FRONTIERS

Bringing Nobel Prize Physics in the Classroom

“Energy, mass and other exploding concepts in Physics”

DCU ELLINOGERMANIKI AGOGI NUCLIO EGO EUROPEAN GRAVITATIONAL OBSERVATORY IASA Paris Centre for Cosmological Physics

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Background information for teachers

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HEP GROUP

Overview of this lesson pack:

Name of the activity	Energy, mass and other exploding concepts in Physics
Topics introduced	Einstein mass- energy equivalence, nuclear fission, radioactivity, nuclear power plants, chain reaction, particle accelerators
Curriculum Connection	PORTUGAL: Atomic nuclei and radioactivity: Nuclear binding energy and nucleus stability GREECE:Energy, Kinetic Energy conservation of (mechanical) energy 10th grade:
Reference Demonstrator	Mass-energy equivalence
Age of students	Greece:15-16 Portugal:16-17
Duration	135 minutes

Overview of this lesson pack:

Type of activity	Problem-based learning/ Inquiry
Description of activity	Teacher activities: Teacher motivates the students and captures their attention discussing selected introductory videos. Teacher explores the students' initial ideas on nuclear physics and introduces them to the basics of nuclear fission, radioactivity ,nuclear power plants , chain reaction , particle accelerators. Teacher supervises and with his/her questions initiates discussions and directs the problem based learning inquiry activities Student activities: Students reflect on the introductory videos and on the strength of the nuclear power. They read new information, exploit applets to assimilate knowledge, perform calculations and discuss the results between them in the class. They answer questions and apply the new knowledge they acquired in order to understand the science behind atomic bombs, accelerators and power plants.
Equipment requirements	internet connection, a computer, a video projector, calculator
Prior knowledge for students	Atomic composition Mass conservation The amu units are revised

Background and overview of the XXX demonstrator:

Mass-Energy Equivalence

The link is:
http://inspiringscience.rdea.gr/delivery/view/index.html?id=a60b5ab51cc848719e45df037eaa134d&t=p

orienting , hypothesis & planning ,investigation & analysis , conclusion & evaluation

Presentation for students

Teacher guidelines can be found in the notes attached to each slide

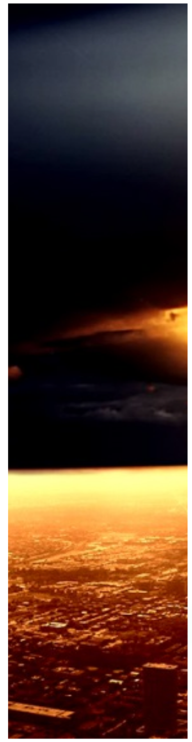
Motivation

On Saturday 26 April 1986, in the Chernobyl Nuclear Power Plant, during a safety procedure test, nuclear reactor n.4 exploded. An open-air reactor core fire followed that released airborne radioactive contamination for about nine days that affected parts of the USSR and Western Europe.
The **Chernobyl disaster** is considered -up to now- the worst nuclear disaster in history both in terms of cost and casualties. Almost thirty years later the disaster was brought back to life in a popular TV miniseries. Watch the official trailer in https://www.youtube.com/watch?v=s9APLXM9Ei8, discuss with your fellow students and answer the questions below

The atomic bomb shed death and doom on Hiroshima and Nagasaki in 1945. Fortunately, this type of weapon was not used again in human conflict. Watch the first 2 mins of the video in https://youtu.be/AZsngBRP8o0
and answer the following questions.

- *What elements the two atomic bombs the US used against Japan were based on?*
- *Did you hear any of these two elements used in the Chernobyl power plant?*
- *After the initial blast of the atomic bomb that killed instantly thousands of people and the initial explosion in Chernobyl, what induced cancer and other problems to the living beings in both nuclear sites?*

When any bomb explodes, a large amount of energy gets released in the form of heat, sound, kinetic energy of debris radiation etc

