Senior High School

Department of Education
National Capital Region
SCHOOLS DIVISION OFFICE
MARIKINA CITY

Physical Science

First Quarter - Module 1
Formation of Heavy Elements

Vince Marko A. Saño
Christine Ann G. Faraon

City of Good Character
DISCIPLINE • GOOD TASTE • EXCELLENCE

What I Need to Know

You may have an idea about the Big Bang Theory from your science course or you may have read about it on Cosmology. It is the cosmic explosion that is hypothesized to have marked the origin and development of the universe. It also represents the beginning of the chain of events that led to the development of humanity.

This lesson focuses on the final step of stellar nucleosynthesis, through the explosion of stars that have exhausted all their energy. This is an important concept because it demonstrates how energy-consuming reactions resulting in heavier elements require the energy of a supernova. This is the first lesson in this unit, and at this point, you are expected to be familiar with the periodic table of elements.

In this fraction of module, you are expected to attain the following skills to:

1. **give evidence for and describe the formation of heavier elements during star formation and evolution (S11/12PS-IIIa-2);** and
2. **explain how the concept of atomic number led to the synthesis of new elements in the laboratory (S11/12PS-IIIb-11).**

Moreover, you will learn concepts and do practice activities that will help you to do the following which are linked to the main lesson:

1. describe the formation of heavier elements during the stellar nucleosynthesis or fusion;
2. explain the supernova nucleosynthesis or fusion;
3. explain the processes that occur on the formation of heavier elements during the stellar formation and nuclear fusion; and
4. appreciate the importance of the processes that led to the formation of other elements.

What I Know

Read the question carefully and encircle the letter of the correct answer.

1. On the formation of elements in the beginning of time, which phenomenon created hydrogen?
   A. Big Bang
   B. Man-made
   C. Supernova
   D. Stellar Nucleosynthesis

2. What is the indicator of the identity of an element?
   A. Number of neutrons
   B. Number of electrons
   C. Number of protons
   D. Number of quarks

3. What phenomenon characterizes the explosion of a star?
   A. Big Bang
   B. Supernova
   C. Black Hole
   D. Fission

4. What is the nuclear reaction in which a nucleus and one or more neutrons collide to form a heavier nucleus?
   A. Neutron capture
   B. Neutron collision
   C. Nuclear fusion
   D. Nuclear fission

5. What happens in the protons and neutrons during a Beta-Minus Decay?
   A. Neutron appears while a proton is lost.
   B. Neutron is lost while a proton appears.
   C. Neutron appears while an electron is lost.
   D. Neutron is lost while an electron appears.

6. What were the original two elements in our universe?
   A. Oxygen and carbon
   B. Hydrogen and oxygen
   C. Helium and nitrogen
   D. Hydrogen and helium

7. How does two or more nuclei form a single, heavier nuclei?
   A. Nuclear physics
   B. Nuclear fusion
   C. Nuclear fission
   D. Nuclear combination

8. Why does a nuclear fusion process need a significantly high temperature to occur?
   A. At high temperatures, nuclei recombine with other nuclei.
   B. At high temperatures, nuclear force becomes significant.
   C. At high temperature, nuclei melt to fuse with other nuclei.
   D. At high temperatures, nuclei move faster and electrical force repelling them is overwhelmed thus making them collide and fuse.

9. What specific nuclear fusion process occurs in the core of the sun?
   A. Proton-Proton Chain
   B. Carbon Cycle
   C. Triple-Alpha Process
   D. Calvin Cycle

10. What does a low to average mass star turn into over the course of time?
    A. White dwarf
    B. Neutron star
    C. Black hole
    D. Supernova

11. What state of equilibrium refers to releasing of energy through the nuclear fusion process which prevents the star's gravitational collapse?
    A. Osmotic Equilibrium
    B. Radiative Equilibrium
    C. Hydrostatic Equilibrium
    D. Thermodynamic Equilibrium

12. What is the collective term for the nuclear reactions taking place in stars to build the nuclei of the heavier elements?
    A. Nuclear Fusion
    B. Stellar Nucleosynthesis
    C. Big Bang Nucleosynthesis
    D. Supernova Nucleosynthesis

13. What is "R" in the R-Process?
    A. Race
    B. Rear
    C. Rare
    D. Rapid

14. What happens in an R-Process during the formation of elements heavier than Iron?
    A. Neutron capture is faster than beta-decay.
    B. Neutron capture is slower than beta-decay.
    C. Neutron capture and beta-decay happens at the same time.
    D. None of the above.

15. A Triple-Alpha Process begins with the fusion of two helium nuclei which produces an unstable beryllium-8. How is it possible for a beryllium-8 to fuse with a helium nuclei to form carbon-12?
    A. Collision of beryllium-8 and helium-3.
    B. Collision of beryllium-8 and a positron to become stable.
    C. Helium nuclei faster than a beryllium-8 so a collision is possible.
    D. A faster rate of increase in the number of beryllium-8 nuclei to fuse with helium before it decays.

