CERN

HST2023

Study Groups

FINAL REPORTS

CONTENTS

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Particle Accelerators

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1) Curriculum & Classroom Connections

Although particle accelerators are typically not mandatorily taught with the exception of Australia, they relate to many different concepts of senior physics and can used as a context for the following:

Lorentz Force
Ionization
Electric and Magnetic Fields
Relativistic Effects

2) Key Ideas

Particle accelerators are used to accelerate particles to high energies for various types of collisions
Atoms are ionized in order to be accelerated
Particles are accelerated using electric fields
Particles are bent using magnetic field dipoles and focussed using magnetic field quadrupole

3) Potential students' conceptions and challenges

Misconceptions
Accelerators speed up only electrons - false
They accelerate particles one at a time - false
Electric field used to accelerate is static - false
You can make a black hole with an accelerator - false
Particle accelerators have nothing to do with my life - false

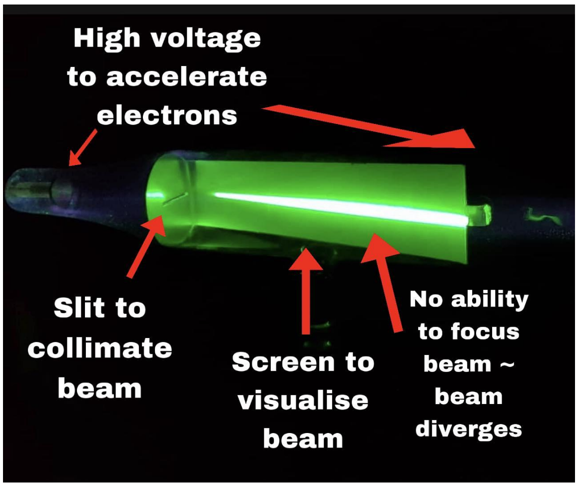
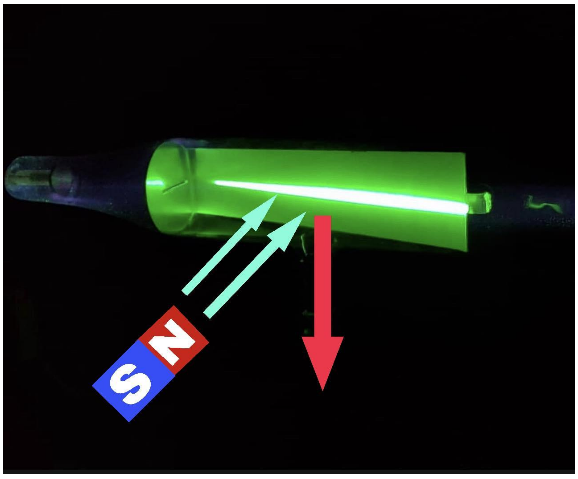
4) Helpful material and resources

Cern video of the LHC
https://videos.cern.ch/record/1750702
https://www.youtube.com/watch?v=cghodl3jlDc
https://www.youtube.com/watch?v=FLrEghnKncA

RF Cavity Video / GIF
https://videos.cern.ch/record/1750712
https://giphy.com/gifs/CERN-UVMOs73qqh2E3kN9Vk
Focusing Beam
https://videos.cern.ch/record/1750723

5) Best Practice Example

Particle accelerators can be used to probe the fundamental nature of matter, although this is intrinsically interesting to the physicists in the classroom it will leave many students behind. We strongly put forward the case to also highlight to students that particle accelerators can and are being used to treat cancer. Not just topical skin cancer but also deep organ cancers using proton and carbon ion treatments. Cancer will affect 1 in 2 humans by the time they are 85 and adequate treatment can result in remission.
Following this contextualisation, students can understand that electrons are easily removable from atoms. A quick sticky tape activity can be used to demonstrate that even friction can result in a charge imbalance.
Students can be engaged with Particle Accelerators through the use of a variety of demonstrations and activities. The cathode ray tube with a phosphorescent screen is a ubiquitous resource that is analogous to a particle accelerator. Several components that are shared between cathode ray tubes and particle accelerators can be identified by students using guided questions such as;
Teacher
"What is the purpose of the high voltage power supply?"
Student
"To provide an electric field to accelerate the charged particles"
Teacher
"What is the purpose of the slit in the cathode ray tube?"
Student
"To remove extraneous electrons" or "To collimate the beam"
Teacher
"What is the purpose of the screen?"
Student
"The see and detect the particles"
Teacher
"Yes! Indeed the screen allows us to visualise the particles, which means it is acting as a beam detector"
Extension Activity
Building upon using cathode ray tubes as a model of a particle accelerator, students can be asked how can the beam be bent? The answer is using either an electric field or magnetic field. Students can then be asked to deduce which way the beam of electrons will go when a magnet is brought near the tube using the right hand rule. Finally a magnet is brought near the tube perpendicular to the beam to demonstrate the force that is exerted on the beam.

