Exponential decay law

THE AUTHOR

Beata Jarosievitz is Scientix Ambassador for Hungary. She teaches physics and informatics at SEK Budapest International School. Beside Scientix she has also experience in other European projects as SPICE or XPERIMANIA.

IN OTHER LANGUAGES

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The exponential decay law

Aim of the course

The aim of this course is to teach some of the fundamental properties of the radioactivity: the random behaviour, the exponential decay law, notions of half-life, decay constant and activity.

Introduction

Many atomic nuclei emit a particle without any external effect and transform themselves into another nucleus. These nuclei are radioactive, and the process is called radioactive decay. The emitted particles form the radioactive radiation.

The radioactive decay is a random, statistical process. Since the radioactive decay is a random process, it is impossible to predict the time when an individual nucleus of the radioactive material will decay.

However, in a macroscopic material containing a large number of nuclei the average time when the radioactivity of the material decreases to the half of its initial value can be determined. The decay probability of a nucleus is independent of the time since the nucleus already exists.

The transition (decay) process is characterised by the half-life. This is the time during which half of the initially existing nuclei decay.

Topic 1

ADMINISTRATION

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SEARCH FORUMS

Step1

Start with the review the fundamentals of the theory of probability. Use the following **multiple-choice questions (quiz).** 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

- Explaining the quiz please draw the attention of the students to the fact that the probability is determined by the ratio of the numbers of "good cases" and of all events.
- The number of "good cases" depends also on the fact whether the coins can be distinguished or not.
- The last question helps to understand that the probability is independent of the previous "life".

Topic 2

Step2.

Play the following statistical game with your students, already divided in small groups of 3-5 students/each group. Try to model the behaviour of the decaying nuclei.

Necessary tools:

- 30 similar coins, these are modeling the radioactive nuclei

- Squared paper for graphical representation of the results

Go

Advanced search

RECENT ACTIVITY

Activity since Sunday, 7 August 2016, 10:13 PM

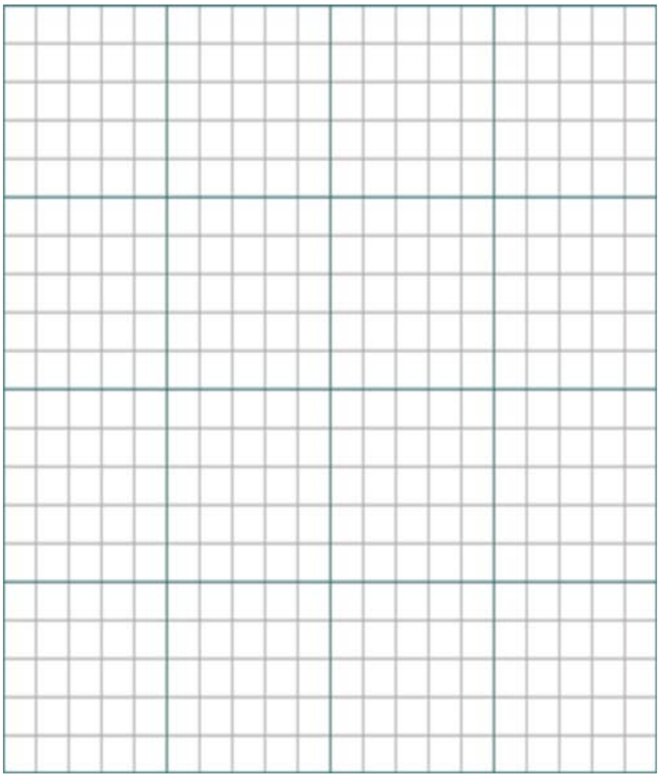
Full report of recent activity...

No recent activity

MESSAGES

No messages waiting

Messages

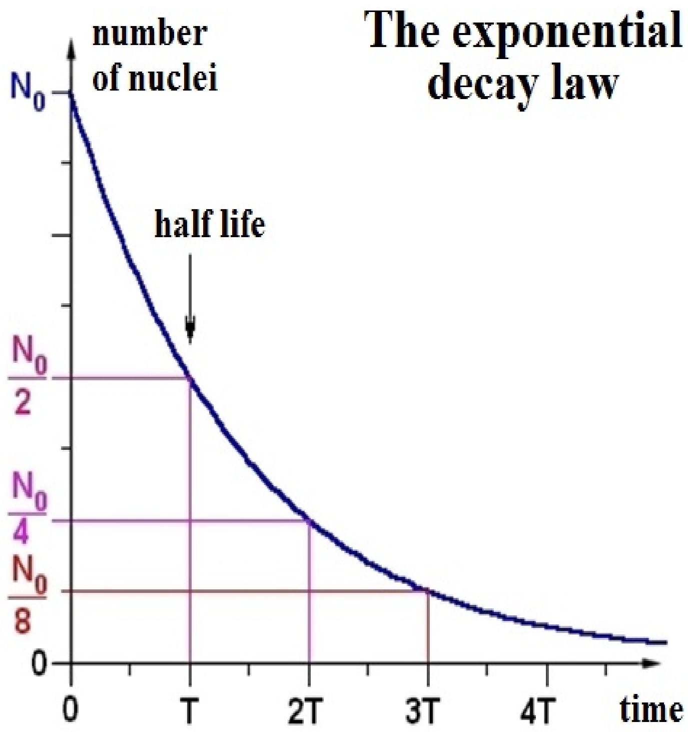


Task for your students

Each group should follow the instructions bellow:

- Step a: Toss the coins.
- Step b: Select the coins with heads and put them away. These are modeling the decayed nuclei.
- Step c: Count the coins remaining on the table, and note the result in a table like this. The previous 3 steps should be repeated until no more coins remain.
- Step d: Plot the number of the coins in function of the steps. (x –axis: number of steps, y-axis: number of coins)

If the result is plotted well, you get a curve similar see below.