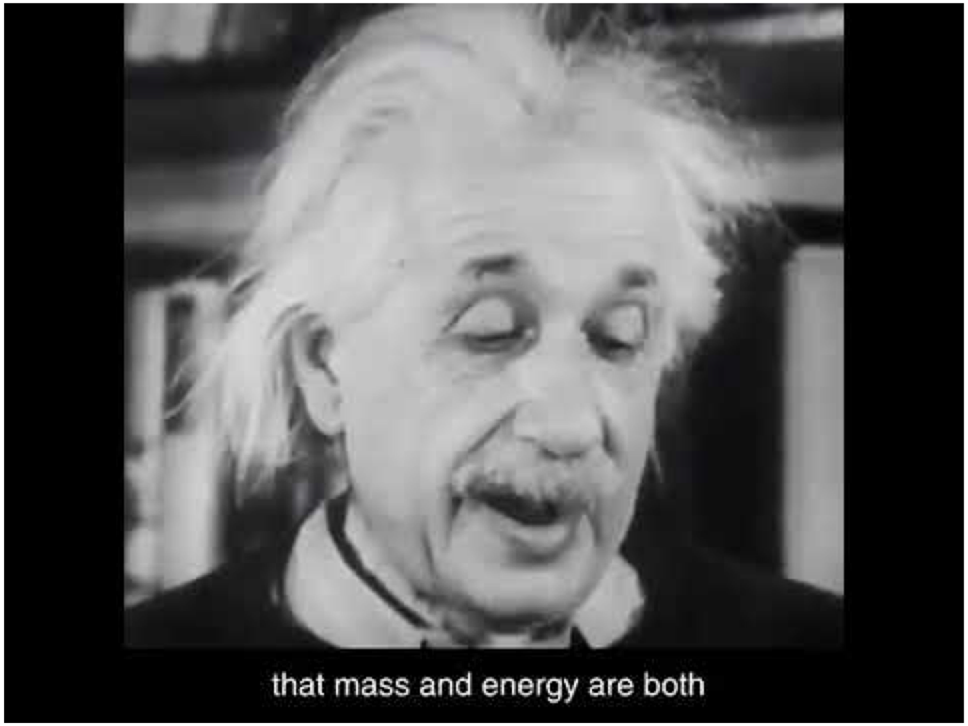


Question for students: keeping in mind what we know up to now that energy is conserved and it just changes forms, where do you think this energy comes from?

Lets get some help from Einstein's most famous equation

Watch Mass-energy equivalence announced by Einstein himself in

https://youtu.be/drzw_Z6ltn0



So Uncle Albert suggests that mass is energy and energy is mass and not only that, but the one can convert in the other also!

Question:
Do you remember the value of the speed of light c? Please write it down.............
Now calculate how much c^2 is.
$c^2=c*c=$ ....
This is definitely a very big number!!

So, a very small amount of mass is equivalent to a big amount of Energy and vice versa

- What is the necessary Energy to boil 1 kilogram of water at 0^0C?

$$E = mc\,\Delta T$$

$$E = 1x4{,}18x10^3x100 = 4{,}18x10^5\ J$$

- According to Einstein Equation can we calculate how much mass can be converted to Energy to boil the water?

$$E = mc^2 \qquad m \cong 5x10^{-12}\ kg$$

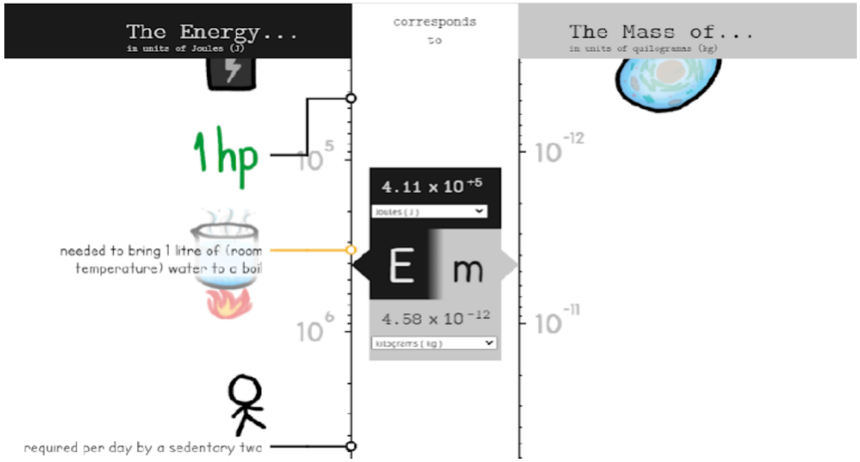
5 ng

- **Let's see if we are right…**

How can we measure this quantity?

Is it possible?

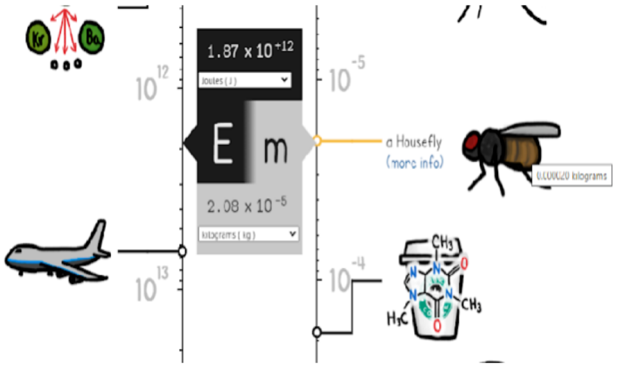
In your lab, check the accuracy of your scale
How many orders of magnitude is this lower than the "ng" accuracy we need in order to measure this mass loss?