 Figure 1. Using a Cathode Ray tube with a phosphorescent screen as an model of a particle accelerator	 Figure 2. A magnetic can be brought near the cathode ray tube to demonstrate the Lorentz force. N.B. The right hand rule

Particle Detectors

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1) Key ideas

- The students must be able to:
- Explain the concept of detection in particle physics.
    - Determine the type of a particle and its properties from “raw data”
- Distinguish the following types of particles by their properties:
    - Electrons (beta particles)
    - Alpha particles (helium nuclei)
    - Muons
- Explain the basics workings of a cloud chamber.
- Explain why detectors are important and what are there real-world applications.
- Explain briefly how ATLAS and CMS work.

2) Best practice example

We used a “Demonstrate. Question. Instruct. Reflect. Assess.” strategy:

Engage and Demonstrate:
Firstly, we decided to introduce the topic with the help of a cloud chamber. Given enough time and resources, the students might even build one themselves. This then will be used it in the class to demonstrate the detection of alpha particles, electrons (and possibly muons).
Instead of an actual cloud chamber, we can use a youtube video clip: Cloud Chamber Simulation to demonstrate the tracks in the cloud chamber more clearly. It is even possible to use the Android App used for generating the video.

Questioning:
The students were then asked the following questions: “What do you see?” “What phenomena did you see?” using the MENTIMETER app.

Instruction:

- Engagement with cloud chamber/video/sim
- Show/repeat that in radioactivity, we already did some kind of detection.
- Differentiate particles by penetration behaviour.
- Differentiate particles by their behaviour in a magnetic field.

- Explain the relevant properties of the particles responsible for the behaviour.
    - Go back to the cloud chamber/video/simulation/…
    - Distinguish different types of tracks
        - short & thick (α)
        - thin/jittery (β)
        - thin/long (μ)

Reflection/Review:

A Kahoot could be used to review basic concepts covered in this module.

Assessment:
Multiple options:

- Formal assessment where a partially labeled diagram of CMS or Atlas is given. Individual simplified tracks of particles will be in the diagram. The students will need to infer whether the particles are neutral, negative or positive and whether they are heavy or light.
    - This could also be done with an unlabeled diagram and have students draw potential tracks and answer the same questions.
- Mini project which would incorporate using the Lego kits for Atlas and CMS. The students would have to document their process of building the models by taking photographs of each part and giving a brief explanation of each. They would also need to explicitly explain what a particle detector is. The format can be in the form of a short video or a poster presentation. Which would be graded with a rubric.

3) Helpful material and resources

- CERN Cloud Chamber kit. https://home.cern/news/news/experiments/how-make-your-own-cloud-chamber
- Youtube https://www.youtube.com/watch?v=XGNvAEtYZkw
- Mentimeter Application. https://www.mentimeter.com/
- Kahoot Application https://kahoot.com/
- LEGO Detectors
- Picture of cross sections of CMS/ATLAS without tracks
- Picture of cross sections of CMS/ATLAS with simplified tracks

Engineering @CERN

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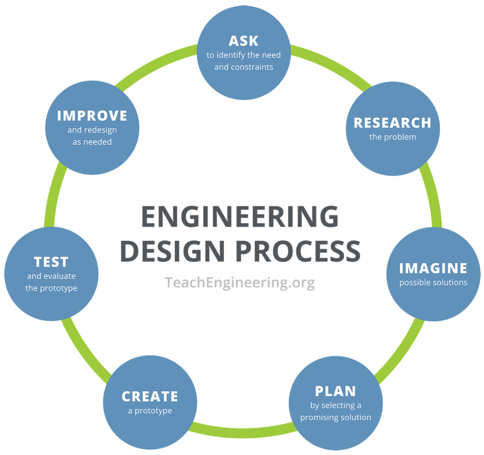
1) Key ideas

Key idea in the engineering process is the engineering design cycle which structures the process and helps users effectively achieve goals. There are many versions available and one of them is presented here as taken from the site https://www.teachengineering.org/.
Although there are many versions the main points are the same and can be summarised as follows:

1) Identify problem or situation
2) Review available resources
3) List possible solutions
4) Choose and create solution
5) Test and review



In this cycle there are some ideas that are essential for students to understand and that are to some extent contrary to their everyday experience, when comparing an instant result to the engineering process.

The main one is idea that engineering is ongoing process and mindset that is carried out through various situations. In the engineering process vast amount of various knowledge is used to find solution to problem.
The second ides is that this is iterative process, meaning that students have to try and test many solutions in order to come up with with the best one. It is crucial students to understand that mistakes and errors are great resource for learning and should be in their learning curve.