Lesson 1 Formation of Heavy Elements

What's In

Formation of Light Elements

The Big Bang Theory is the cosmic explosion that is hypothesized to have marked the origin and development of the universe. The theory explains how the elements were initially formed. The formation of different elements involved many nuclear reactions, including fusion, fission, and radioactive decay.

Activity 1.1

Arrange the jumbled words to define the stages of Big Bang Theory. Write your answers on a separate sheet of paper.

1. GASYNLTIIRU - ___________________ is a point in space and/or a moment in time where the universe was in a state of dense and hot matter.
2. LIOAINNFT - __________________ is a theory of exponential expansion of space in the early universe that occurred as fast as 10^{-36} seconds.
3. NHUYSTSEIENOLSC - ___________________ is the process that creates new atomic nuclei from pre-existing nucleons, primarily protons and neutrons.
4. IOTNNBEACRMIO - ___________________ refers to the epoch at which charged electrons and protons first became bound to form electrically neutral hydrogen atoms.

Figure 1.1 illustrates how the universe started from a singularity – with no space around and just nothingness. After an explosion, the universe started to expand at a speed of light.

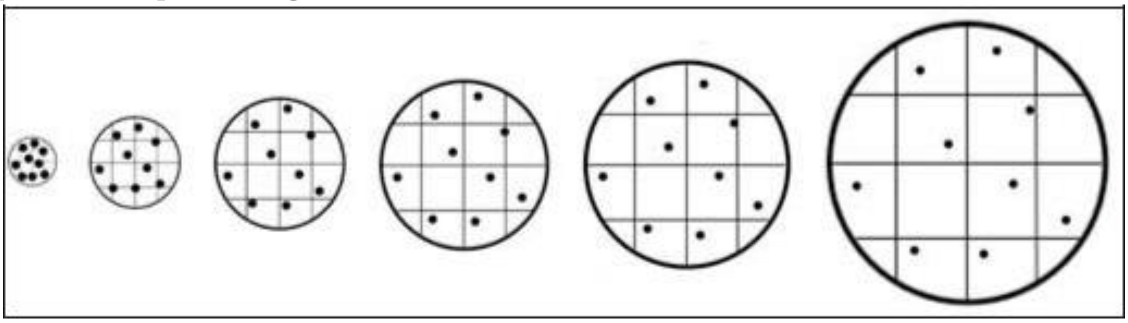


Figure 1.1. The Big Bang Theory

Source: *"The Big Bang Theory." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Right after the Big Bang, the protons, neutrons, and electrons were flying around without control. When it started to cool down, the quarks started making primitive elements.

A Brief Background about Stellar Evolution

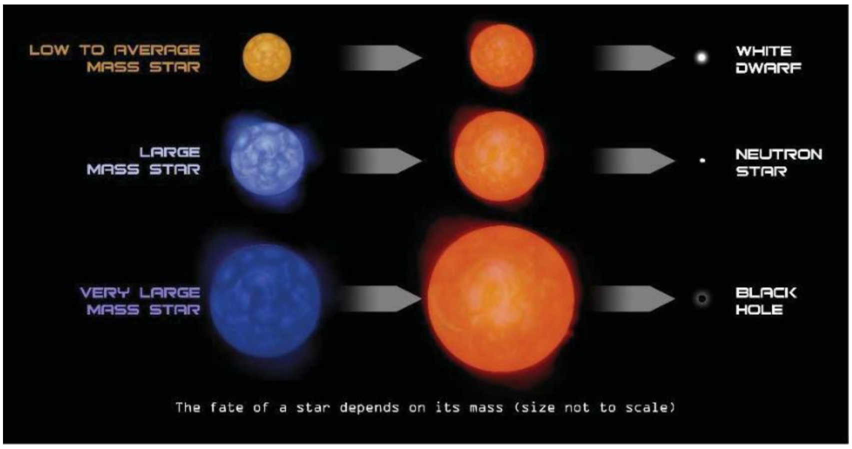


Figure 1.2. Fate of a star

Source: *"Fate of a Star." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Figure 1.2 shows that what eventually happens to stars depend on their masses. Thus:

- A low-mass star ends up as a white dwarf.
- A high-mass star ends up either as a neutron star (after a supernova explosion) or a black hole.
- A star is formed when a cloud of gas and dust collapse to the point where the material in the center of the clump is so dense and hot that the nuclear fusion of hydrogen nuclei and helium occurs.
- The outflow of energy released by them provides the pressure necessary to halt the collapse. The pressure and gravity are in hydrostatic equilibrium.