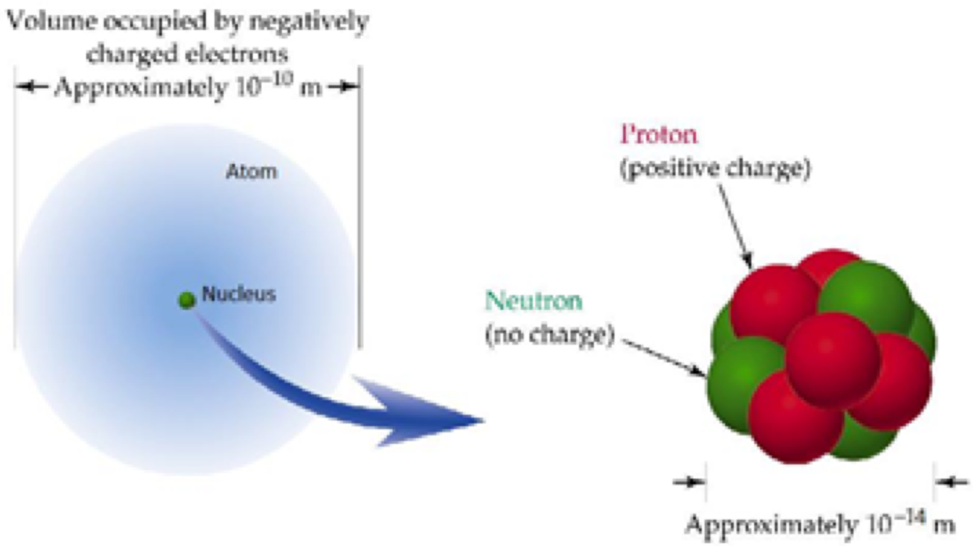
http://labs.minutelabs.io/Mass-Energy-Scale/

- Now for fun in the applet find the Energy equivalent to the mass of an housefly.

Now (keeping in mind that this is a logarithmic scale) discuss in the class how many houseflies you need to top the fuel energy available to a Boeing 747 aircraft.



The atomic nucleus consists of **protons** and **neutrons** and is the core of every atom. Its size is of the order 10.000 smaller than the size of the atom:



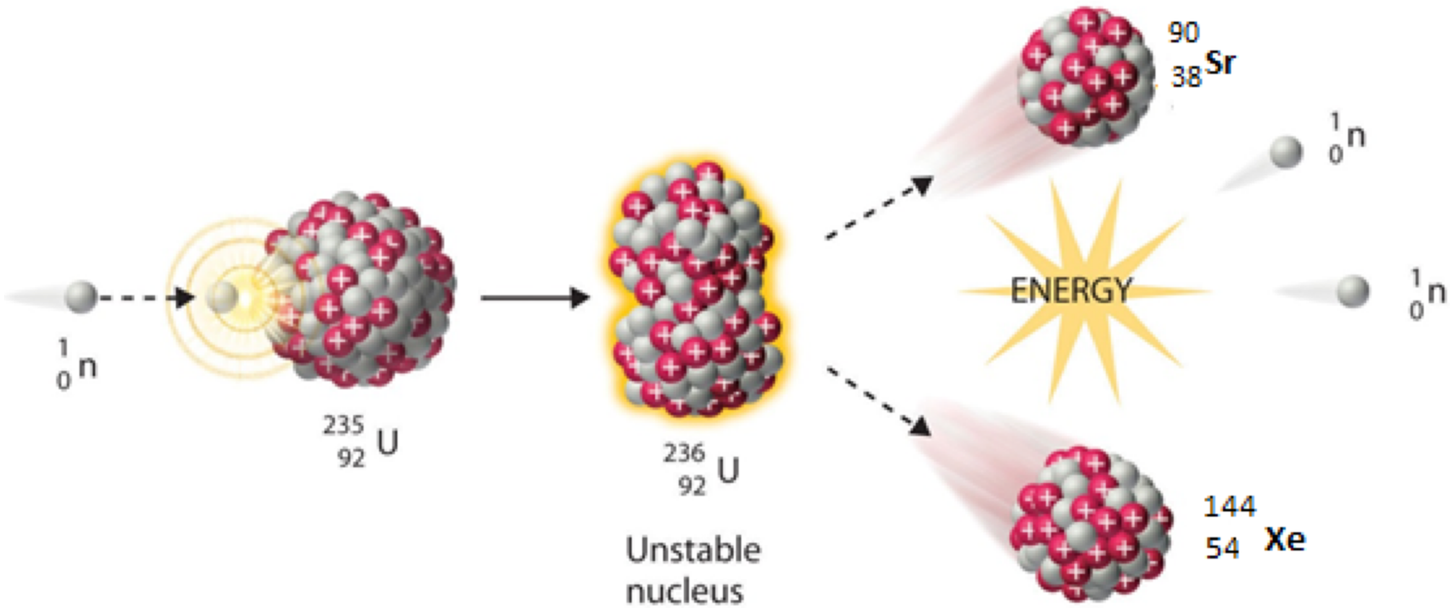
Remember **isotopes** - atoms with the same atomic number but different mass number.
Atomic number - number of protons in the nucleus
Mass number - number of protons plus number of neutrons in the nucleus

$^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

During the end of the 19th and the beginning of the 20th century, scientists (Joliot, Curie, Becquerel, Rutherford) measured that some nuclei are actually unstable!