2) Best practice example

One of the ways to teach engineering in schools is via project work or project based learning. It means that students have hands-on activities where they need to use all or part of the engineering design cycle.
If looking from long term planning, types and scope of projects should change starting from easy ones that can be done in one study lesson and ending with such ones that take several months to complete. Structure of instructional design would be similar to all projects with giving problem or situation description at the beginning, then having time for planning and understanding available resources and continuing with prototyping, testing and evaluation.
As a project has several stages teachers should include evaluation or discussion after several stages or projects. These discussions and evaluation will help students to review work done and learn from the process and improve their performance on the next project. For example, it is important to review the planning process so that students next time would improve their planning skills and plan projects better as it is often one of the problems.
Some strategies, techniques or procedures should be given to students also before projects. For example, regarding the planning process, one could introduce students with Gantt chart templates and their usage in

the planning process. It would help students to do project planning and in review afterwards. Project specific skills and techniques should be adjusted and given according to size of project and student knowledge.
If projects are done in physics course, attention should be paid also to physics knowledge which are needed in completion of the project. Students either know it beforehand or learn physics during the project process. For example, building a pot pot boat project (https://en.wikipedia.org/wiki/Pop_pop_boat) could be one of the project examples where students use engineering design cycles and also use physics knowledge. Building process could be done in parallel with thermodynamics studies and thus students see the respective principles in action or project can also be done afterwards as a summary where all principles are used to explain action of the boat.

To summarise, there is many ways how to teach engineering process (https://www.sciencebuddies.org/blog/teach-engineering-design-process) and one of them include project based learning, where students learn process via project. By doing project students both learn project specific stages, techniques, tools and use physics related knowledge. When teaching engineering attention should be paid to both parts - process and content.

3) Helpful material and resources

https://sites.google.com/site/scientificabilities/isle-based-labs
ISLE-based labs place an important role in the Investigative Science Learning Environment (ISLE) approach to learning physics [http://www.islephysics.net]. They can be used if you implement the ISLE approach in large lecture courses with an integrated lab or in studio-based courses that use ISLE-based materials.

https://www.teachingexpertise.com/classroom-ideas/engineering-kits-for-high-school/
Knowing where to start with engineering kits can be a little difficult at first. There are countless ones available and it can be daunting trying to decide which one is best. To help you out, this resource contains the best engineering kits for high school students to ensure optimal learning.

https://www.egr.msu.edu/future-engineer/games-activities
The resource provides hands-on activities for the students in the form of fun games and activities best fit for students of high school.

https://www.nasa.gov/education/materials/

https://www.nasa.gov/stem/forstudents/9-12/index.html
Nasa STEM engagement resources are one of the most popular and widely used teaching materials in the class when it comes to teaching about sciences and engineering. The teaching material can be printed and used easily in the classroom as they also include the easily understandable instructions both for teachers and students.

https://phet.colorado.edu/
Teachers and students can have access to simulation-specific tips and video primers, resources for teaching with simulation, and activities shared by the teacher community.

https://www.commonsense.org/education/lists/best-engineering-resources-for-students
Tech and engineering skills are becoming increasingly important for school, life and work and this raises the necessity of presenting the science as scientific inquiry. The resource includes fun, intuitive intros to the basics, platforms for creation, and hubs for inspiration.

https://freerice.com/home
Freerice is an educational trivia game that helps you get smarter while making a difference for people around the world. Every question you answer correctly raises 10 grains of rice for the World Food Programme (WFP) to support its work saving and changing lives around the world.

https://education.gov.scot/resources/a-summary-of-stem-resources/
The resources outline a vision of Scotland as a nation with a highly educated and skilled population, equipped with the skills, knowledge and capability to adapt and thrive in a fast-paced and changing world and includes various resources for STEM helping teachers and pupils of different levels and stages.

Medical Applications of Particle Physics

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1) Key ideas

- The Concept of Radiation - radiation is energy that moves from one place to another in a form that can be described as waves or particles
- The EM spectrum shows the inverse relationship between wavelengths and energy.
- Larger wavelengths are too big to have intense effects on the human body due to the inability to penetrate the skin, bones, other organs and cells. However these waves are utilized for diagnostic instruments.
- The smaller wavelengths can penetrate providing the potential diagnostic and treatment instrument as well as damage to organs, cells and DNA
- Engineering Design Process - In order to use particle accelerators in a hospital setting, they must be easy to use, relatively cheap and have a small footprint. These goals require an intimate knowledge of the engineering design process and fundamental physical principles to minaturize particle accelerators as much as possible.
- Radiotherapy - Using photons, electrons or hadrons to treat cancer patients by killing the tumor cells.
- Ionizing Energy - Understanding of how far a given form of radiation is capable of traveling before it has deposited all of its energy into surrounding molecules.
- Bragg Curve - Graph showing the ionizing energy versus the depth. Treatment plans are based on how deep the tumor is within the patient and choosing a particle that will deliver the greatest amount of ionizing energy at the desired depth without harming the healthy cells while penetrating.
- Scientific literacy - Knowledge about how particles can affect our health is very important to our everyday life.

2) Best practice examples

Introduction to Medical Applications
1. Use humor and interests to motivate and spark curiosity
2. Assess prior knowledge in curious and hopefully a fun and entertaining way
3. Address misconceptions in non-threatening or condescending manner
4. Adjust modes and method of instruction based on prior knowledge
5. Provide scaffolding for future concepts.