What's New

Activity 1.2

Use the cryptogram below, to **unlock sets of numbers into words**. Decode the following set of numbers using the randomly generated cryptogram and answer the question that follows. Each number in a cryptogram stands for a letter; e.g., 21=A, 19=B. The semi-colon is used as a space between the words. The concepts to decode are related to the formation of elements. Write your answers on a separate sheet of paper.

A	B	C	D	E	F	G H	I 22	13	J	K	L	M	N
21	19	15	18	4	5	24			7	10	17	23	20

O	P	Q	R	S	T	U	V	W	X	Y	Z
8	1	26	2	25	11	3	14	12	9	16	6

1. 19, 24, 22; 19, 21, 20, 22; 20, 3, 15, 17, 4, 8, 25, 16, 20, 11, 13, 4, 25, 24, 25

2. 25, 11, 4, 17, 17, 21, 2; 5, 8, 2, 23, 21, 11, 24, 8, 20; 21, 20, 18; 4, 14, 8, 17, 3, 11, 24, 8, 20

3. 25, 11, 4, 17, 17, 21, 2; 4, 9, 1, 17, 8, 25, 24, 8, 20; 8, 2; 25, 3, 1, 4, 2, 20, 8, 14, 21

After decoding the cryptogram, what specific group of elements were formed during the stages? Differentiate each stage.

____
____
____

What Is It

Stellar Nucleosynthesis (Stellar Formation and Evolution)

- It is the collective term for the **nuclear reactions taking place in stars to build the nuclei of the heavier elements.**

Nuclear Fusion

- It is a nuclear reaction process bonding to or more nuclei, into a single, heavier one.
- It is possible in stars because their interior is so hot. Under normal conditions, hydrogen nuclei repel because they have the same charge. But extremely high temperatures can cause hydrogen nuclei to collide.

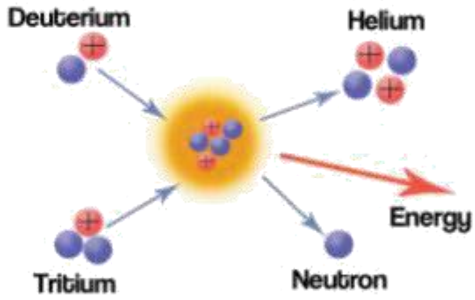


Figure 1.3. Nuclear Fusion of a Deuterium and Tritium
Source: *"Nuclear Fusion of a Deuterium and Tritium." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Group the following stellar nucleosynthesis processes accoridng to which nuclear fusion process they belong to:

Choices:

Carbon-burning	Proton-proton chain	Carbon Cycle
Triple-alpha process	Neon-Burning	Lithium-burning
Oxygen-burning	Silicon Burning	

Hydrogen burning	Helium burning	Burning of heavier elements
1. ____________ 2. ____________	1. ____________ 2. ____________	1. ____________ 2. ____________ 3. ____________ 4. ____________

The following are the nuclear fusion processes:

Hydrogen burning: Proton-proton chain

- The first stage of nucleosynthesis is the proton-proton chain where hydrogen is converted to helium. This is the dominant **process in stars that have a similar mass to the sun** or core temperatures less than 15 million Kelvin.

The proton-proton chain consists of three steps:

1. Collision of two Hydrogen-1 nuclei to form Hydrogen-2

$$_1\mathbf{H} + {_1\mathbf{H}} \rightarrow {_2\mathbf{H}} + \mathbf{e}_+ + \mathbf{v}$$

2. Collison of Hydrogen-2 with Hydrogen-1 to form Helium-3

$$_1\mathbf{H} + {_2\mathbf{H}} \rightarrow {_3\mathbf{He}} + \mathbf{y}$$

3. Collision of two Helium-3 to form one Helium-4 and two Hydrogen-

$$_3\mathbf{He} + {_3\mathbf{He}} \rightarrow {_4\mathbf{He}} + {_1\mathbf{H}} + {_1\mathbf{H}}$$

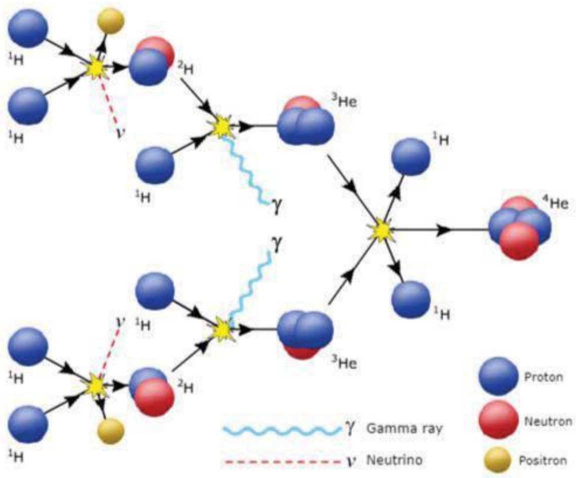


Figure 1.4. Steps of a proton-proton chain
Source: *Steps in a proton-proton chain. Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Hydrogen burning: Carbon- Nitrogen- Oxygen (CNO) Cycle

- The second stage involves the carbon cycle. The cycle of reactions results to the formation of a helium nucleus. This is the dominant **process in stars more massive (1.3x) than our sun** or with core temperatures greater than 15 million Kelvin.

