Radioactivity

THE AUTHOR

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Radioactivity

Aim of the course

The aim of this course is

- -to teach the composition of the nucleus and some of the fundamental notions: atomic number, mass number, isotope.
- -to teach the changes in the nuclear composition during the different radioactive decay modes: the alpha, beta and gamma decay.

Content of the course:

This course begins with defining some of the fundamentals of the composition of the nucleus, then the knowledge of the students should be tested using multiple-choice questions.
The second part is a simple explanation of the decay types.
Finally: the students will be ready to perform knowledge tests again using multiple-choice questions.
The feedback questions and problems help the students to draw the conclusions, discussing the topic given by the teacher.

Topic 1

Step1: Start to review or teach about The composition of the nuclei.

Methods to use
This content can be used in practising and training of the terms and notations used in nuclear physics as well as in the better understanding and in the memorisation of the different changes in the composition of the nuclei in the different decay processes.

For practising and training of the terms and notations used in nuclear physics teachers can use the following methods: discussions, collaborations and communications.

The composition of the nuclei

Nuclei consist of protons and neutrons. Protons are electrically charged particles, and neutrons are electrically neutral. Both particles have almost the same mass (the neutron is a tiny bit heavier). Nuclei are characterised by the number of protons in them (atomic number, denoted by Z) and the sum of the protons and neutrons (mass number, denoted by A).
Usually the mass number is written as left-side superscript to the chemical

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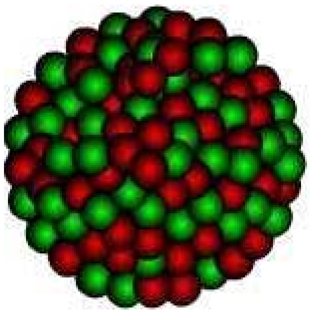
symbol of the atom, whereas the atomic number is written as left-side subscript.



(© Cs. Sükösd and B. Jarosievitz)

For example, $^{209}_{83}Bi$ denotes a bismuth (Bi) nucleus with 83 protons inside (left-side subscript) and containing 209 particles in total (left-side superscript). From these values the number of neutrons can also be easily determined: 209 – 83 = 126.

Naturally, the chemical symbol already determines the number of protons in the nucleus, therefore the atomic number can be omitted in certain cases.

Two types of this shorter notation are commonly used: 209Bi, or Bi-209.

If needed, the atomic number of the element can be determined from the periodic table using the chemical symbol of the element (see periodic table of elements with song). Wake up your students, with song!

Video used from: https://www.youtube.com/watch?t=57&v=zUDDiWtFtEM

Task for your students

Build a bismuth nucleus using the online interactive simulation program from the page: https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html

Topic 2

Step2
Use the following multiple-choice questions (quiz: <-click here).
Discuss the questions with your students, they should not only guess, they should justify their answer!

Methods to use

This quiz can be evaluated individually or in groups. If there is enough time, during the evaluation the following methods can be used: discussion, collaboration and communication.

Evaluation of multiple-choice questions

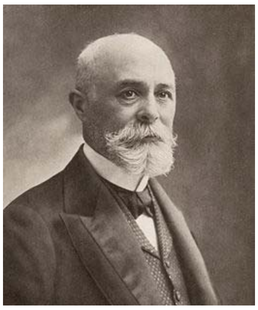
For correct answers of the Q1..Q5 multiple choice questions it is recommended to calculate the neutron numbers of the nuclei shown in the figures. Number of neutrons = mass number – atomic number (N = A – Z). If the neutron numbers are available, the exercises can be solved easily.