Treatment of Cancer:
1. Introduce the idea of radiotherapy as a less invasive way of destroying tumor cells in the body through the use of particles.
    a. X - Rays - Use of photons
    b. Leptons - Use of electrons accelerated by a particle accelerator
    c. Hadrons - Use of protons or carbon nuclei that have been accelerated by a particle accelerator
2. Discuss the idea of ionizing radiation by using some of the activities found HERE, or if you have access to the equipment the IOP has many activities found HERE.

3. Show an image of a Bragg Curve and ask the students to - Think-Pair-Share the meaning of the x and y axis and what the curve represents for a given particle.
4. Introduce a scenario that shows an exemplar PET Scan with actual values detailing the depth of the tumor. Ask the students the THINK - PAIR - SHARE which form of radiotherapy would be most appropriate for the treatment of such a tumor.
5. Extensions - Treating cancer with Laser Wakefields such as IORT, ESRT

Scientific literacy

1. Emphasize the importance of the knowledge acquired in the classroom in becoming a scientific literate citizen
2. Bring attention to historical events related to radiation that may be of particular interest to your students

3) Helpful material and resources

Radiation Exposure Activities offered by the U.S. EPA
Radiation definition - https://www.iaea.org/newscenter/news/what-is-radiation
EM Spectrum Image - https://www.uib.no/en/hms-portalen/75292/electromagnetic-spectrum
Introducing Radioactivites offered by the IOP.
Summary of Laser Wakefield Technologies - Nicks, et. al.
Ideas around Hadron Therapy - Amaldi and Prino, et. al.
Bragg Curve Data - Brookhaven National Laboratory
Radiation Biology - A handbook for Teachers and Students - IAEA
Lesson plans offered by the Atomic Heritage Foundation
The radiological accident in Goiânia - IAEA report
X-ray FYYSIKA.EE: röntgen näeb läbi https://youtu.be/nP0GPLjJ9Oo

Theoretical Physics and Higgs Physics

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1) Key ideas

Theoretical Physics is an extensive field of research in Physics, with many subfields spanning every framework in our current understanding of natural sciences. As such, this report cannot encompass neither every aspect of research nor its possible implementation in high school education. Our study group decided to focus mainly on Nature of Science, Linguistic accuracy, and Empathy.
Nature of Science is of course part of every science class curriculum; however, it is rarely emphasized enough during Physics lessons. From experience, we propose that this is mainly due to time constraints, content-heavy programs, and preconception from teachers. We argue that the time taken in Physics lessons making sure students understand the importance of model building, its limitations, and the necessity of improving such models is very effective in transmitting social practices to our students. Those social practices are what sets Physics apart from other Natural Sciences and can lead to many cross-curricular concepts such as theory of knowledge and human curiosity. We suggest that in-class experiments and demonstrations are perfect opportunities to stress that experiments not only rely on theoretical foundations, but also refine the range of applicability of such models.
Linguistic accuracy is paramount in Theoretical Physics. This is especially the case for its introduction at high school level. High school students rely more on language than mathematical prowess when being acquainted with new concepts. Students have preconceptions linked to those concepts, but also about Theoretical Physics. And so do teachers! Great care should be spent on language when comparing older models to current models. We observed that very often shortcuts are applied to contemporary models, with descriptions mixing current understanding and the reality of Nature around us. Language can also have an impact on engaging students with the content. By an incorrect selection of words, students can be discouraged to even question current models, or can develop misconceptions about their ability to create their own models. Teacher training is extremely important to communicate the importance of linguistic accuracy, and how to discuss the concepts of truth and reality in Physics.
Teacher training, especially with a heavy emphasis on Theoretical Physics have another important spin-off, empathy. Physics teachers have a familiarity with the models they are teaching and can feel quite comfortable to discuss their mathematical ramifications. This is extremely at odds with the typical high school student that will struggle to absorb new content and integrate it. Training from experts in specialized topics, especially with strong connections to Theoretical Physics, can destabilize teachers, and make them question their own teaching. This way they can reconnect with their personal scientist persona and identify better with students and their growing intuitions.

2) Best practice example

Nature of science can be introduced at early levels of scientific training for students. An excellent activity that has plentiful variations, and thus can be catered to various year groups, is the Black Box/Mystery Box experiment.

The black box can be used to model any system that has inputs and outputs. Students build a model to explain an internal structure or mechanism, they can either work through observation, which models typical working culture in astrophysics and biology, or through experimental probing which models typical methods in chemistry and physics.

Black boxes can be any closed object containing mechanisms or objects, from the very simple drawstring bag filled with objects to an electrical system hidden in an opaque box.