The steps of carbon cycle are:

1. Carbon-12 fuses with a proton to form Nitrogen-13. Afterwards, one of the protons decays, emitting a positron and a neutrino to form Carbon-13.
2. Two more proton capture processes occur, producing Nitrogen-14 and Oxygen-15.
3. Another neutron decays leaving Nitrogen-15.
4. Another proton capture produces Oxygen-15, which emits an energetic alpha particle to return to Carbon-12 to repeat the cycle.

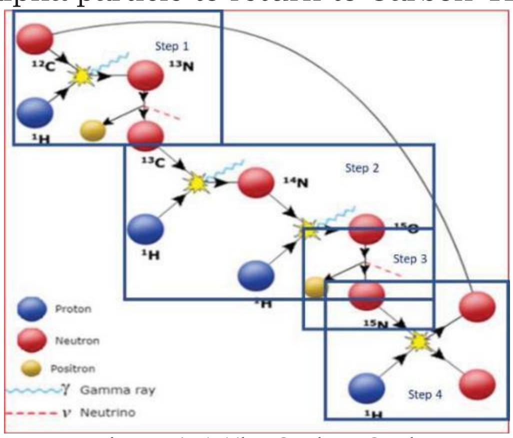


Figure 1.5. The Carbon Cycle
Source: *"The Carbon Cycle." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Figure 1.5 shows the repetitive steps of the Carbon Cycle.

Now that you have learned how the Carbon Cycle works, check your understanding by completing the table below:

	p^+	n^o	**Next Step (Add or Convert)**
^{12}C	6	6	Add a proton
^{13}N	______________	6	____________
^{13}C	6	7	____________
^{14}N	______________	7	Convert a proton
^{15}O	8	7	____________
^{12}C	6	6	____________

The second stage of nuclear fusion begins after most of the hydrogen is burned.

Helium burning: Triple-alpha process

- In the triple-alpha process, three helium-4 nuclei or alpha particles, fuse to form a carbon nucleus:
- The steps of a triple-alpha process are:
    1. Two helium nuclei(alpha) will fuse to produce an unstable Beryllium-8. Being unstable, it decays back instantly to a smaller nucleus.
    2. Helium nuclei are fusing together faster that their product (Berylium-8) which then decays back into two helium nuclei.
    3. Once Beryllium-8 is produced a little bit faster than it decays, the number of Beryllium-8 nuclei in the stellar core increases to a large number which can then fuse with another helium nucleus to form a stable Carbon-12.

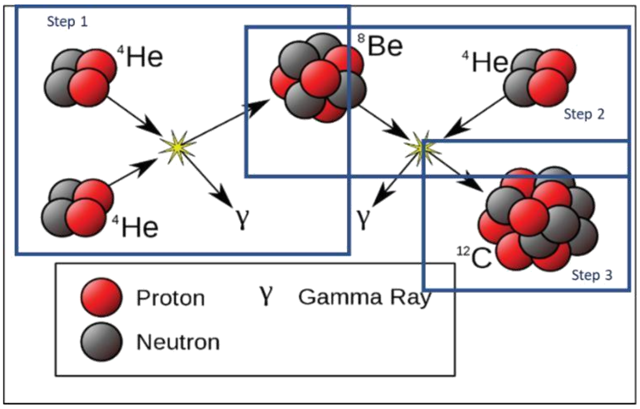


Figure 1.6. The Triple Alpha Process

Source: *"The Triple Alpha Process." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

Figure 1.6 illustrates the burning of helium through the triple-alpha process.

- As soon as carbon is present, the alpha process begins where the formation of neon, oxygen, and silicon takes place.

Burning of Heavier Elements

- If the star is massive (> 8x solar masses), another set of nuclear fusion reactions begins.
- Stellar nucleosynthesis is responsible for the production of heavy elements up to iron.
- These include the burning of carbon, neon, oxygen, and silicon, which lead to the formation of heavier elements until if finally produces iron.
- There are several nuclear synthetic routes and various nuclei formed as by-products shown below:

$$^{13}\mathbf{N},\ ^{13}\mathbf{C},\ ^{14}\mathbf{N},\ ^{15}\mathbf{O},\ ^{15}\mathbf{N},\ ^{12}\mathbf{C},\ ^{16}\mathbf{O},\ ^{17}\mathbf{F},\ ^{8}\mathbf{Be}$$

- Eventually, the temperature in the stellar interior increases and more nuclear synthetic pathways become available producing the elements below:

$$^{20}\mathbf{Ne},\ ^{23}\mathbf{Na},\ ^{23}\mathbf{Mg},\ ^{24}\mathbf{Mg},\ ^{28}\mathbf{Si},\ ^{31}\mathbf{P},^{31}\mathbf{S},\ ^{32}\mathbf{S},$$

and all the way up to $^{56}\mathbf{Fe}$

- Stars evolve so that they have **"onion-like" shells** of thermonuclear combustion with differing nuclear chemistry.
- After the star consumes its "fuel" for certain stage, it consumes its next fuel to continue its burning process and to sustain its life.

