



Exploitation of Research results In School practice



Guide



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Elementary particles and fundamental forces

Guide

The package is recommended for students in upper secondary schools, age 15-18, who have followed previously physics and chemistry classes about the atomic constituents of matters and about forces in nature.

The package can be used as an advanced material for optional physics classes or in the curriculum introducing nuclear and particle physics applications for society.

It helps to achieve specific competences included in the physics Romanian core curriculum, especially:

- Formulate hypothesis and drawing conclusions from physics experiments;
- Solve theoretical and practical problems issued from applying physics in practice;
- Analyse causal relations in physics phenomena.
- Establish connections between physics theories and technological applications
- Identify instances to apply the theoretical knowledge gained studying the field

As far as the educational content is concerned, the package refers to the following points in the Romanian core curriculum:

The student:

- can solve exercises of kinematics from special relativity theory;
- understand the structure of the matter from the perspective of Rutherford experiment;
- can describe the structure of a particle accelerator and a particle detector;
- can identify practical applications of particle accelerators;
- is able to characterize the elementary particle (electron, proton, neutron, photon) based on their statistic and quantum properties (rest mass, spin, isotopic spin, baryonic charge);
- can classify the elementary particles according to the type of interactions it takes part to;
- is able to select and present updated information about elementary particles.

Fast paced the material can be covered in three class hours, if time allows in optional classes can be extended to a full chapter.

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Age of students	15-18
Stage of education	Upper secondary school
Subject	Physics
Overview of package content	
From ancient times we have observed the nature and tried to find explanations and fundamental causes for the phenomena we encounter. The Antique people thought that everything can be explained as a combination of four basic elements: earth, water, air and fire. Although not very precise in explanations, their intuition was good, today we use the classification: solid, liquid, gas and plasma for the explanation of the matter states. More than that, their idea of an ultimate form of matter that you can reach by continuous division, was confirmed and it is still used today by the researchers who study the particle physics. The current picture that we have today about the elementary structure of nature, refined after more than a century of modern researches, is the following: the matter is made up of two classes of particles, leptons and hadrons which interact with each other by means of four fundamental forces: strong force, electromagnetic force, weak force and gravitational force (except the leptons which don't "feel" the strong force, but only the other three). This set of basic elements, which form the so called Standard Model of elementary particles, and their compounds allows one to explain the wide range of phenomena we experience from the sub-microscopic scale to the astronomical one and the scale of the evolution of the Universe. The discovery of the Standard Model was a long and difficult process, understanding its implications and extensions continues even today, however this doesn't prevent us to try to introduce earlier the basic notions and techniques from the field. As science progress our body of knowledge grows and we need to reconsider what we view as fundamental, what feature is generic or a detail. In previous grades students already learn in different disciplines about electrons, protons and forces, why not to go deeper and speak about quarks and fundamental forces? The new concepts have a chance of being met again and they also can sparkle the imagination on how we think about our world, see for example the anti-matter concept. Secondly, some applications of the field in medicine or technology will become more important and an earlier exposure can help understand it. Thirdly, the proposed exercises of analysing real data can offer a glimpse on how research is performed and inspire future studies path. The package has three main parts: introduction on the Standard Model and examples of research facilities, exercises and a hands-on experiment and an exercise of analysing real data about particle collisions taken from recent experiments. The analysis exercise, „Measurement of the lifetime of D0 meson” is selected from the exercises developed by the International Physics	



Particle Outreach Group within International Masterclass program. Covering the full material takes at least four class hours with the last one dedicated to concluding the lessons, time for individual work is needed to cover the analysis part.

The information support material contains a presentation with slides which cover the full material, a variant of the presentation with side notes for teachers to support the preparation of classes and a short video presentation summarizing the information and underlining some key observations.

The practical part contains a worksheet for students which includes exercises, indications for performing the classroom experiment and minimal instructions for following the Masterclass exercise. Solutions for the exercises are provided in a separate document.

Many more informative resources are available on the internet and with the development of Open Data movement real data is available and ready to use in classroom scenarios. However, they are mostly fitted for the enthusiastic programmers.