Topic 3

Step3: Start to review or teach about the:

Radioactive nuclei, radioactive radiation

Antoine Henri Becquerel
(15 December 1852 – 25 August 1908) was a Nobel laureate French physicist, who discovered the radioactivity



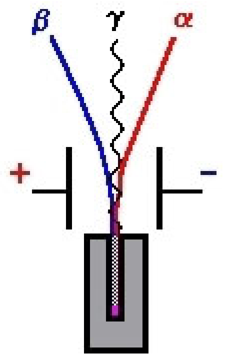
Source: https://en.wikipedia.org/wiki/Henri_Becquerel

Many atomic nuclei emit particles without any external effect and transform themselves into other nuclei.
These unstable nuclei are called radioactive, and the process is called radioactive decay. The stream of the emitted particles form the radioactive radiation.

Types of radioactive decay:

There are three types of decay of natural radioactive materials: alpha (α), beta (β) and gamma (γ) decay. These differ from each other by the emitted particles.

Alpha particles are positively charged, beta particles are negatively charged, whereas gamma photons are neutral. Therefore a mixed radiation can be separated into three components using electrical fields.



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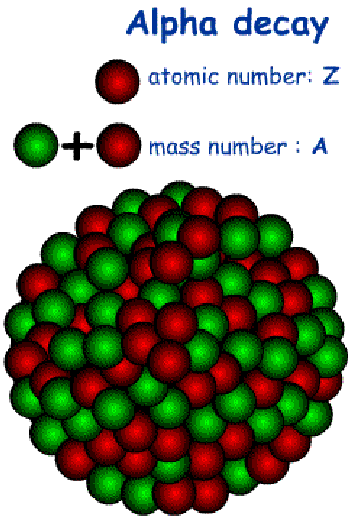
Topic 4

Step4: Start to review or teach about Alpha-decay



Animation of alpha decay (© Cs. Sükösd and B. Jarosievitz)

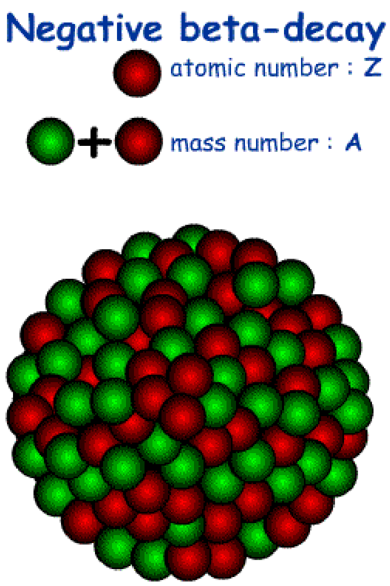
Discuss with your students what they have seen in the animation above!

During the alpha-decay a helium-ion (α-particle, 4He) is emitted.
Rutherford found in 1909 that the alpha-particles emitted in the alpha-decay process are highly energetic helium ions. Therefore the atomic number of the decaying nucleus decreases by two, and the mass number decreases by four in an alpha-decay.

The range of the alpha-radiation is very short. The particles reach only a few centimetres in the air, their range is about tenth of a millimeter in a solid material.

Topic 5

Step 5: Start to review or teach about Beta-decay



Animation of beta decay (© Cs. Sükösd and B. Jarosievitz)

Discuss with your students what they have seen in the animation above!

During the beta decay electrons are emitted, while the nucleus transforms itself to another nucleus.

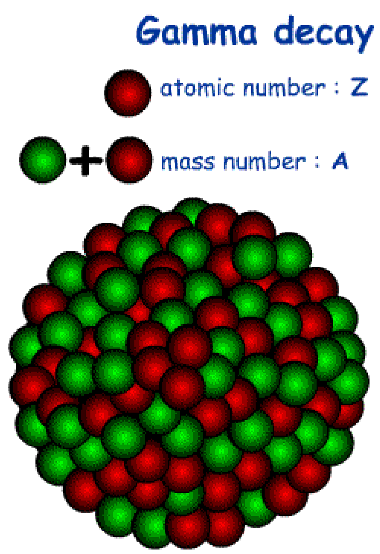
Becquerel discovered that the beta rays are negatively charged, and their charge to mass ratio is identical to that of the electrons. This way he identified the beta-particles as high velocity electrons.