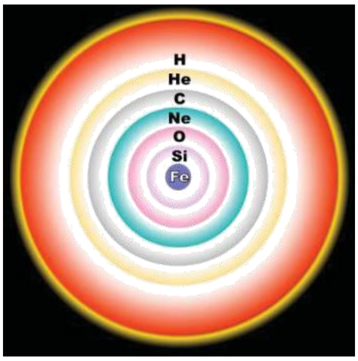


Figure 1.7. "Onion-like" shells of thermonuclear combustion

Source: *"Onion-like" shells of thermonuclear combustion." Digital Image. Frontlearners. Accessed August 8, 2020. http://www.frontlearners.com*

- The formation of an iron core signals the end of massive star's life.
- Iron cannot burn or release energy since it is the most tightly bound of all nuclei. As a result, attempting to fuse additional protons to it, weakens the bonds and absorbs energy rather than releasing it. Nuclear fusion stops with iron, and a star with an iron core is out of fuel.

With the pressure surging, it lifts the outer layers away from the star through a titanic explosion – a supernova.

Supernova Explosion and Further Nucleosynthesis

- A supernova is the explosion of a star. It is the largest explosion that takes place in space. It happens when there is a change in the core, or center of a star.
- This synthesis of new **elements heavier than Iron are achieved through neutron capture- either through the s-process or r-process.**

Neutron Capture

- ➢ Neutron capture is a nuclear reaction by which an atomic nucleus and neutrons collide to form a heavier nucleus.
- ➢ **By transforming a neutron captured by a nucleus to a proton, a new element is determined.**

Beta-Minus Decay: Neutron to Proton Transformation

- ➢ The neutron to proton process undergoes a beta-minus decay, with β- being that a neutron is lost, and a proton appears (on the other hand, β+ means that a neutron appears while a proton is lost).
- ➢ **The number of protons determines the identity of an element**. Thus, an atomic nucleus with electrons that are captured must "transform" these neutrons into protons to become new elements.

The neutron capture and beta-minus decay processes are needed in the synthesis of heavy elements. Both the s-process and the r-process make use of neutron capture and beta decay but differ in rate and sites where these occur.

S-Process

- ➢ S-Process is termed as **"slow neutron capture"** to synthesize heavier elements. S-process does not really occur in supernovae events, but in evolving low-to-medium-sized stars. However, it is worth noting that the "seed" for the S-Process is Iron.
- ➢ In the slow neutron capture, neutrons are added at a rate such that whenever an unstable nucleus is formed, it decays beta decays) before another neutron can be added.
- ➢ Beta-minus decay follows afterwards to transform neutrons into protons.

R-Process

- The R-Process works by **“rapid neutron capture”** to synthesize heavier elements.
- This process mostly occurs in supernovae events due to the rapid process that the time scale would be too short.
- In rapid neutron capture, neutrons are added rapidly that the unstable nuclei formed cannot decay before additional neutrons are added until a nucleus is eventually produced that will not accept a further neutron. This nucleus, however, will eventually be subject to beta decay, thus permitting further neutron capture.

Synthesis of Heavy Elements in the Laboratory

The invention of the device called **cyclotron** paved the way for transmuting one element into another artificially. The high-energy particles that are produced from the cyclotron upon hitting heavy target nuclei produce heavier nuclei.

- The bombarding of **Molybdenum** with deuteron formed **Technetium** which is the first artificially made element.

$$^{96}_{42}\mathbf{Mo} + {}^{2}_{1}\mathbf{H} \longrightarrow {}^{97}_{43}\mathbf{Tc} + {}^{1}_{0}\mathbf{n}$$

- Transuranic elements are synthetic elements with atomic numbers higher than that of Uranium.