We have used black boxes in teaching the following content areas:

- Introduction to science
- Structure of the atom & The Gold foil experiment
- Particle physics and detector physics
- Nuclear Radiation
- Magnetic induction
- Electrical components

Applications are not limited to physics, there are also content areas of biology and chemistry than can benefit from using black box models

- Action of medicine / Developing medicines
- Psychology

Black boxes can also support more complex aspects of building and testing models, their limitations and experimental design. The teacher can prompt students to explore the limitations of the model by using statements like the following, 'I can predict a hard object is in the box because it rattles, but I cannot predict the colour of the object'. Students can work individually or collaboratively to
build a series of statements of this nature. This can be further extended by asking students to design experiments or further observations to test their predictions or fill in the missing information.

Once the activity is completed, there is an opportunity to link the process to curriculum content, for example we have used this alongside learning the structure of the atom, students were prompted to describe how their process connected with the gold foil experiment, which is in many curricula. This can support students to understand how the scientific method is applied in a more complex context.

Teachers must exercise their judgement in selecting an age appropriate black box and whether to reveal the 'true' contents. In reality scientists cannot simply peer inside a proton, and gluing your object closed ensures that you maintain this aspect of building a model. However some students may disengage or feel frustrated by this, it is up to each educator to make this decision in a way that is best for their students.

A detailed example: The black box resource from the perimeter institute.

1. The teacher holds the tube and pulls on one or two pieces of rope.
2. Students draw what they think is in the tube.
3. The teacher gives more observational evidence, or allows students to direct the next steps (shake it, pull rope C etc.
4. Students refine their model
5. Students interact directly with the tube and test their models
6. Repeat steps 4-5 as suitable for your class.

A simple mystery tube from S'Cool lab

3) Helpful material and resources

- https://www.worldscientific.com/doi/epdf/10.1142/S2661339522500196
- The Mystery of Dark Matter – Perimeter Institute
- Beyond the Atom: Remodelling Particle Particles – Perimeter Institute
- Making Models: Wooden Blocks – Perimeter Institute
- The Process of Science – Perimeter Institute
- Beyond Bohr: A Quantum Approach to the Atom – Perimeter Institute
- Everyday Einstein: GPS & Relativity – Perimeter Institute
- Black Holes – Perimeter Institute
- https://www.symmetrymagazine.org/
- The Challenge of Quantum Reality – Perimeter Institute
- The Expanding Universe – Perimeter Institute
- Fields – Perimeter Institute
- Higgs in a box
- Mystery box S'Cool lab
- Nine black box activities for optics
- https://iopscience.iop.org/article/10.1088/0031-9120/48/4/477
- https://iopscience.iop.org/article/10.1088/1361-6552/aa62eb

Computing and Data Analysis

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1) Key ideas

- CERN collects a massive amount of data in short amount of time
- The computing technology and storage capabilities doesn't match the production of data, which requires researchers to use triggers
- Analyzing this volume of data requires programming skills
- Collaboration between and across research groups is critical to the successful data analysis

2) Three Best Practice Examples

- Our group created an introductory lesson that applies to many science classes. It includes basic math principles like standard notation, scientific notation, unit conversions, percentages and dimensional analysis. We noticed at CERN, that the discovery of the Higgs Boson required many such mathematical concepts and this lesson tells the story of the Nobel Prize winning discovery while taking students through these introductory concepts. (Math exercises links below)

- CERN gathers a huge amount of the data which are subsequently accessible by Worldwide LHC Computing Grid (WLCG) for deeper analyses.
  Our activity proposes gathering data alike from remote experiment with recommended method to analyze them in order to get a value of the Planck`s constant.
  The proposed measurement method utilizes the light emission from the semiconductor devices known as LED. The idea of the experiment with LED is the following:
  A direct current flows through the junction (electrons from the doped zone N to zone doped P and holes in the opposite direction); the electrons recombining with the holes in the vicinity of the junction produce photons of energy close to the energy gap value (a gap between the valence band and conduction band) of the junction material.
  With LEDs, we can measure the voltage at which the LED first emits lights, V(threshold). This voltage is related to the energy gap by

$$E_{gap} = eV_{threshold} \qquad (5)$$

  where e is the charge on the electron. Thus, the frequency of the brightest light emitted by the LED and the threshold voltage are related by:

$$eV_{threshold} = hf_{light} = \frac{hc}{\lambda_{light}} \qquad (6)$$

Solving for Planck's constant,

$$h = \frac{eV_{threshold}}{f} = \frac{eV_{threshold}\lambda}{c} \quad (7)$$

The main idea to determine $V_{threshold}$ for LED of different colour is by measurement of Volt-amper characteristics of the LED and analyze the gathered data. Where the dependence of voltage on current is linear, we fit these values with linear regression. Then we read the intersection of regressed line and x-axis, we have got $V_{threshold}$ value.