Assumed educational aims

The student knows:

- the elementary constituents and fundamental forces from the Standard Model
- what antimatter is
- the concept of conservation laws (electric charge, energy, momentum)
- the application of particle technologies in medicine
- what a histogram is
- to indicate a research experimental infrastructure
- what signal and background is in a measurement

The student understands:

- the relation between macroscopic forces and fundamental forces
- how interaction mechanism acts at the particle level
- why producing new particles require large energies
- how particles properties are inferred from indirect experiments
- how plots are used to interpret the results
- the use of probabilistic arguments in physics
- the main steps of a particle experiment
- the roles of the layers of a particle detector
- how particles are seen in detectors
- how parameters are extracting from fitting the data
- the role of systematic errors in an experiment



The student can:

- apply conservation laws and predict composed particles
- make estimation about the sizes in the particle physics
- read and interpret a histogram (calculate averages, find maximum and minimum values etc.)
- draw a histogram from a basic collision type experiment
- determine the dimensions of a grid with indirect experiments
- connect to Masterclass application and visualize the detector's layers
- interpret the path of particles in detector
- select signal particles over background
- extract the lifetime from fit
- find additional resources on the internet

Package content

1. "Elementary particles ..." – presentation;
2. "Elementary particles ..." – presentation with notes for teachers;
3. "Elementary particles ..." – movie based on the presentation;
4. "LHC_movie" – animation of LHC accelerator; youtube:
<https://www.youtube.com/watch?v=YDqrNIApMwg>
5. "Standard Model and applications" – worksheet;
6. "Standard Model and applications" – solutions for the worksheet;
7. Methodological guide with lesson plans;

Supplementary materials

General particle physics links

- "Particle adventure" website (eng, it, fr) <http://particleadventure.org/>
- Mobile phone application, Android and iPhone: LHSee
- Video animations with LHC accelerator www.youtube.com/watch?v=pQhbhpU9Wrg
www.youtube.com/watch?v=08x49b9tTNQ
- Advanced data analysis for programming enthusiasts
<http://particle-physics-playground.github.io>
- Resources proposed by the Quarknet <https://quarknet.i2u2.org/>
- International Masterclasses website physicsmasterclasses.org
- Link to online quiz: <https://play.kahoot.it/#/?quizId=89b40b98-e277-498a-9270-82b88c1f83d1>

LHCb Masterclass links

- LHCb International Masterclass webpage lhcb-public.web.cern.ch/lhcb-public/en/LHCb-



[outreach/masterclasses/en](#)

- Masterclass exercises - video <http://www.youtube.com/watch?v=x2qJUbF2qUQ>
- Overview of LHC experiment: www.youtube.com/watch?v=rsmBMuTFdkA
- International Masterclass programme: www.physicsmasterclasses.org
- Link to online quiz: <http://play.kahoot.it/#/?quizId=b8fb8212-b6ce-4c28-83cb-92432f4c1881>



Lesson 1

Subject: Introduction to the Standard Model of particle physics

Lesson plan for “Elementary particles and fundamental forces”

Necessary materials and equipment:

- multimedia projector, computer, loudspeakers;
- video about LHC accelerator included in the package
- mobile phones for students;
- package materials (no. 1, 5)

Lesson aims:

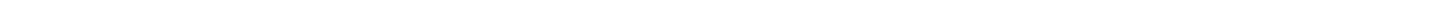
General and specific aims as specified in “Elementary particles and fundamental forces”

Methodological suggestions:

- expository methods: lecture, talk;
- demonstration methods: presentation, video;
- activation methods: brainstorming, online questionnaire;
- practical methods: worksheets

Lesson procedure:

1. Start of the lesson, organisational activities, checking the register.
2. Introduction of the topic, why do we study particle physics? The teacher invites students to comment on structure of matter as they know it from other courses and ask if that is the final level of the organization of matter.
3. The teacher reviews examples of forces the students are used with and ask them if it is possible that all forces have a common structure. This moment can be used to remind students about the topics learned in previous chapters. Use [“Elementary particles ...” – presentation 1](#) for examples about forces
4. The teacher argues about the hierarchical organization of the matter presenting the periodic table of the elements and the two fundamental forces known to students: gravitational force and electromagnetic force.
5. This moment of lesson introduces an activation didactic method the online questionnaire on Kahoot site. This method has the advantage that stimulates a short fast feedback competition between the students and allows them to use their mobile phones. Link to the game <https://play.kahoot.it/#/?quizId=89b40b98-e277-498a-9270-82b88c1f83d1>
6. The Standard Model presentation. Teacher introduces the SM table and the elementary particle classes.
7. Expository moment, the fundamental forces of the SM are introduced.
8. Students are asked to solve exercise 1 from the worksheet.
9. Homework: exercises 2, 3 from [“Standard Model and applications” – worksheet 5](#)