  ✓ Neptunium (Z = 93) – synthesized by Edwin MacMillan in 1940

$$^{238}_{92}\mathbf{U} + {}^{1}_{0}\mathbf{n} \longrightarrow {}^{239}_{93}\mathbf{Np} + {}^{0}_{-1}\mathbf{ß}$$

  ✓ Plutonium (Z = 94) - synthesized by Edwin MacMillan and Arthur Wohl in1941

$$^{238}_{92}\mathbf{U} + {}^{2}_{1}\mathbf{H} \longrightarrow {}^{238}_{93}\mathbf{Np} + {}^{21}_{0}\mathbf{n}$$

$$^{238}_{93}\mathbf{Np} \longrightarrow {}^{238}_{94}\mathbf{Np} + {}^{0}_{-1}\mathbf{ß}$$

- Superheavy elements are elements with atomic numbers beyond 103. These are produced by bombarding heavy nuclear targets with accelerated heavy projectiles.

  ✓ Bohrium (Z = 107)

$$^{209}_{83}\mathbf{Bi} + {}^{54}_{24}\mathbf{Cr} \longrightarrow {}^{261}_{107}\mathbf{Bh} + {}^{21}_{0}\mathbf{n}$$

What's More

Activity 1.3

Color the corresponding boxes according to their respective cosmic stages. Color the box **YELLOW** if it describes a formation of heavy elements during a stellar evolution, **RED** if formation of heavy elements occurred on a supernova, and **BLUE** if it is made in the laboratory.

Slow neutron capture process	Collapse of an Iron core	Rapid neutron capture process
Formation of elements heavier than Iron	Bombarding of Mo with a deuteron to form Technetium	Carbon Cycle
Conversion of Hydrogen to Helium (Proton-proton chain)	Fusing helium nuclei to form beryllium and then, carbon.	Transmuting one element into another using Cyclotron
Formation of elements heavier than Beryllium up to Iron	Process where neutron capture is faster than beta-decay	Supernova Explosions

What I Have Learned

Activity 1.4

Briefly discuss the following. Write your answers on a separate sheet of paper.

1. What are the elements produced in stellar evolution and supernova explosions?
2. Explain the process that occurs in massive stars of core temperatures greater than 15 million Kelvin.
3. Explain the difference between the s-process and r-process.
4. At this moment, you already know that the universe is expanding. Now, try to run a video of a universe moving backward on your mind, what do you see?

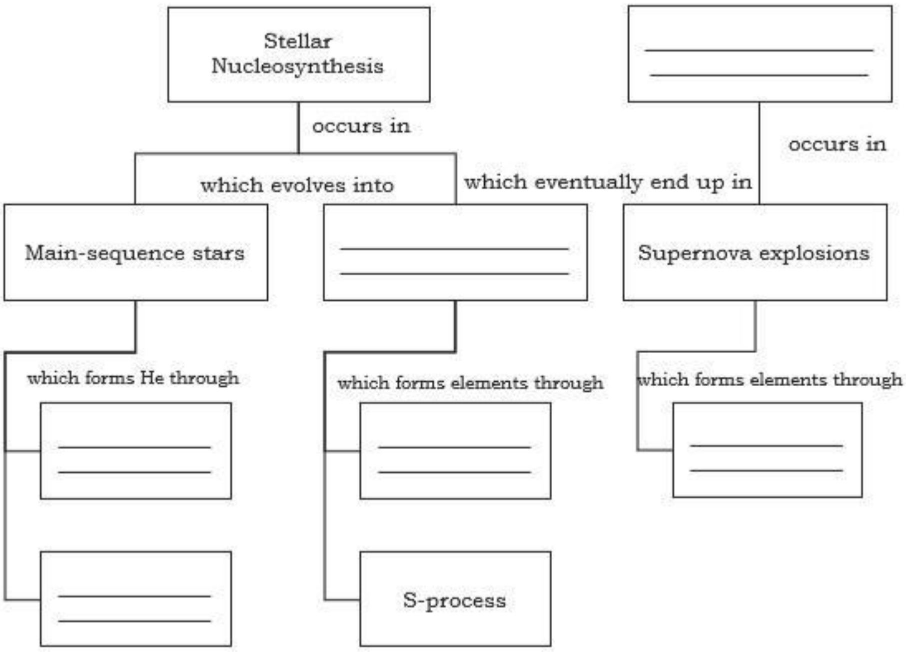
What I Can Do

Activity 1.5

Complete the concept map below by filling up the boxes with the appropriate concepts using the linking words/phrases as guide on how these concepts are related to each other.

Concepts:

R- Process Proton-proton Chain	Triple Alpha Process Red giant stars	Carbon Cycle Supernova Nucleosynthesis



Posttest

Read the question carefully and encircle the letter of the correct answer.

