# The Energy Sources of Stars

Evolution of Stars. Activity 7

Classroom Activity

## Overview

**Age Range:**

14 – 17 years

**Prep. Time:**

Zero, if Activity 2 is done before

**Activity Time:**

20 min

**Cost per activity:**

Printing of student's worksheets

**Includes the use of:**

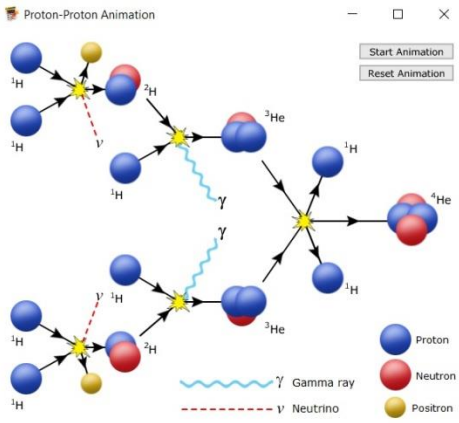
Computer for each group of students

## Outline

By using computer animations students will explore two main energy production cycles of stars to understand how hydrogen is converted into helium and energy is released.

## Pupils will Learn:

- That main sequence stars generate energy by converting hydrogen into helium in two different cycles: proton-proton cycle and CNO cycle.
- That energy is released as positrons, neutrino and gamma rays.




Screenshot of the animation used for this activity

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

# Lesson Plan:

| Description | Time | Notes |
|---|---|---|
| Before the lesson: if the Activity 2 was not done before | 15 min | Go to the download's page at http://astro.unl.edu/downloads to get the free *ClassAction* software. The software is courtesy of the Astronomy Education at the University of Nebraska-Lincoln Web Site (http://astro.unl.edu). Download and run the appropriate files for your system and follow the prompts to install the software on the teacher and students computers. |
| Pre-activity step | 2 min | Divide students in groups |
| Introduction to the subject | 3 min | Dialogue with the students. If necessary, main facts of atomic structure are reminded. |
| Activity 1 | 5 min | Students work with the *ClassAction* animation *Sun and Solar Energy/Proton-Proton Animation* and fill the worksheet. |
| Activity 2 | 5 min | Students work with the *ClassAction* animation *Sun and Solar Energy/CNO Cycle Animation* and fill the worksheet. |
| Assessment | 5 min | Students answer the questions. |

# Introduction to the subject:

The purpose of this lesson is to introduce students to the two main energy production cycles of stars: proton-proton cycle and CNO (carbon-nitrogen-oxygen) cycle. Main sequence stars are composed mostly of hydrogen and helium. At both cases hydrogen is converted into helium but in different ways. Energy is released as particles and radiation.

If necessary, main facts of atomic structure have to be reminded. Atomic nucleus consists of protons and neutrons. Nucleus is surrounded by the electrons. Positron is the antiparticle of the electron. Neutrino is a lightweight particle created in some interactions.

# Activity 1:

Students watch the *ClassAction* animation *Sun and Solar Energy/Proton-Proton Animation* and fill the worksheet.

Step 1. From two protons (hydrogen atom nuclei) one deuterium (heavy hydrogen) nucleus is created, positron and neutrino are released. Positron annihilates with the free electron in the environment (not shown), creating gamma ray.

Step 2. By adding one more proton, helium-3 nucleus is created and gamma ray released.

Step 3. Two helium-3 nuclei merge releasing two protons and forming one stable helium-4 nucleus.

Students answer the questions in their worksheet:

1. How many protons are involved in the cycle? 6.

2. How many protons are needed to create one helium-4 nucleus? 4

3. What kind of particles and radiation (taking into account the annihilation of the positron) are released? Neutrino and gamma rays.

So the net result is that **hydrogen is converted into helium**. Teacher explains that 4 protons are heavier than helium-4 nucleus. The difference of mass is converted into particles and radiation according to famous formula $E=mc^2$. Neutrino interacts weakly with the stellar matter and easily escapes from the star, taking away few percents of energy. So the **main energy is released as gamma rays**. From the other side we know that the stars radiate mostly the light and heat. Gamma rays are transformed into light and heat while going through the internal layers of the star. Proton-proton cycle is dominant in the stars with mass not exceeding 1,3 solar masses.

## Activity 2:

Students watch the *ClassAction* animation *Sun and Solar Energy/CNO Cycle Animation* and fill the worksheet.

Step 1. By adding one proton, carbon-12 becomes nitrogen-13, gamma ray is released.

Step 2. Nitrogen-13 decays radioactively into carbon-13, releasing positron and neutrino. As previously, positron annihilates with the free electron in the environment, creating gamma ray. Neutrino escapes from the star, taking away few percents of energy.

Step 3. By adding one proton, carbon-13 becomes nitrogen-14, gamma ray is released.

Step 4. By adding one more proton, nitrogen-14 becomes oxygen-15, gamma ray is released.

Step 5. Oxygen-15 decays radioactively into nitrogen-15, releasing positron and neutrino.

Step 6. At the last step one more proton is added, nitrogen-15 splits into carbon-12 and helium-4 (not labelled in the animation). Helium-4 is the final product of the CNO cycle. Carbon-12 can be used to start another cycle.

Students fill the worksheet table, first line is already filled. Other expected answers are marked in red.

Table. CNO cycle steps

| Step | Input | Product | Released |
|---|---|---|---|
| 1. | proton, carbon-12 | nitrogen-13 | gamma ray |
| 2. | nitrogen-13 | carbon-13 | positron, neutrino |
| 3. | proton, carbon-13 | nitrogen-14 | gamma ray |
| 4. | proton, nitrogen-14 | oxygen-15 | gamma ray |
| 5. | oxygen-15 | nitrogen-15 | positron, neutrino |
| 6. | proton, nitrogen-15 | carbon-12 | helium-4 |

Teacher explains that this cycle can happen only if carbon, nitrogen and oxygen atoms exist in the star. The quantity of carbon, nitrogen and oxygen atoms does not changes, just each set of 4 protons is converted into one helium-4 nucleus. CNO cycle is dominant in the stars with mass exceeding 1,3 solar masses. But the result is the same as in the case of the proton-proton cycle, **hydrogen is converted into helium** and the **main energy is released as gamma rays**.

## Assessment:

Questions for students:

1. What are the similarities and differences of both cycles? Expected answer. In both cycles hydrogen is converted into helium, neutrino and gamma rays are released. Proton-proton cycle needs only protons, in CNO cycle carbon, nitrogen and oxygen atoms are involved. Proton-proton cycle is dominant in the stars with mass not exceeding 1,3 solar masses, CNO cycle is dominant in stars with larger masses.

2. Main energy in the central part of stars is released as gamma rays. Why the stars radiate mostly the light and heat? Gamma rays are transformed into light and heat while going through the internal layers of the star.

3. Which cycle is dominant in our Sun? Proton-proton cycle.

4. Which element in stars become less abundant and which – more plentiful? Can this continue forever? There is less hydrogen and more helium, this cannot continue forever, eventually this energy source will be exhausted. (What happens next, we will discuss in the *Evolution of Stars*. *Activity 8*).

## Further Activities:

You may continue with the *Evolution of Stars*. *Activity 8*.

## Background Material/Knowledge:

Proton-Proton Cycle. https://en.wikipedia.org/wiki/Proton%E2%80%93proton_chain_reaction

CNO Cycle. https://en.wikipedia.org/wiki/CNO_cycle