Some heavy nuclei can “break apart” in smaller nuclei and emitting radiation and this is called **radioactivity.**

If a *heavy* nucleus is bombarded by a neutron, then it can break in two almost equal in mass smaller nuclei and emit other particles *such as neutrons* in the process.
This reaction is called **nuclear fission.**



Now, after a tour in the microcosm of the nucleus we are going to investigate our hypothesis on **Einstein's equation** using the tool of radioactive decay provided to us by nuclear physics.

Therefore, if $E=mc^2$ is accurate, we will be able to measure it in nuclear phenomena.

Useful Information

Units of energy in the microcosm

The Energy in the SI is measured in Joule but when we dive into the mi crocosm this is a huge amount of energy so we use a smaller unit, the “eV”.

$1\ eV = 1.602 \times 10^{-19} J$

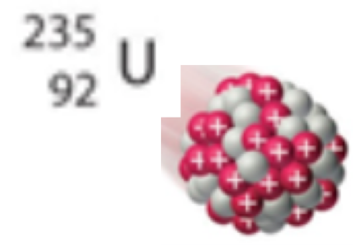
1 eV equals to the energy of a particle with charge equal to e (electron/proton charge) accelerated by a potential difference of 1 Volt.

- 1 keV = 1000 eV=10^3 eV
- 1 MeV=1000000 eV=10^6 eV
- 1 GeV =1000000000 eV =10^9 eV

Units of mass in the microcosm

As a unit of mass, we use the atomic mass unit (1 a.m.u or amu).
1 amu equals to 1/12 of the mass of the ^{12}C atom.
Lets see:
C has 6 protons and 6 neutrons in its nucleus. It also has 6 electrons around the nucleus
The neutron is slightly heavier than the proton and both are approximately 1 amu.
The electron is very very light, almost 2000 times lighter than the proton or the neutron.
Question: Now can you think why we used the 1/12 of the mass of ^{12}C atom ?

Question:If you have a Uranium nucleus that has 92 protons and 143 neutrons like the one in the image on the right.
Can you guess its mass (approximately) in amu?



Check if you are close to the right answer in the following link:

https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

Brief instructions:open the link in the blue graph, under “nuclide” write the mass number and the symbol of the element (example 235 U). Another table appears below and you have to go far right to find the atomic mass. Alternatively, you can move on the graph to find the nuclide.
Be careful: the atomic mass is in µamu and 1 µamu=10^{-6} amu

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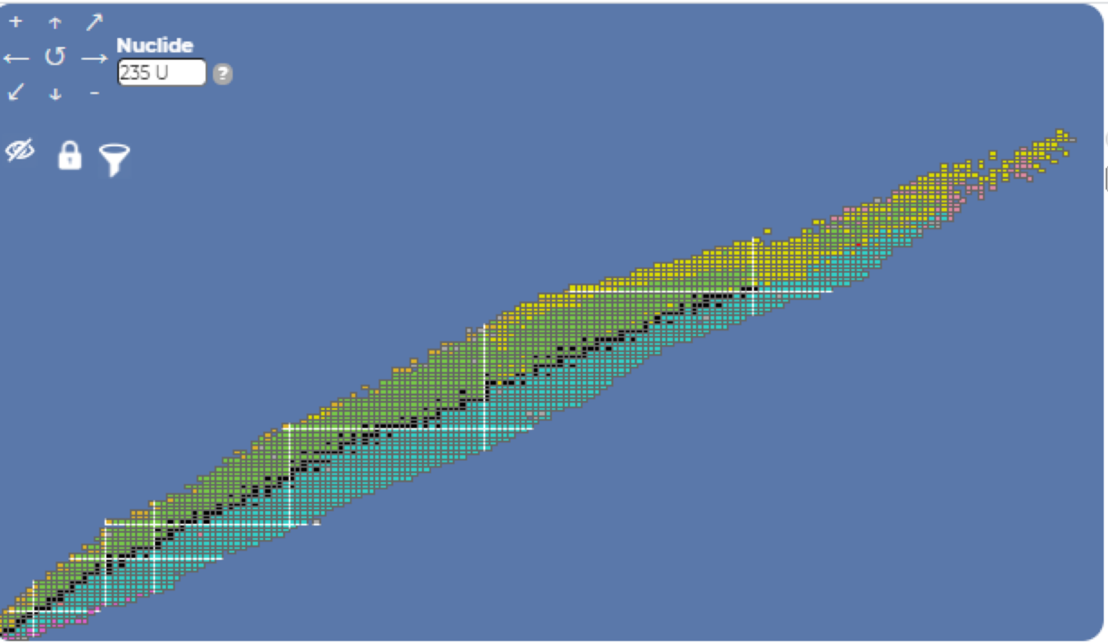


Live Chart of Nuclides

nuclear structure and decay data ms: *18747*
email: nds contact point guide & sources

Color zones by
value quantile

Main Decay Mode

- alpha
- EC+ beta+
- beta-
- P
- n
- EC
- SF
- Stable

Mass chains
β and ec decays plotting

Neutron Cross Sections
Resonance Integrals

List of updates
From Jan 2019 to Oct 2019

- **Click** on a nuclide to fill the data tabs.
- **Double click** to bring it to the centre.