The negative beta-decay of a nucleus can be imagined as if a neutron of the nucleus would transform to a proton, while an electron and an antineutrino would be emitted. Therefore the atomic number of the nucleus increases by one, and the mass-number remains constant during the beta-decay. Draw the attention of your students to the change in color in the above animation: a green-colored neutron (pointed by the red arrow for a short time) turns into a red-colored proton. It shows that during negative beta-decay a neutron is transformed into a proton inside the nucleus.

The range of the beta-rays is between the range of the alfa-particles and that of the gamma-rays. The beta-particles penetrate only a few millimetres into solid materials and metals, therefore it is relatively easy to shield them.

Topic 6

Step 6: Start to review or teach about Gamma-decay



Animation of gamma decay (© Cs. Sükösd and B. Jarosievitz)

Discuss with your students what they have seen in the animation above!

In the **gamma-decay** the nucleus emits electromagnetic rays (called γ -photons), therefore this process is similar to the light emission of atoms.

However, there are differences between the visible light emission and gamma-ray emission! First, the gamma photons are emitted by the nucleus, whereas the visible light is emitted by the electron shell of the atom. Second, the energy of the gamma-photons are much higher than that of the visible photons. Therefore, the wave-length of the gamma-rays is much shorter than that of the visible light.

Gamma rays are dangerous because their penetration range is large. Only a thick bulk of matter composed of heavy atoms (e.g. lead) can reduce their intensities.

Topic 7

Step 7: Task for your students

Ask your students to download in their android tablets the following free apps from Google Play store: http://www.vascak.cz/?p=2192&language=en#demo

Open the following simulation: Radiation: http://www.vascak.cz/data/android

/physicsatschool/template.php?f=jadro_zareni&l=en and start a conversation, discussion with your students, about the alfa, beta gamma particles penetration through different shields.
This discussion will be focused in the feed-back of the material discussed before.

Topic 8

Step 8: Task for your students to review the previous knowledge

Use the following multiple-choice questions and check your students knowledge (quiz: <-click here).
Discuss the questions with your students, they should not only guess, they should justify their answer!

Methods to use

This quiz can be evaluated individually or in groups. If there is enough time, during the evaluation the following methods can be used: discussion, collaboration and communication.

Evaluation of multiple-choice questions

For answering the Q1...Q4 multiple choice questions one should remember how the atomic and mass numbers of the decaying nucleus change in the different decay modes.

In the alpha-decay the atomic number decreases by two, and the mass number by four.
In the negative beta decay the mass number is constant, but the atomic number increases by one.
In the gamma-decay the mass number and the atomic number remain constant.

Topic 9

Glossary

Activity
The activity of a sample is defined as the number of decays in a unit of time. (The time-unit should be much shorter than the half-life).

The unit of the activity in the SI system is: becquerel
Denoted by: Bq
1 Bq = 1 decay/s.

The activity of a sample is proportional to the number of the nuclei N in the sample.The proportionality coefficient is called decay constant λ .

$$A = N \cdot \lambda$$

Since the number (N) of the radioactive nuclei in a sample follows the exponential decay law, the activity of the sample is also decreasing at the same rate.

Alpha-decay
In the alpha-decay a helium-ion (α-particle, 4He nucleus) is emitted, therefore the atomic number of the decaying nucleus decreases by two, and the mass number decreases by four.

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Decreasing the mass number of light elements is not an energetically favorable process, therefore, alpha-emitters can be found only among the heavy elements.

Beta-decay
Beta particles are electrons emitted from the nucleus; the term "beta particle" is a historical term used in the early description of radioactivity.

There are three types of beta-decay:

- Negative beta decay
- Positive beta decay
- Electron capture

Only the negative beta decay occurs in natural radioactive decay chains, therefore only this type will be discussed below.