Lesson 2

Subject: Matter investigations with indirect experiments

Lesson plan for “Elementary particles and fundamental forces”

Necessary materials and equipment:

- multimedia projector, computer, loudspeakers;
- completed exercise 1 and 2 from worksheet;
- video animation [“LHC movies” – video 4](#);
- plastic/marble balls;
- package materials (no. 1, 4, 5)

Lesson aims:

Perform an experiment simulating collisions of particles,

Methodological suggestions:

- expository methods: lecture, talk;
- demonstration methods: presentation, video;
- activation methods: student present their results from measurements;
- practical methods: worksheets, experiment with balls

Lesson procedure:

1. Start of the lesson, organisational activities, checking the register.
2. Students watch the video about the LHC accelerator [“LHC movies” – video 4](#). The main steps of particle physics experiment are identified, the extraction of the beam, accelerating of the beam, the composition of a the beam, collision of the particles, detection the final states particles.
3. Teacher introduces the example of CERN laboratory a large infrastructure for research in particle physics and emphasis the collaborative nature of science.
4. Two application of particle physics technologies in medicine are presented. Depending on the total available time dedicated to the package a homework can be assign for researching documentation about the applications.
5. The teacher introduces the idea of indirect measurements in physics and follows the example from [“Elementary particles ...” – presentation 1](#) about beam collisions on a target. Students will learn to read a histogram.
6. Setup of the experiment. As explained in [“Standard Model and applications” – worksheet 5](#), exercise 5 an experiment simulating particle scattering on atoms can be performed at macroscopic scale. The balls will play the role of the atoms and of the projectile particles.
7. The students are split in teams (4-5 students), each team takes its turn in performing the experiment throwing the balls, 10 - 20 throws per student. Each team plots the data from experiment on the histogram and answer the questions asked by the exercise [“Standard Model and applications” – worksheet 5](#), exercise 5



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8. Summation of the results. Teacher gathers all the results and makes a final histogram. The new result is comment and the importance of controlling the errors in an experiment is underlined.
 9. Exercises 3 and 4 from ["Standard Model and applications" – worksheet 5](#) are assigned for homework.



Lesson 3

Subject: Understanding particle detectors and data analysis

Lesson plan for “Elementary particles and fundamental forces”

Necessary materials and equipment:

- multimedia projector, computer, loudspeakers;
- computer for every 2 students
- completed Lesson 1 and Lesson 2;
- Video about the exercise
<https://www.youtube.com/watch?v=x2qJUbF2qUQ>
- package materials (no. 1, 5)

Lesson aims:

Understand the structure of a particle physics detector, of particle tracks and perform an analysis of data from a real experiment. Learn about selection the signal, fitting the data, extracting parameters and about systematic errors.

Methodological suggestions:

- expository methods: lecture, talk;
- demonstration methods: presentation, video, simulations;
- activation methods: brainstorming, team work;
- practical methods: work on computers

Lesson procedure:

1. Start of the lesson, organisational activities, checking the register.
2. Introduce the LHCb experiment and detector from slides or playing parts of the movie www.youtube.com/watch?v=rsmBMuTFdkA
3. The teacher uses the presentation “Elementary particles ...” – [presentation 1](#) or the LHCb Masterclass website to explain the purpose of the exercise.
4. Students start the first exercise and the kaons and pions tracks which might come from a D0 particle.
5. Students work in pairs at one computer. The available event dataset is split between the group of students. Students start visualize event by event and take watch the mass histogram.
6. Students start the second part of the exercise visualizing the mass histogram from a larger dataset. The signal and background components can be seen distinctly and tuning the selection parameters the difference between the types can be increased.



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7. Look at the lifetime plot and register the result. Repeat the exercise varying the selection of the signal, see the trend in lifetime values.
 8. Try to explain the trend of lifetime values and introduce the concept of systematic errors.
 9. Online Kahoot questionnaire about the Standard Model. Link
<http://play.kahoot.it/#/?quizId=b8fb8212-b6ce-4c28-83cb-92432f4c1881>