Topic 3

Step3

Ask your student and discuss!

Questions (feedback)

1. How is the half-life of the nuclei modeled?
2. After one toss do we get always the half of the coins?
3. Why we get only similar graphs to the simulation and not exactly the same?

Topic 4

Step4

Explain to your students!

Simulation of radioactive decay

The decay of radioactive materials is a random process. The probability that a nucleus decays in a unit of time (e.g. 1 s) is called **decay constant.**

Usually the decay constant is denoted by:

λ

Its unit (in SI system): 1/s.

In the simulation bellow 200 nuclei are decaying with the given probability.

The radioactive nuclei are represented by **blue circles**, the decay products are the **red circles**.

For one particular nucleus we cannot predict when it will decay, but for a large number of nuclei we can make more or less precise predictions.

The more nuclei we have, the better is the expected value approached by the number of the actual remaining nuclei.

The expected number *N(t)* of the remaining nuclei can be calculated in function of time by the following mathematical expression:

$$N(t) = N_0 \cdot \left(\frac{1}{2}\right)^{t/T} = N_0 \cdot 2^{-\frac{t}{T}}.$$

Here t is the time, N_0 is the number of the radioactive nuclei at the beginning ($t=0$), and T is the half-life.

Simulation of radioactive decay (© Cs. Sükösd)

Simulation in full screen

The aim of the simulation exercise

- To explain the decay of radioactive materials.
- To demonstrate the fundamental idea of the age determination, based on the ratio of the daughter and parent atoms

Topic 5

Step 5

Motivate your students to perform the following tasks in pairs .

Exercise 1.

Use the previos interactive simulation of radioactive decay.

- Enter 0.5 for the decay constant (decay probability).
- Run the simulation in single step mode.
- Note the number of the remaining nuclei N, after each step in a table similar to this.

t	1	2	3	4	5	6	7	8	9
A									
B									
C									
D									
E									

- Repeat the experiment 5 times (A, B, C, D, E)!

Questions

1.What is the expected value of the remaining nuclei after 1, 2, 3, 4, 5 time steps?
2.Why did not you get exactly these values?
3.Determine the interval containing your simulation results for each time step! Express the interval of your results in X +/- Y form (e.g. [7,13] interval is expressed as 10 +/- 3)

Answer

1. Since the expected number of the coins halves after each throw, the half-life of the nuclei is modelled by the time between the throws.

2. Since the decay is a statistical phenomenon, therefore deviations may occur from the expected values. Only for very large numbers approach the "actual" values closely enough the "expected" values. 200 (the number of coins) is not "large enough".

Topic 6

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 and to the 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.

Decay constant

The decay of radioactive materials is a random process. The probability that a particular nucleus will decay in a unit of time (e.g. 1 s) is called decay constant.

The decay constant is usually denoted by :
λ
The unit of the decay constant is (in SI units): 1/s.

Small value of the decay constant results in slow decay, large value of the decay constant results in fast decay.

If the decay constant is known, the activity of the material can be determined by the expression:

$$A = N \cdot \lambda$$

Here A represents the activity of the material (number of decays in a unit of time), N is the number of the radioactive nuclei in the sample.

The decay constant is also related to the half-life:

$$T = \frac{\ln 2}{\lambda} = \frac{0{,}693}{\lambda}$$

T is the half-life of the sample.

Half-life

The amount of time necessary for the half of a parent isotope to turn into its daughter isotope is called half-life.

The expected number of nuclei *N(t)* in function of time (*t*) can be calculated by the following mathematical expression.

$$N(t) = N_0 \cdot \left(\frac{1}{2}\right)^{t/T} = N_0 \cdot 2^{-\frac{t}{T}}.$$

Here *t* denotes the time, N_0 is the number of nuclei at the beginning (*t=0*) and *T* is the half-life.

The half-life is characteristic of the isotope. The half-life of the different radioactive materials can range from several billion years to billionth of a seconds.

The probability that a particular nucleus decays during *T* time (*T* is the half-life) is exactly *1/2.* The decay probability during the next *T* time period is again *1/2*, and it is independent since how long the particular nucleus is “waiting” already for the decay.

Topic 7

Useful links

http://sukjaro.eu/SCsaba/DecaySeries/DecaySeries.htm
http://www.walter-fendt.de/ph14e/decayseries.htm
http://www.walter-fendt.de/ph14e/lawdecay.htm
http://www.sikh-history.com/education/physics/rad.html

Topic 8

Forum

Exponential decay law

Topic 9

Evaluate this course