- **Mouse:** to move the chart **drag**
  Use the **wheel** to zoom
- **Numeric keypad:** zoom with **3 and 7**
  Use **8, 6, 2, 4, 9, 1** to move and **5** to reset

Ground State isomers | Levels | Gammas | Decay Radiation | Nuclear Moments | Neutron Capture | Fission Yields | Schema Plot

Comments · **Click on a column header to open the guide** · **Uncertainty** for numeric values refers to the last digits of the value: **12.1 *23* means 12.1 ± 2.3** · **Data from:** ENSDF Angeli & Marinova A
Sources

· **Evaluation**: E. BROWNE, J. K. TULI **Publication cut-off**: 1-Feb-2014 **ENSDF insertion:** 2014-11 **Publication:** Nuclear Data Sheets 122, 205 (2014)

Nuclide	Energy [keV]	J^π	$T_{1/2}$ Abund. [mole fract.]	$T_{1/2}$ [s]	Decay Modes	BR [%]	Isospin	μ [μ_N]	Q [barn]	R [fm]	Q_{β^-} [keV]	Q_α [keV]	Q_{EC} [keV]	$Q_{\beta^- n}$ [keV]	S_n [keV]	S_p [keV]	Binding/A [keV]	Atomic [μ AMU]
$^{235}_{92}U_{143}$	0.0	7/2-	7.04×10^8 y *1* **0.7204 % *6***	2.22E16 *3.16E13*	α SF ^{28}Mg ^{20}Ne	100 7×10^{-9} *2* 8×10^{-10} 8×10^{-10} *4*		-0.38 *3*	+4.936 *6*	5.8337 *41*	-124.3 *9*	4678.0 *7*	-1370 *14*	-7107 *8*	5297.50 *23*	6709 *4*	7590.914 *5*	2350439

Now that we know how to find nuclear masses we are going to investigate the hypothesis that the mass is conserved in a nuclear reaction.

We have the following nuclear reaction

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow {}^{144}_{54}Xe + {}^{90}_{38}Sr + 2n^{1}_{0} + Energy$$

Using the previous link find the masses of the constituents and put them in the following table in units of amu (in the link the units are μamu) . Keep six decimal digits

We give you the neutron mass to be: 1.008665 amu.

mass of ^{235}U	mass neutron	mass ^{144}Xe	mass ^{90}Sr	mass of 2 neutrons

Δm_nuclear=total mass before - total mass after

= (mass of ^{235}U+mass neutron)-(mass^{144}Xe+mass^{90}Sr+mass of 2 neutrons)

Write down your result Δm_nuclear=…………………………………… and answer the following question "Is mass conserved in nuclear reaction ? ………………………………."

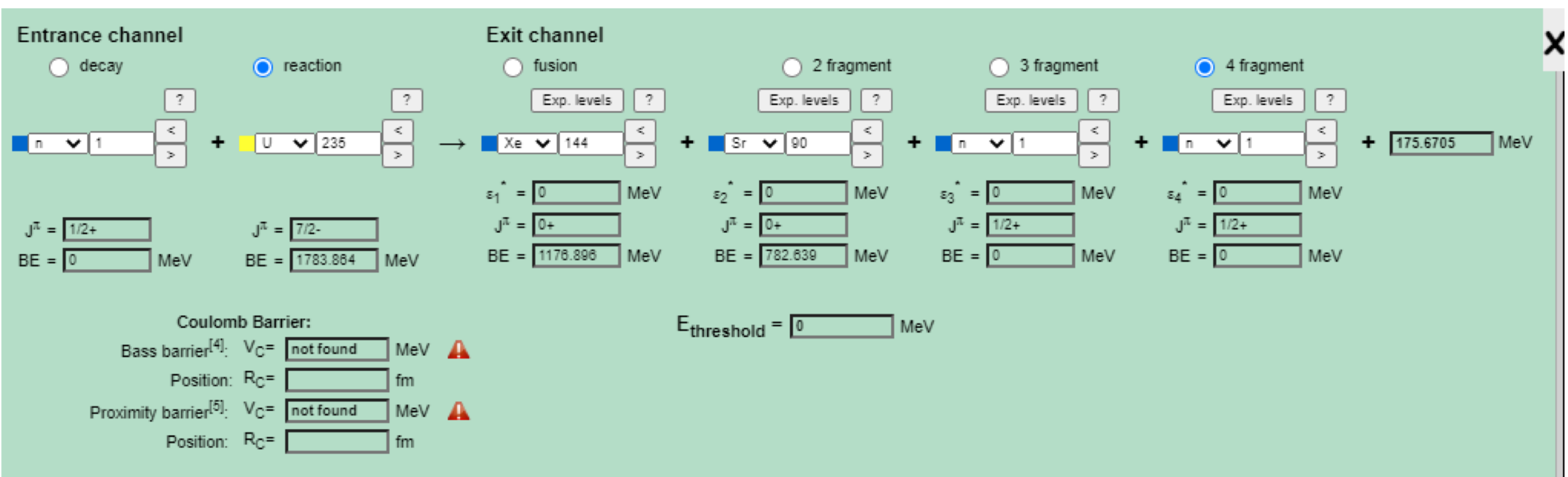
You must have realized that mass isn't conserved in nuclear reactions.