1. What kind of star will the sun become over the course of time?
   A. Supernova
   B. White dwarf
   C. Neutron star
   D. Black hole

2. What is the first nuclear fusion process that occurs in stars?
   A. Hydrogen Burning
   B. Helium Burning
   C. Lithium Burning
   D. Oxygen Burning

3. How massive should a star be for it to conduct further set of nuclear reactions?
   A. >2 solar masses
   B. >4 solar masses
   C. >6 solar masses
   D. >8 solar masses

4. On the thermonuclear combustion, what is the next element to burn after consuming the carbon “fuel”?
   A. Hydrogen
   B. Helium
   C. Neon
   D. Oxygen

5. On the thermonuclear combustion, what is the next element to burn after consuming the silicon “fuel”?
   A. Carbon
   B. Helium
   C. Iron
   D. Oxygen

6. A specific nuclear fusion process occurs depending upon the mass of a star and its corresponding core temperature. At approximately what stellar core temperature does Carbon Cycle occur?
   A. 273 K
   B. < 15 million K
   C. > 15 million K
   D. > 100 million K

7. What is the end-product of a Triple-Alpha Process?
   A. Beryllium
   B. Carbon
   C. Helium
   D. Hydrogen

8. A helium atom is similar in structure to this particle which is produced in a decay process. Being such, a helium atom is sometimes called as this particle. What is this particle?
   A. Alpha Particle
   B. Gamma Ray
   C. Neutrino
   D. Positron

9. Which of the following is a stable nuclei?
   A. Helium-3
   B. Hydrogen-3
   C. Beryllium-8
   D. Carbon-12

10. Which of these is true about the Big Bang model?
   A. Cosmic expansion stopped at some point in time.
   B. The singularity is an established, well-defined part of the model.
   C. Part of its proof is the amounts of H and He we have in the universe today.
   D. Big Bang was a big explosion that threw matter into many different directions.

11. What element is formed at the end of a star's life?
   A. Hydrogen
   B. Iron
   C. Oxygen
   D. Silicon

12. Why does stellar nucleosynthesis stop at the element of iron?
   A. It does not have enough protons in their nuclei.
   B. It does not have enough electrons in their nuclei.
   C. It does not have enough positrons in their nuclei.
   D. It does not have enough neutrons in their nuclei.

13. What happens to a star when it builds up too much iron?
   A. It dies.
   B. It regenerates.
   C. It starts over burning hydrogen.
   D. It starts unmaking iron and goes backwards.

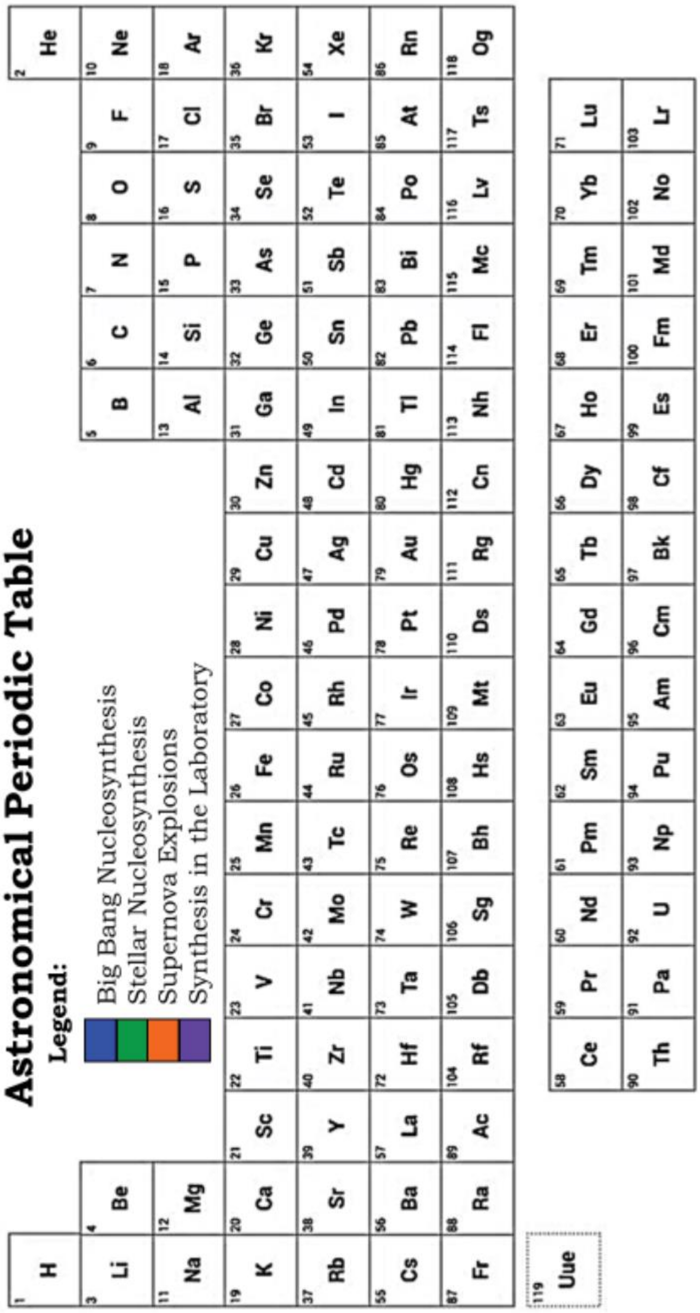
14. Which process in the formation of elements create the element gold?
   A. S-Process
   B. R-Process
   C. Nuclear Fusion
   D. Nuclear Fission