Negativ beta-decay
During the negative beta decay a neutron of the nucleus is transformed into a proton, while an electron (e-) is emitted.

(During the decay also a small neutral elementary paricle – antineutrino - is emitted, but this particle can be neglected from a practical point of view, because this particle interacts very weakly with the matter).

The negative beta-decay is described by the following equation:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \tilde{\nu}$$

In the negative beta-decay the atomic number of the nucleus increases by one and the mass number remains constant.

Gamma-decay
In the gamma-decay the nucleus emits electromagnetic rays (called γ -photons), therefore this process is similar to the light emission of atoms.

However, there are differences between the visible light emission and gamma ray emission! First, the gamma photons are emitted by the nucleus, whereas the electron shell of the atom emits the visible light. Second, the energy of the gamma-photons is much higher than that of the visible photons. Therefore, the wavelength of the gamma rays is much shorter than that of the visible light.

Decay constant and Half-life
The decay constant is inversely proporitonal to the half life: the larger is the half life of a radioactive material the smaller is its decay constant. For more information see course: http://moodle.scientix.eu/course/view.php?id=177

Mass number
The nucleus is composed from protons and neutrons. Their common name is “nucleon”.
The number of protons (usually denoted by Z) is the atomic number of the element. (This corresponds to the place of the atom in the periodical table of elements).

A = Z + N

The total number of the protons and neutrons is called mass number, and it is denoted by A.

Usually the mass number is written as left-side superscript to the chemical symbol of the atom.

For example ${}^{238}_{92}U$ denotes a uranium (U) nucleus with 92 protons inside (left-side subscript), and containing 238 particles in total (left-side superscript).

Neutron
It means “neutral” in Latin. The neutron is an electrically neutral elementary particle. Usually it is denoted by n. Together with the proton the neutron can be found in every nucleus (exception: the light isotop of the hydrogen). The common name of the neutron and the proton is “nucleon”.

Mass: 1,674920* 10-27 kg = (1,00866497±0,0000004) u.

Proton
It means “first” in Greek. The proton is a stable elementary particle, the nucleus of the light hydrogen atom.

Mass: 1,672614* 10-27 kg = (1,007264433 ± 0,0000008) u,
Charge: 1,6021917* 10-19 C (positive elementary charge).

Isobar nuclei
Isobar nuclei have the same mass number, but their atomic numbers are different. Isobar atoms can be transformed into each other with different forms of beta-decays.

Isotope nuclei
Isotope nuclei have the same atomic number, but their mass numbers are different, since they have different numbers of neutrons.

The chemical and biological behaviour of the isotopes are completely the same. However, they are different particles and they have different nuclear physical properties.

This was discovered by George de Hevesy (01. 08. 1885. Budapest – 05. 07. 1966. – Freiburg – Chemical Nobel prize in 1944), and it has been used for the method of radioactive traceing.

Please note that the word "isotope" is used with different meanings. A "radioactive isotope" means one particular element, which is not stable, and decays, emits radioactive radiation. Whereas when we talk about "isotopes" (in plural) we understand several elements (not necessarily radioactive), where their mass numbers (A) are the same but their atomic numbers (Z) are different.

Topic 10

Forum

Radioactivity

Topic 11

Useful links

https://www.youtube.com/watch?t=57&v=zUDDiWtFtEM
http://www.walter-fendt.de/ph14e/decayseries.htm
http://www.walter-fendt.de/ph14e/lawdecay.htm
https://play.google.com/store/apps/details?id=com.radcalc&hl=hu
http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/radact.html
http://www.vascak.cz/data/android/physicsatschool
/template.php?s=jadro_zareni&l=en
https://phet.colorado.edu/en/simulation/alpha-decay
https://phet.colorado.edu/en/simulation/legacy/radioactive-dating-game

Topic 12

Evaluate this course

Scientix is financed under the European Union's Seventh Framework Programme for Research and Development

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