General information

The first ChETEC-INFRA Masterclass "A Journey through the Elements" deals with the basics of nuclear astrophysics. For this purpose, basic principles of nuclear physics are taken up and treated in an astrophysical context in order to reconstruct the formation of the elements. An essential part of the masterclass is to convey the basic ideas and research approaches of the scientific field of nuclear astrophysics by analyzing together with the participants data of a current experiment relevant to the topic.
Below is a description of the Masterclass procedure and all the necessary information is enclosed so that they can give a Masterclass in nuclear astrophysics themselves.

General

- The goal of this project is to design a **reproducible teaching concept** for nuclear astrophysics. It follows that
    1. all materials used can be easily created. No software installations are necessary and the Masterclass does not include complex experimental setups.
    2. the materials are translated into different languages and used internationally. Thus, there is also no targeted curriculum orientation.
    3. All materials have been published under the Creative Commons license CC-BY-SA 4.0: [Creative Commons Attribution-ShareAlike 4.0 International (CC-BY-SA 4.0)]

- **The target group of** the Masterclass are high school students aged 15 and older as well as first-year students in the field of physics.
    - No prior knowledge of astrophysics and astronomy is necessary to understand the Masterclass.
    - Basic knowledge of nuclear physics (basic structure of atomic nuclei and nuclear transformations) is also not necessary, but helpful.
    - Due to group and partner work, the group size for a Masterclass run should ideally be between 12 and 24 participants.
- The total duration of the Masterclass is 6 hours or 8 lessons of 45 minutes each.
  The time specifications (see schedule) are to be understood as rough guidelines.

Learning targets

The conceptual learning targets of the Masterclass are listed below. These are referenced in the schedule by their numbers and assigned to the work phases (LT).

The participants
1. Know the physical characteristics that define a chemical element and a nuclide.
2. Understand the basic structure of atomic nuclei and the concept of stability of atomic nuclei.
3. Apply conservation laws to establish nuclear reaction equations.
4. Gain insight into the different types of stars and their characteristics.
5. Understand the connection between the evolution of stars and the nuclear-physical processes that drive them.
6. Understand how chemical elements can be created by nuclear fusion processes in stars.
7. Gain insight into the formation of higher elements by neutron capture processes.
8. Gain insight into the stochastic nature of thermonuclear processes in stars.
9. Investigate a nuclear reaction using gamma spectroscopy.
10. Gain insight into nuclear physics investigation methods.
11. Design an understanding of the basic ideas of nuclear astrophysics.

Materials & media needed

To give a masterclass, the following is needed:

1. A projector to display the full **PowerPoint presentation** (ideally interactive whiteboard).
2. A **notebook** or PC with Internet access for every second participant.
3. A **calculator** for each participant
4. The room structure and space to work in groups of four and partner work.
5. The Nuclide board game requires 1 die for each group of four and a game piece for each participant.

6. Printed the following materials (see http://mc.chetec-infra.eu/de/materials/materials_print.zip):
   - The group puzzle worksheets ***GroupPuzzle_Full.pdf*** in A4, one page for each participant.
   - The ***StarCards.pdf*** completely printed, colored and cut to size. (In the end, each star card should be about A6 size).
   - The data analysis worksheets ***WS_Data.pdf*** in A4, for each participant.
   - The document ***Nuclide_board.pdf*** printed in A3 for each group of four. This is a game board, so it may make sense to print it on thicker paper or laminate it as needed.
   - The document ***rules.pdf*** for each group of four printed in A4

7. Furthermore the following websites are used, which are also linked at http://mc.chetec-infra.eu:
   - The **interactive nuclide map**.
     - 2D representation (conversion types): https://tinyurl.com/2dNuclideChart
     - 3D representation (binding energy/nucleon): https://tinyurl.com/3dNuclideChart
   - The data analysis tool http://mc.chetec-infra.eu/histo/histogram.html
   - Multiple shared boards via the **Miro.com** tool
     1. Brainstorm board for entry and conclusion
     2. Online Hertzsprung-Russell diagram
     3. Data sheet to enter the measurement results and calculations of the data analysis

     Note: It should be noted here that the facilitator ensures that all boards are empty before the masterclass begins and returns the boards to their original state after the masterclass.

Schedule

	Phase	Content	Method	Materials	LT	Time
Part I Introduction	Introduction & welcome	Introduction, give an overview of the process	Lecture	Presentation	-	5
	Activation: Brainstorming	Open brainstorming board, Have questions answered and then discuss	Group work, Plenum	Brainstorming board	-	15
	What is an element?	Evolution of the idea of the chemical element over the centuries, Insight into element abundances	Lecture	Presentation	11	10
	Insight into modern research	Rock cellar laboratory tour: research technology	Video	Presentation: Video	10	5
Part II Atomic nuclei and their peculiarities	Fundamentals of nuclear physics	Structure of atomic nuclei and labeling of nuclides	Lecture	Presentation Nuclide chart	1,2	10
	Basics of nuclear reactions	Tasks see AB: First expert groups for the 4 reactions, then share results in home groups.	Group puzzle	AB Group puzzle Nuclide chart	2, 3	45
	Binding energy and (in)stability	Valley of stability and connection with element frequencies	Lecture	Presentation Nuclide chart	2	5
Part III Evolution of stars	The Hertzsprung-Russell diagram	1-2 star cards per participant:in, read card and enter star in board	Group work, Plenum	HRD Board Star charts	4,5	25
	Story of a star	Evolution of our Sun from protostar to main sequence to white dwarf, Evolutionary stages and fusion processes	Lecture	Presentation	4,5,6	25
Part IV On to higher elements!	Neutron sources and their importance	Formation of the elements after iron	Lecture	Presentation	7	5
	The nuclide race	In groups of four, follow rules of the game, first replay s-process and then r-process.	Group work, Board game	Game board, rules, dice, game pieces	7,8	45
	Summary S and R processes	Repetition and comparison of the two processes	Lecture	Presentation	7,8	10
Part V Stars in the laboratory	Core process measurement	Astronuclear Nibble Video: Basics + Measurement Technique	Video	Presentation: Video	10	10
	Basics of gamma spectroscopy	Tasks see AB, discussion tasks together	Partner work Plenum	AB Data Analysis 1 Nuclide chart	9	60
	Summary gamma spectroscopy	Goal of measurement and transition to data analysis	Lecture	Presentation	9	10
	Data analysis: measurement & evaluation	Processing the tasks see AB, enter measurement results in DataSheet, discuss measurement uncertainties qualitatively.	Partner work Plenum	AB Data Analysis 2, Data Analysis Tool, Data Sheet Board Presentation	9,10	60
Conclusion	Repeat brainstorming	Review and correct answers, check learning effect	Group work, Plenum	Brainstorming board	11	5
	Outlook into nuclear astrophysics	Open questions of nuclear astrophysics, role of the science field and cosmological consideration.	Lecture	Presentation	11	10

360min