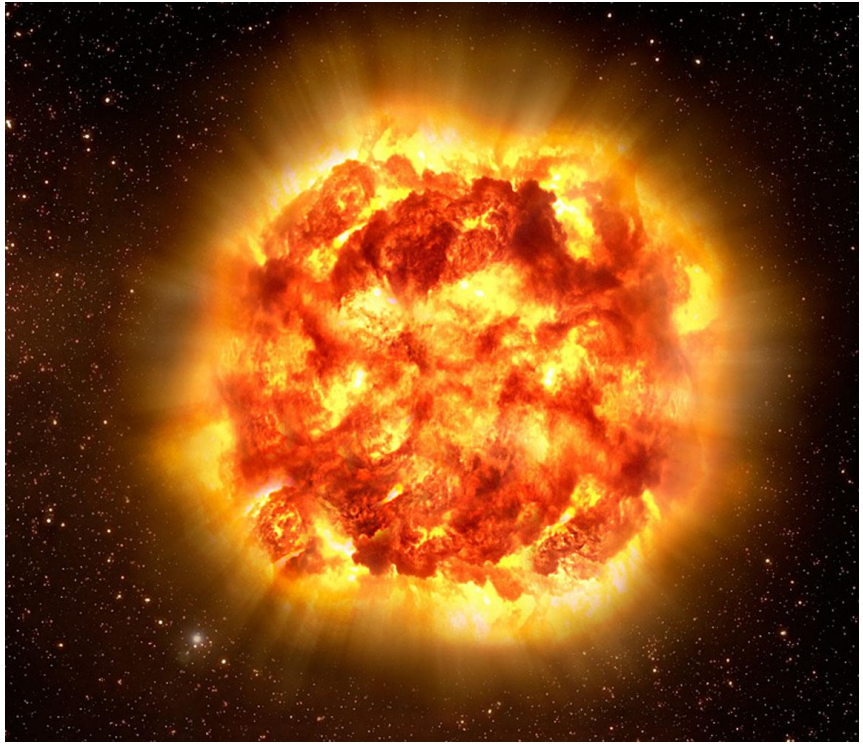
Hydrogen



Helium

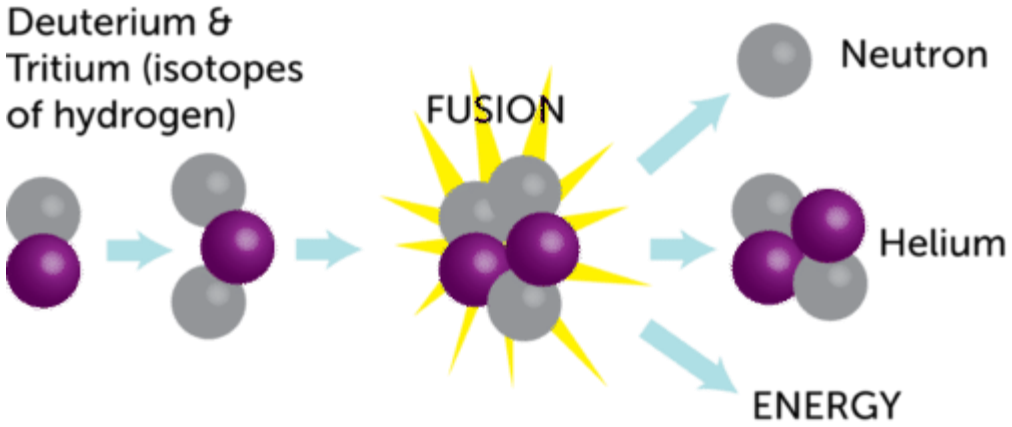
Stellar Nucleosynthesis

Process by which nuclei are formed in the center of stars.