- We also created a lesson that allows students to explore the probabilistic nature of particle collisions. Students will use dice to represent the products of a proton-proton collision. (Resource for particle collision below)

3) Helpful material and resources

Math Exercises with the Higgs Story STUDENT COPY
Math exercises with the Higgs story TEACHER COPY

Resource for Plank's Constant Measurement

Search for Z and Higgs Boson

Resource for particle collision probability activity

Resources for introducing data analysis using Python:
https://github.com/QuarkNet-HEP
https://www.w3schools.com/python/
https://readwritecode.blog/the-primm-instructional-model-8ece921f9ba7
https://primmportal.com/

Neutrino Physics

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1) Key ideas

Although the Standard Model is studied is some countries, it can be introduced in all countries through topics like conservation of energy, momentum, or nuclear and atomic physics.

The neutrino was proposed in 1930 by Wolfgang Pauli to keep the conservation of momentum and energy (and spin if you go that far) during β-decay. Clyde Cowan and Frederick Reines found experimental evidence of the particle in 1956 studying Cerenkov effect in a nuclear powerplant pool. This indicates the importance of theory to help predict the existence of certain objects as well as the importance of experimentation to check theory.

Neutrinos are elementary particles. They were hard to discover because they had little mass and were neutral. We have three types of neutrinos (electron, muon, and tau). Other than that, depending on the curriculum, you can include neutrinos oscillation.

Here are some of the current experiments being done on neutrinos that you can use to spark interest in your students:

- IceCube
- Japan Super Kamiokande
- Majorana Demonstrator
- MINOS
- DUNE
- NOvA
- MINERvA
- MicroBooNE
- ICARUS
- KATRIN
- GERDA
- NEXT

Interesting questions that can be mentioned to students are:

- Neutrinos are their own anti-particle?
- Neutrinos have mass but don't interact with Higgs?
- Are there only three flavors of neutrinos?
- Are they the reason why we have a universe made of matter and not antimatter?
- How can we use the neutrino in our every day lives?

2) Best practice example

First idea to approach neutrinos topic in classroom is writing a song parody. It must include:

- at least three scientific facts about neutrinos,
- a reference of at least one thing physicists are still trying to understand about neutrinos,
- a mention of a scientific experiment or a research center where neutrinos are being studied.

Second idea is to propose a role playing. We would assign one characteristic of neutrinos to groups of students and have them act it out. They would have the following information:

- they don't interact much with matter,
- they have three flavors that oscillate
- they are only left-handed.

Third idea is to show their oscillation from a beach ball demonstration. The beach ball has three colors: blue, red and yellow, representing three flavors of neutrinos. We are going to observe beach ball with a special sun glasses which has horizontal gap on the surface (the picture of sun glasses is on slides). We are going to use these two items to explain neutrino oscillations* (see neutrino oscillation in the table below).

3) Helpful material and resources

Topic	Type	Source	Link	Accessible for HS students?
General	Short article		https://nures.uta.edu/home-2	X
General	Short article	Symmetry (FermiLab)	https://www.symmetrymagazine.org/article/april-2010/explain-it-in-60-seconds-neutrino?language_content_entity=und	X
General	Article		https://www.scienceinschool.org/article/2011/neutrinos/	
History	Video	Fermi Lab	https://youtu.be/RGv-pcKRf6Q	X
History	Article	Cern Courier	https://cerncourier.com/a/cerns-neutrino-odyssey/	
Detection	Video	FermiLab	https://youtu.be/gKO8f79Ekew	X
Detection	Video excerpt	FermiLab	https://youtube.com/clip/UgkxWbe-660b7X-hOyHVvRVrkoVtLum3JCx8	X
DUNE	Article		https://www.innovationnewsnetwork.com/dune-experiment-unlock-mysteries-neutrino/21061/	
Detection	Site	FermiLab	https://www.fnal.gov/pub/science/particle-physics/experiments/neutrinos.html	
Detection	Podcast	FASER	https://physicsworld.com/a/faser-searches-for-dark-photons-at-the-lhc-and-also-finds-neutrinos/	X
Neutrino oscillation *	Video	FermiLab	https://youtu.be/eBT1-dV1BTM	
Neutrino oscillation	Video		https://youtu.be/7fgKBJDMO54	X
Ice Cube	Short article		https://physics.aps.org/articles/v16/115	X
Ice Cube	Podcast		https://player.fm/series/science-technology-voa-learning-english/a-new-way-to-look-at-the-milky-way-july-05-2023	X
Nuclear reactor	VR-demo		https://disk.yandex.ru/d/dDZruxePogBGFw https://disk.yandex.ru/i/WLUgEel12pEiiA	
Beta-decay	Simulation		https://www.labxchange.org/library/items/lb:LabXchange:d96d1be6:lx_simulation:1	X