Look again at the nuclear reaction:

$$^{235}_{92}\mathrm{U} + ^{1}_{0}n \rightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2n^{1}_{0} + Energy$$

Use the application in the following link : http://nrv.jinr.ru/nrv/webnrv/qcalc/ to find the energy release of the reaction in MeV: (Remember :1 MeV = 1.000.000 eV= 10^6eV).

Choose "reaction" and "4 fragments" ……..the final screen will be :



This Energy is shared among the daughter nuclei produced by the fission and the neutrons in the form of kinetic energy.

For the reaction to take place, the neutron that reacts with the ^{235}U nucleus is thermal This means it has a very small kinetic energy (less than 1 eV) while the nucleus is at rest. After the reaction all constituents have some kinetic energy (neutrons have energies of the order of 1 MeV) and there is also additional energy released.

Does Energy seem to be conserved?

……………………………………………

Let's investigate if this excess in Energy we found comes from the mass-loss (Δm_nuclear).

Convert the Δm_nuclear you found in kg.

You may use : **1 amu = 1,6605402 x 10^{-24} g=1,6605402 x 10^{-27} kg**

or the link below for help: **https://www.translatorscafe.com/unit-converter/el-GR/mass/63-2/Atomic%20mass%20unit-gram/ but there you must convert g to kg**

Use Einstein's equation: $E = mc^2$, $m = \Delta m\_nuclear$ (kg) and $c = 3*10^8$ m/s

E=...................................Joules

Transform the value of energy you found from Joules to MeV

E=...MeV

Compare with the 174 MeV Energy release provided to us by experiment.

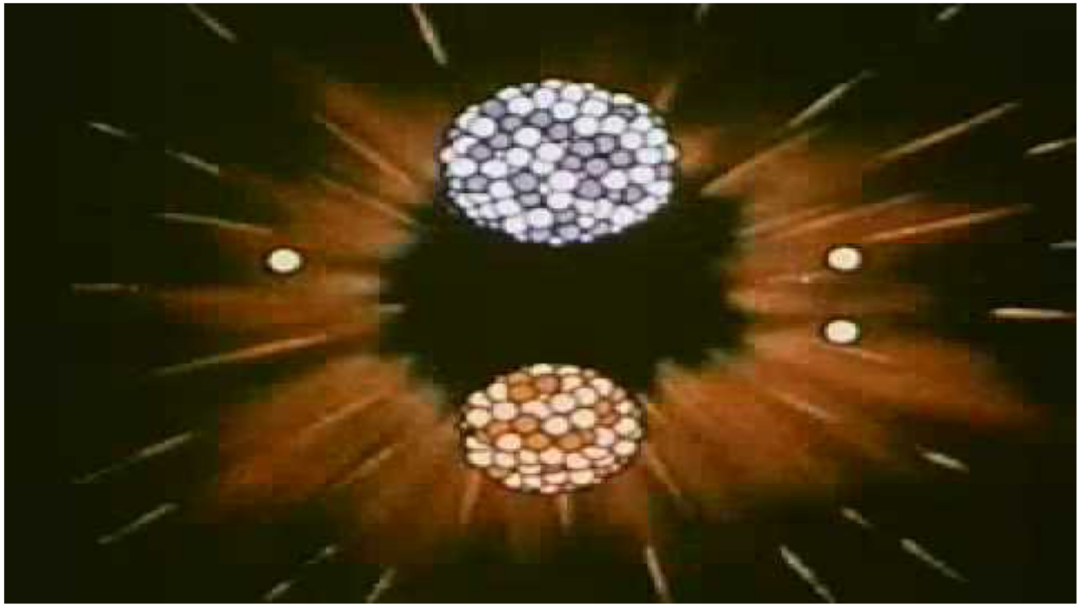
Discuss your observations.