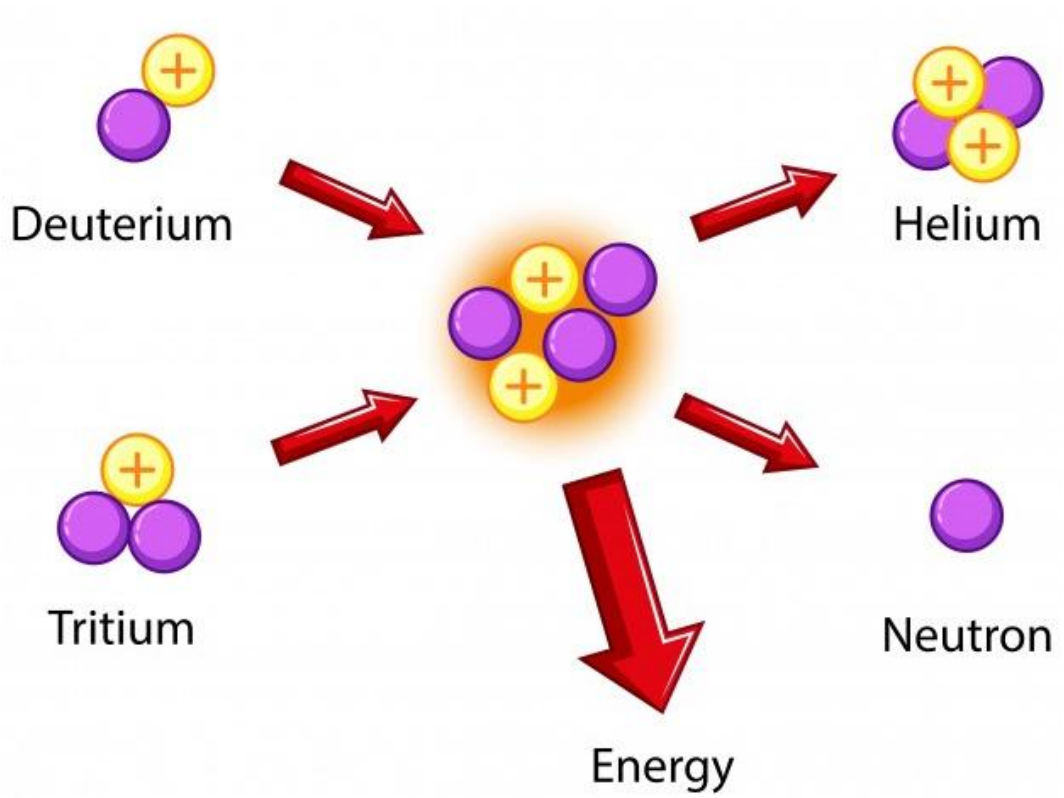
Stellar Nucleosynthesis

Elements from helium (He) to Iron (Fe) are made through the process called **Nuclear Fusion.**