15. Which of the following processes is likely to generate the heaviest element?
   A. Carbon cycle
   B. R-process
   C. Triple-alpha process
   D. Big Bang nucleosynthesis

Additional Activities

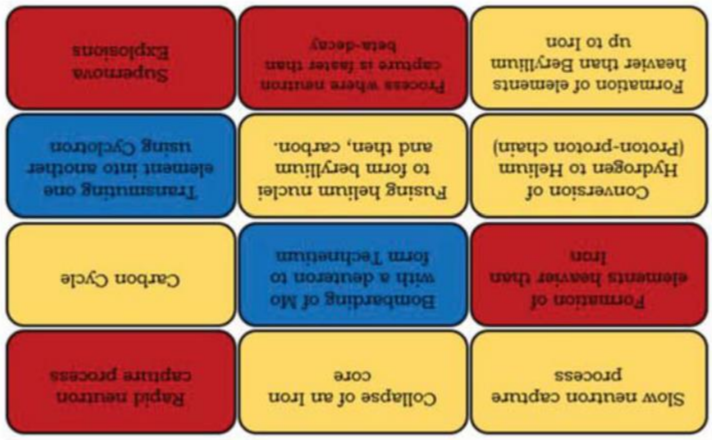
For additional knowledge, attached on the next page is a plain periodic table. Create an “Astronomical Periodic Table” by coloring the boxes of respective elements in accordance to their origins. For the color coding of the elements, please refer to the statements below:

- **BLUE** – if the elements originated in big bang nucleosynthesis.
- **GREEN** – if the elements are formed during the stellar nucleosynthesis.
- **ORANGE** – if the elements are formed through supernova explosions.
- **VIOLET** – if the elements are man-made or synthesized in the laboratory.



Answer Key

Activity 15.
What I Can Do



Activity 13.
What's More

Stellar explosion, or supernova – formed the elements heavier than .Iron .3
Stellar formation and evolution – formed the elements heavier than Beryllium to .Iron .2
Big bang nucleosynthesis – formed the light elements Hydrogen, Helium and .Lithium .1

Activity 12.
What's New

Recombination .4
Nucleosynthesis .3
Inflation .2
Singularity .1

Activity 11.
What's In

What I Have Learned

Activity 14.

x Elements are produced via stellar .evolution However, it is limited only to iron being the
limit of a star's .fuel Supernova explosions, the end of life of some stars, produce heavy
elements heavier than .iron

x The carbon cycle occurs in massive stars with core temperatures greater than 15 million
.Kelvin It is the fusion from carbon, nitrogen, and oxygen, then back to carbon,
repeating the .cycle

x The s-process or "slow neutron capture" is a process where beta-decay is faster than
neutron capture .itself The r-process or "rapid neutron capture" is a process where
neutron capture is faster than beta-.decay

References

(1) Department of Science and Technology (DOST). (2020, July 1). *Department of Science and Technology -STII Starbooks.* Retrieved from Science and Technology Academic and Reasearch-Based Openly Operated Kiosks: www.starbooks.ph

(2) Gopalan, R. (1999). Elements of nuclear chemistry. New Delhi: Vikas Publishing House PVT LTD.

Development Team of the Module

Writers: Vince Marko A. Saño (SEHS)
Christine Ann G. Faraon (BNHS)

Editors: Reynald Alfred A. Recede (MHS)
Russel S. Berador (SEHS)
Maria Carmina R. Martin (MHS)
Emil Constantine P. Buguina
Shynne Izza F. Clemente
Jessica S. Mateo (EPS – Science)

Language Editor: Kristine Joyce G. Montejo (SSSNHS)
Illustrator: Christine Ann G. Faraon (BNHS)

Layout Artists: Ed-Angelo P. Tan (SEHS)
Jemwel Dela Paz (CISSL)

Management Team:

Sheryll T. Gayola
Assistant Schools Division Superintendent
OIC, Office of the Schools Division Superintendent

Elisa O. Cerveza
Chief, Curriculum Implementation Division
OIC, Office of the Assistant Schools Division Superintendent

Jessica S. Mateo
Education Program Supervisor – Science

Ivy Coney A. Gamatero
Education Program Supervisor – Learning Resource Management Section

For inquiries or feedback, please write or call:

Schools Division Office - Marikina City

191 Shoe Ave., Sta. Elena, Marikina City, 1800, Philippines

Telefax: (02) 8682-2472 / 8682-3989

Email Address: sdo.marikina@deped.gov.ph