Antimatter Research

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1) Key ideas

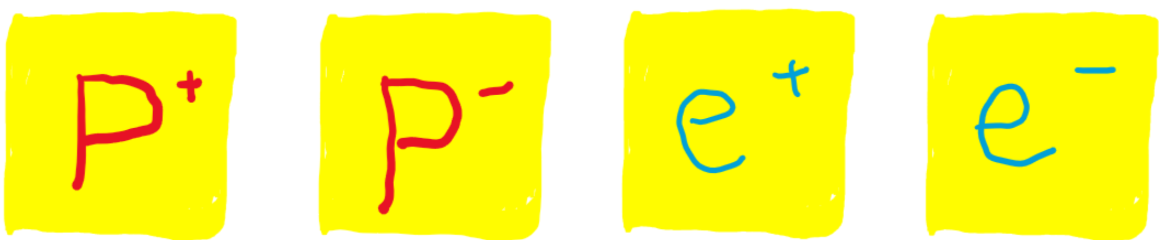
- The universe consists of elementary building blocks. We have chosen to focus on protons, antiprotons, electrons and positrons. Since not all these are elementary particles, we address them as building blocks.
- Positrons and protons are positively charged, electrons and antiprotons are negatively charged. Hydrogen and antihydrogen are neutral.
- Particles move in straight lines when they do not interact.
- Particles interact according to three principles.
  - Repulsion: Particles with the same charge repel each other.
  - Formation of atom systems: Protons and electrons form hydrogen, while antiprotons and positrons form antihydrogen.
  - Annihilation: When an antimatter-particle meets their corresponding matter-particle, they annihilate and radiate photons.

2) Best practice example

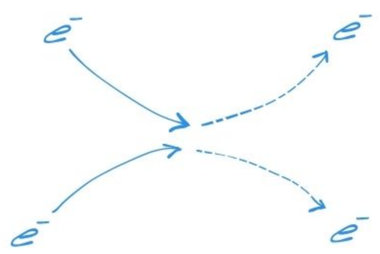
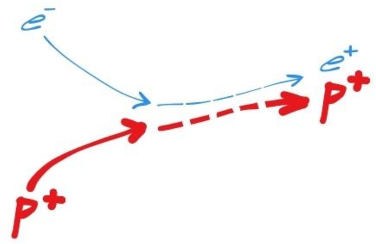
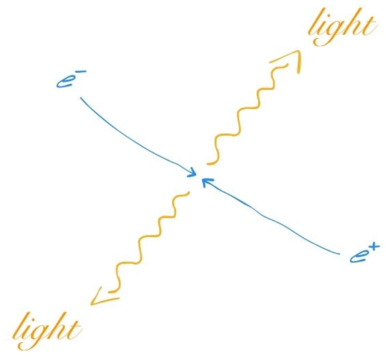
The key ideas for antimatter can be introduced through a game. This game can be adapted for students on many levels and can be used both in physics and as part of an integrated science curriculum. The antimatter game is based on the key ideas presented above. The idea is to assign students' roles as elementary building blocks. These building blocks will then follow game rules on how interactions happen. Through the games' interactions, repulsion, annihilation and formation of atoms and antiatoms can be observed.

Students need no prior knowledge of antimatter to play the game, but they must be familiar with concepts of elementary particles' building blocks, charge and interactions.

In preparation for the antimatter game, the teacher will need to produce one sticky note for each student. There will be four different sticky notes, as illustrated below. The sticky notes represents the proton (p^+), the antiproton (p^-), the positron (e^+) and the electron (e^-)



In the game, the students will interact according to the rules below when they are close enough to shake hands.

		
Repulsion: The students will continue in a different direction.	Formation of atoms: The students will link arms and can only interact with other atoms or antiatoms.	Annihilation: The students become photons and sit down.

During the game, there are three additional rules. 1) Walk slowly, 2) Freeze if the teacher claps, 3) No talking except when interacting.

Teachers may clap to pause the game to highlight or to further emphasize certain interactions to students during the game.

After playing the game, the topic may be elaborated in many ways. If there is slightly more matter than antimatter at the beginning of the game, this will lead to only matter surviving. This can be discussed and connected to the asymmetry of the universe. Another elaboration that can be carried out after the game is to introduce $E = mc^2$, or if it is already established, to have students compare different energy sources, including antimatter.

3) Helpful material and resources

Explaining antimatter to the young mind is a challenge. As a teacher, when you start talking about antimatter with students, their imagination will immediately be drawn towards science-fiction. Teaching using different resources will be helpful to clarify misconceptions, alter initial ideas and can excite students even more than science-fiction.
Using some of the basic examples will act in their first imagination, and showing the real science facts after it will be effective.
The whole purpose of this idea is to involve more students from a younger age. This will increase the chances of having more students who will be willing to continue their education in STEM education.