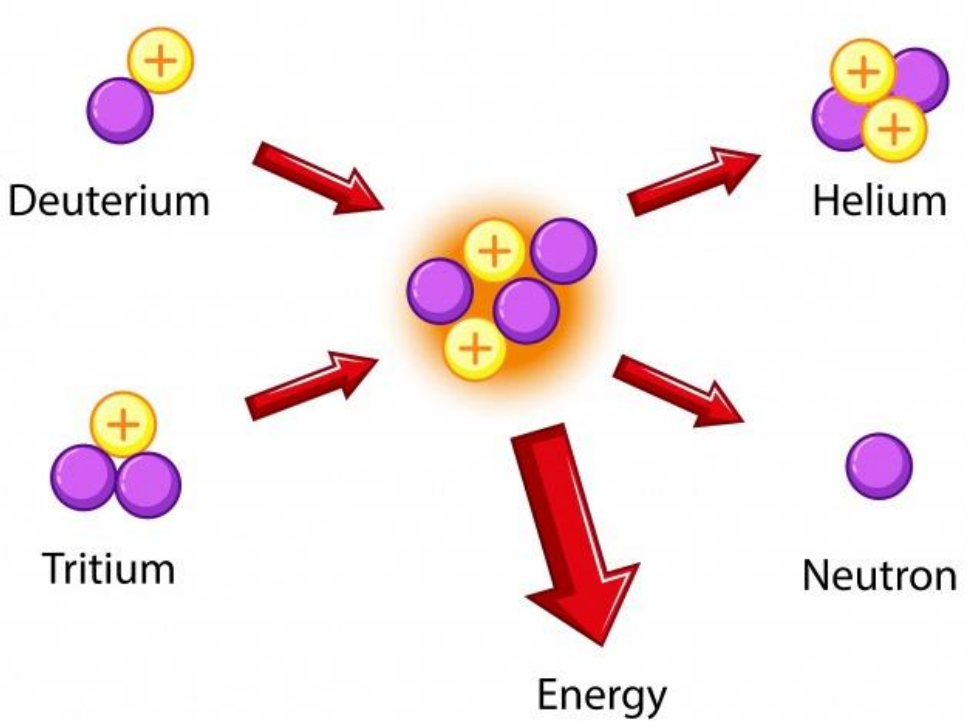
Nuclear Fusion

The process of colliding light elements to form heavier elements



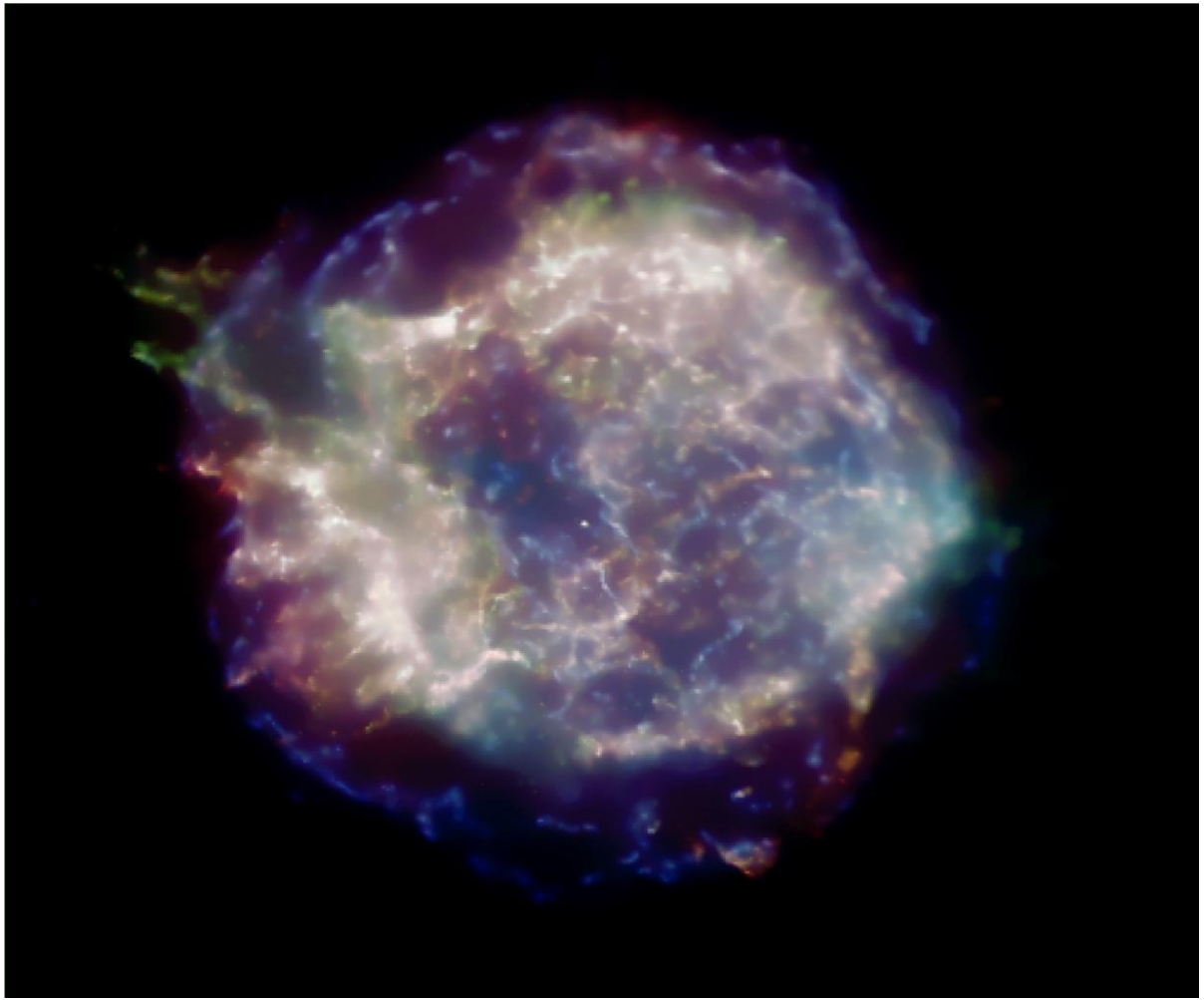
Nuclear Fusion

Energy that stars produce come from the collision if light elements



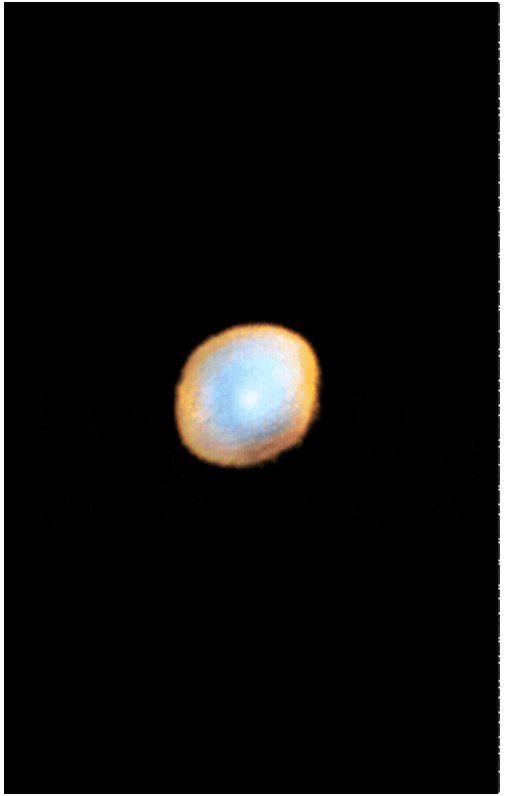
What happens when all of the hydrogen and helium in a star are made into heavier elements?