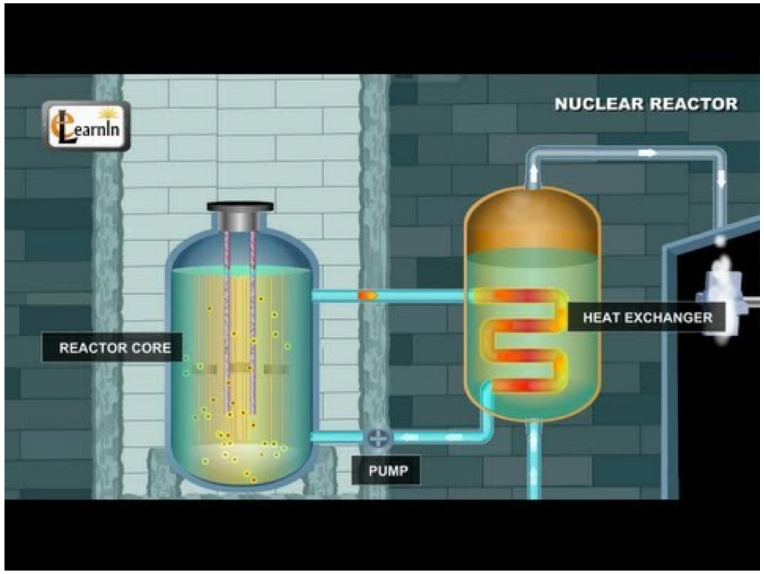
Do you agree with the following statement?

"Energy and mass aren't conserved individually during nuclear reactions. However, if we use $E=mc^2$ then mass-energy is conserved".

Conclusions and evaluation

Check the video on the right that shows the physics behind the atomic bomb (chain reaction)

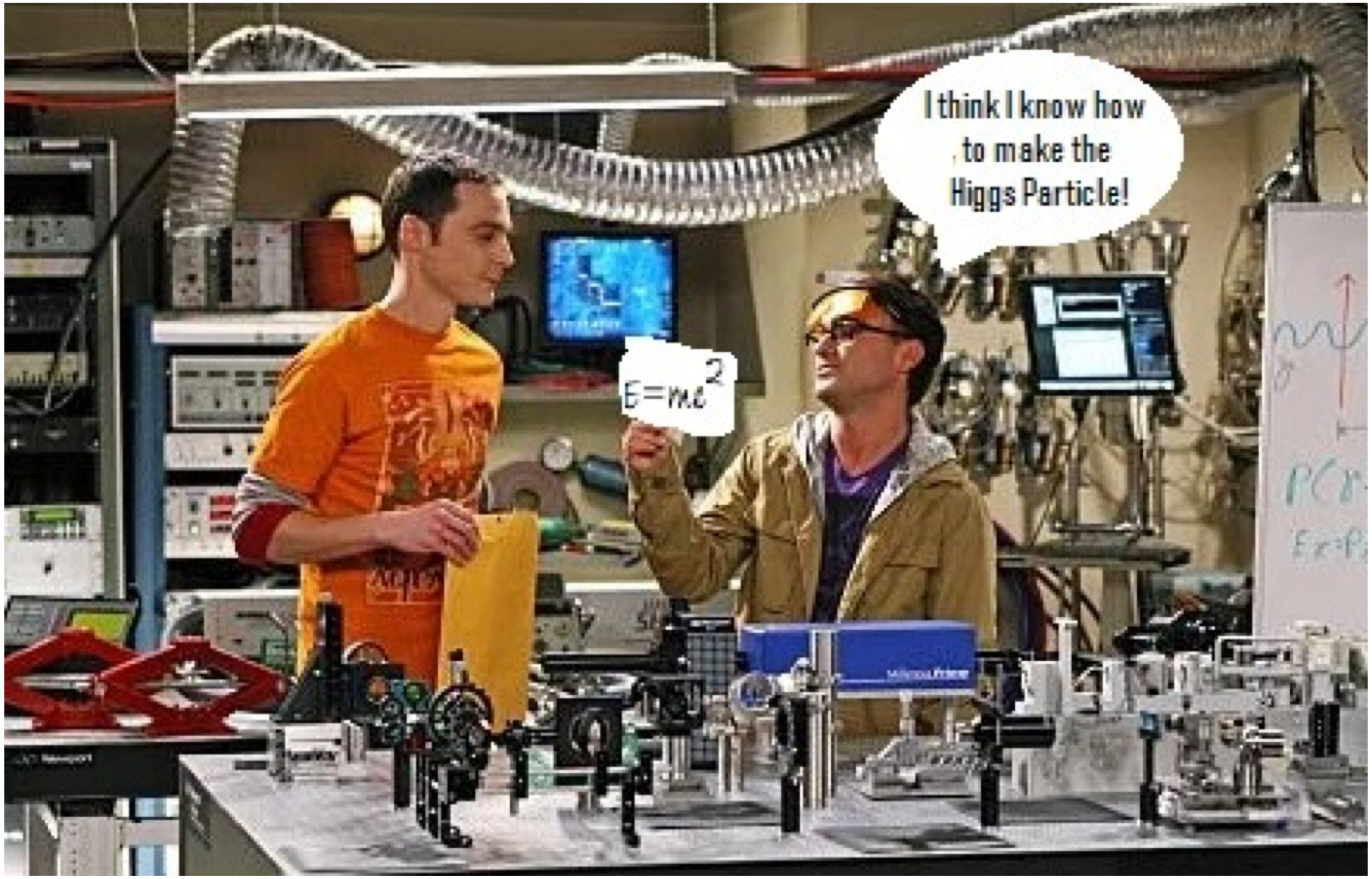




The video on the left outlines how a nuclear reactor works. Watch the video and contemplate on what may go wrong and have a disaster like the one in Chernobyl. Discuss it with your classmates.