- Particle Adventure (The Fundamental of Matters and Force)
- 3D Periodic Table and Interactive Periodic Table
- AAPT-Antimatter Teaching Module
- The Matter with Antimatter (Youtube Video)
- PhET Interactive Simulations (Isotopes and Atomic Mass)
- Antimatter Teaching Modules for students aged 14-15 (PDF)
- What Star Trek Teaches Us about Antimatter - Phil Kesten - Thought Leaders - Illuminate (scu.edu)
- ClassHook | Antimatter Explosion
- Antimatter in the classroom - CERN Bulletin
- Antimatter Matters - Lesson - TeachEngineering

Future Accelerators

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1) Key ideas

Future accelerators are not explicitly covered in any curriculum, but we have identified a number of areas where we think reference to the accelerators, their supporting technology or the particle physics that is being investigated could be mentioned. These are briefly described below:

- Electric and magnetic fields: discuss how the fields that we can produce limit the energy of particles being accelerated
- Circular motion: the size of future accelerators could be analysed using Newtonian mechanics and E&M field equations
- Particle Physics: discuss the flaws in the Standard Model and reasons why higher energy particle accelerators are necessary to address the unanswered questions
- International Mindedness: this is an aspect that must be addressed in the IB DP (International Baccalaureate Diploma Program) and the international collaboration required to develop the technology and obtain the funding could certainly be discussed and explored

Whilst these are all suitable places that future accelerators could be discussed in a secondary Physics classroom, we feel that the most suitable place is in the exploration into Nature of Science (NOS). NOS (which can be referred to by different names depending on curriculum board) is an overarching goal of most science curricula to help students understand how science is explored, tested, scrutinised and evolved. Since these ideas can be discussed with any age of students, it allows some of the interesting Physics associated with future accelerators to be introduced to a wider range of students, including those that do not go on to study Physics at a higher level.
We have used the IB DP elements of NOS to give some examples of discussions or explorations, but these could be adapted to any NOS specifications. See below for examples:

- What is science and scientific endeavour: discuss science for the pursuit of curiosity and making sense of our world using highly developed models to identify flaws in Standard Model and why we are interested to understand more and resolve the flaws
- The understanding of science: discuss how we use current technology in accelerators and supporting equipment, and their limitations to assist in development of new technologies, using hypotheses to test predictions
- The objectivity of science: explore how the scientific method is utilised in the development of future colliders and particle discovery. Discuss that panels os scientists must objectively review all proposals for particle searches, the prototypes and testing required for development of future technologies
- Human face of science: discuss the international collaboration required, sources of the funding and how this will be justified
- Scientific literacy: explore how we explain to non-scientists why we spend unimaginable amounts of money in search of unknown particles

2) Best practice example. Problem-Based Learning activity: Feasibility proposal

Problem-Based Learning is a methodology that structures the learning process of students around solving a problem, either in a hypothetical context or in real life. In this example, the challenge for students is to get the funding for their future accelerator proposal.

For this activity, depending on the amount of students in the class, they will be split into groups of either 3 or 4 people. This task is cooperative, which means that the strengths of each group member will be considered when forming the groups.
A list of future accelerators, currently proposed around the world, will be provided to the class. Each group must then choose one and research about it during the allocated hours. The product of the project will be a poster summarizing the relevant information about the accelerator, and a presentation in front of their classmates. All the class will then become the funding committee, and vote on the proposal that will get the funding in the end.

The activity is designed to take place during six hours. The first one is allocated to introduce the topic, give instructions to students and kickstart the process. During the three following hours, students will work autonomously and under teacher supervision, researching the content of their proposal and designing their poster. Finally, the presentation and votes will take place during two hours, with each presentation having a maximum duration of ten minutes, plus five minutes for questions.

During this activity, the main skills that the students will integrate are communication, social skills, science and technology, ability to learn and digital competency, if communication and information technologies are used during the documentation and the crafting of the poster. Concerning content, the main covered topics are the Scientific Method, Modern Physics beyond the Standard Model, Electromagnetism and Accelerator Physics and, most importantly, Nature of Science.

In order to provide scaffolding with students with diverse learning approaches, the activity is open and the guidelines will be broad but clear. The teacher will revise a draft and give feedback to the students on their work, and they will be closely monitored. If there is time left or students want more of a challenge, their presentation can be expanded to include the options of technology transfer that their accelerator will bring.

The contents of the poster and presentation could follow these guidelines:

- Timeline of the accelerator
- Countries involved in its development
- Research goals. Relevance of that research
- Design of the accelerator and technologies used
- Justification for funding

Since all students must vote on a proposal, and the “funding” can be a prize, extrinsic motivation is also present in this activity. Moreover, the innovative topic is a good basis for a successful integration of Modern Physics in the classroom.

3) Helpful material and resources

Quarknet-Rolling With Rutherford ,Shuffling the Particle Deck, Making it ‘Round the Bend”-Qualitative

Making it ‘Round the Bend”-Quantitative , The Particle Adventure Interactive Website

CERN-How an Accelerator Works, Higgs in a Box: Investigating the nature of a scientific discovery,

Future Circular Colliders Website, Future Circular Collider Video
Particle physics made easy - with Pauline Gagnon

Perimeter-Quantum to Cosmos, Conversations at the Perimeter, The Process of Science ,Perimeter Institute for Theoretical Physics

Quarknet-Cosmic Ray Studies, World Wide Data Day, Masterclass

Texas Gateway, International High School Teacher Programme (2-July 15, 2023) · Indico (cern.ch)