THE STAR WILL COLLAPSE!!!



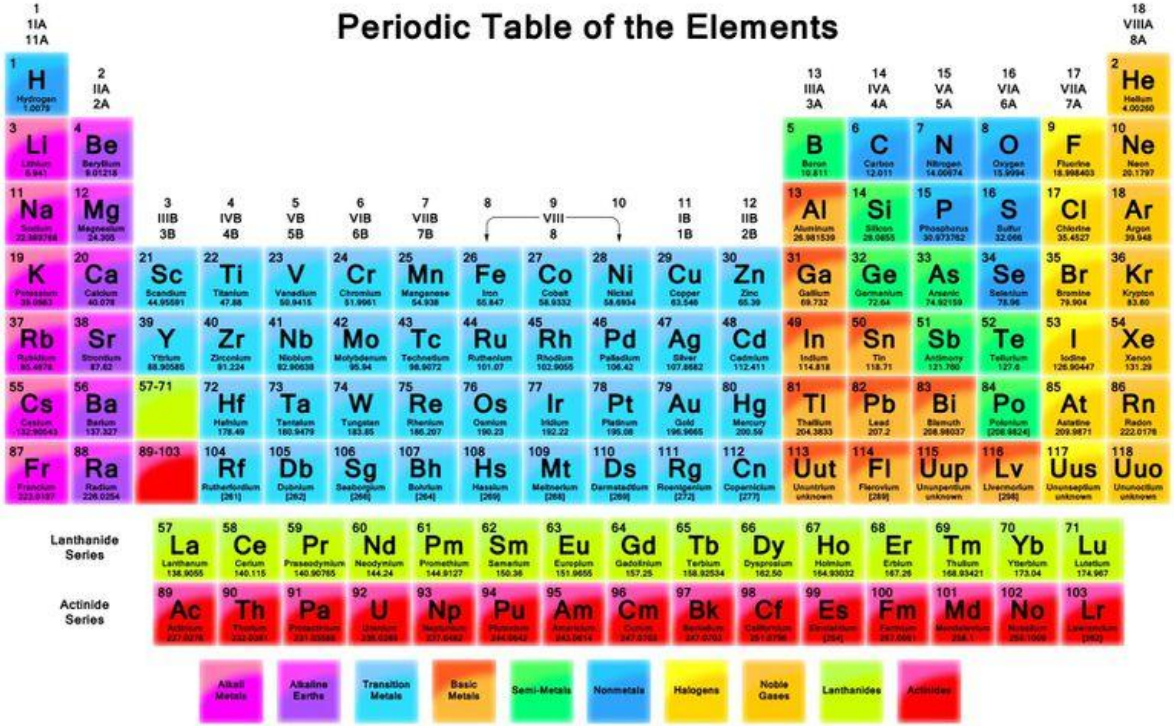
Supernova Nucleosynthesis

When a star collapses, heavier elements can now be fused together.



Supernova Nucleosynthesis

Elements heavier than iron (Fe) are made through this process.



Supernova Nucleosynthesis

When supernovas occur, temperatures increase to 100 billion degrees Celsius and there are extreme numbers of neutrons.

Generalization:

1. During Big Bang Nucleosynthesis, elements Hydrogen and Helium were formed.
2. During Stellar Nucleosynthesis, elements from helium to Iron were formed.
3. During Supernova Nucleosynthesis, elements from Iron to Uranium were formed.

Identification

1-2. These are subatomic particles found in the nucleus of an atom

3. Process that creates new atomic nuclei from nucleons.

4. During this type of nucleosynthesis, the elements hydrogen and helium were formed.

Identification

5. Process by which nuclei are formed in the center of stars.

6. The process of colliding light elements to form heavier elements.

7. This type of nucleosynthesis is where all the elements heavier than iron were made.

Identification

Describe how the elements form from the following equations:

8. $^{20}Ne + {}^{4}He \longrightarrow {}^{24}Mg + \gamma$

9. $^{12}C + {}^{12}C \longrightarrow {}^{24}Mg + \gamma$

10. $^{57}Fe + n \longrightarrow {}^{58}Fe + \gamma$