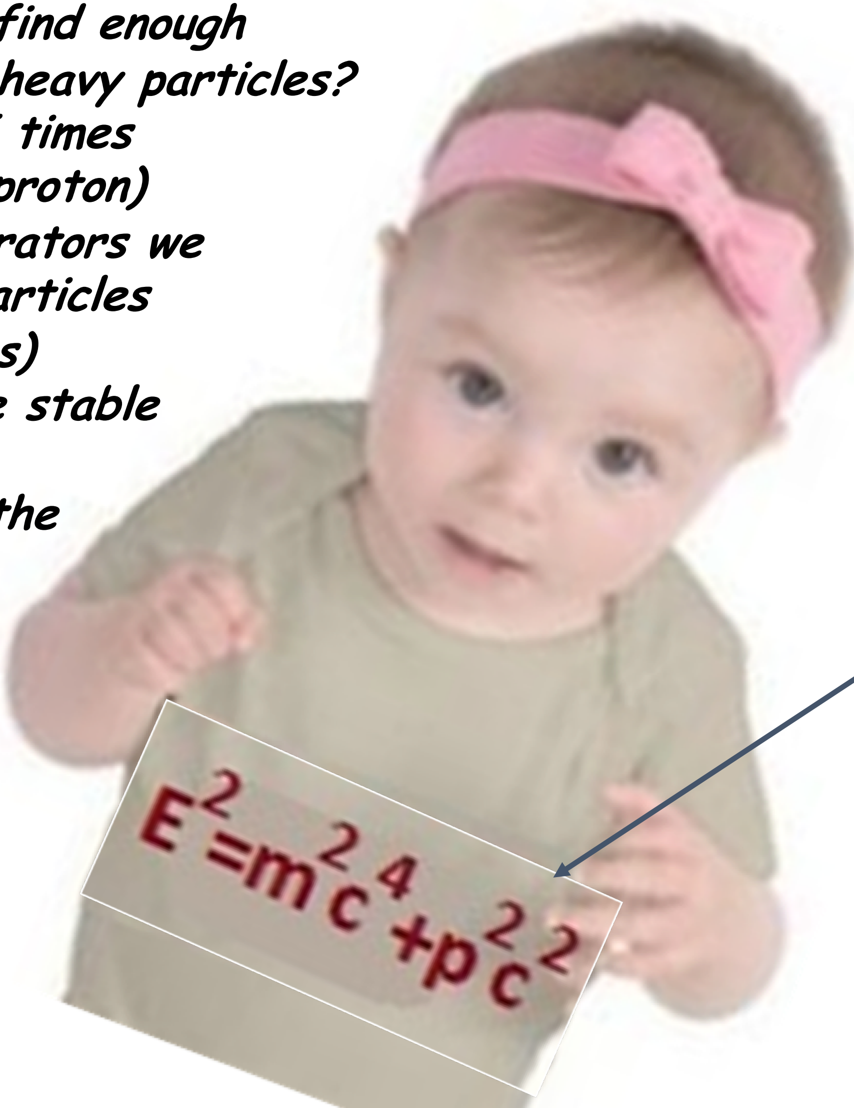
Discovery of new particles in accelerators (CERN Fermilab etc)

Can we use the mass-energy equivalence to create heavy particles from lighter ones?



From the TV series "The big bang theory" in
https://bigbangtheory.fandom.com/wiki/The_Irish_Pub_Formulation
The caption and the equation on the paper are humoristic insertions.

So, where do we find enough Energy to create heavy particles? (The Higgs is 125 times heavier than the proton) In particle accelerators we start with light particles (protons, electrons) because these are stable and we can find them easily. But the energy due to their mass only, is small.



The full mass-energy equivalence has a term p (momentum) that depends also on the velocity and increases as particles move faster

Question: Can you imagine now how we can increase the available energy if we start with particles with small masses?

In accelerators, particles with small masses get accelerated to very high speeds so they acquire very high energy. This very high energy can be transformed into heavier particles with lower speeds. So, from two protons (which at rest have mass (with equivalent energy) = 1 GeV we can produce the Higgs particle which has mass (energy equivalent) =125 GeV

Find information in the [Cern official site] and write a one-page report on the LHC accelerator at CERN

Thank you for your attention !

links

https://en.wikipedia.org/wiki/Chernobyl_disaster

https://home.cern/