US-China Education Review B 5 (2011) 678-687
Earlier title: US-China Education Review, ISSN 1548-6613

How to Stimulate Students' Interest in Nuclear Physics?

Stefania Elbanowska-Ciemuchowska, Magdalena Anna Giembicka
University of Warsaw, Warsaw, Poland

Teaching nuclear physics in secondary schools offers us a unique possibility to increase our students' awareness of the influence that modern science and its achievements have on the everyday life of contemporary people. Students gain an opportunity to learn in what ways the outcome of laboratory research is put to use in such fields as medicine, technology, food conservation and the power industry. At the same time, it is a difficult subject to teach as the physics behind it and the mathematical apparatus required to describe it are very advanced. This part of school curriculum demands abstract thinking and frequently exceeds the students' cognitive powers. In this paper, we will present some teaching techniques which, while being suitable for teaching nuclear physics in secondary schools, stimulate the students' interests and engage them in the learning process. While considering traditional methods of teaching physics, which comprise lectures, problem-solving and experiments, as fundamental and thus not to be neglected, we proposed to improve the teaching process by using such techniques as discussions, students' projects, portfolios, didactic games and excursions.

Keywords: nuclear physics, radiation, teaching methods, active methods, student activity

Introduction

The Polish secondary school curriculum includes an introduction to nuclear physics. The importance of this subject ought not to be underestimated, as it provides students with the knowledge required to formulate their own unbiased opinions on both the threats and advantages brought by the use of radioactive materials. This, in turn, will help them to lead their future lives as conscious citizens. Moreover, teachers ought to keep in mind that the issue of radioactivity can soon become a controversial one in our country, as plans to build a nuclear plant in Żarnowiec are being resurrected.

Additionally, Poland is celebrating the centenary of Marie Curie receiving her second Nobel Prize in 2011. This anniversary and the events it will entail can spur the students' interests and create many favorable occasions to discuss nuclear physics with them.

Of course, teaching nuclear physics in a secondary school is not an easy task. It is a highly advanced branch of physics, employing a sophisticated mathematical apparatus. To fully describe even such an apparently straightforward phenomenon as the radioactive decay, we need to introduce the exponent and at least some elements of the stochastic calculus. All this, coupled with the scarcity of time at our disposal, means that when talking about nuclear physics, we are frequently compelled to confine ourselves to giving a general description of the processes in question, without recurring to the use of equations and problem-solving, which are a firm anchorage for many students. Coupled with the fact that the subject requires abstract thinking on the

Stefania Elbanowska-Ciemuchowska, Ph.D., Division of Physics Education, Faculty of Physics, University of Warsaw.
Magdalena Anna Giembicka, Division of Physics Education, Faculty of Physics, University of Warsaw.

students' part, this means that this section of knowledge frequently proves too difficult for them to master and their interests tend to stray.

Hence, we present a series of teaching methods that can help to make students interested in nuclear physics and actively involve them in the learning process. For each method, we propose concrete activities (Giembicka, 2009) to be used depending on the occasion and current needs. The activities we proposed can be used either in regular classes or to enliven a meeting of the physics circle. Some can involve the class as a whole or divided into groups, in other cases, one student or a group of students can act as experts taking part in a panel discussion or preparing a presentation for their peers.

We proposed to apply the following techniques in teaching nuclear physics in schools: experiments, discussions, projects, portfolios, didactic games and excursions.

Experiments

Experiments have always been an inseparable part of science and one of the most effective ways of acquiring first hand knowledge. Of course, this is true provided that students can take an active part. Depending on the type of school, number of students in class and available equipment, arrangements necessary for students to perform an experiment can pose considerable difficulties. Nevertheless, facing this challenge is well worthwhile, as the benefits are manifold. In the didactics of physics, experiments are a tool to teach self-discipline, organize one's work and take responsibility for it. They stimulate the students' powers of observation and inference.

Contrary to common belief, some interesting experiments on radiation can be conducted in a school class. These include:

(1) Measuring the characteristics of a Geiger-Müller counter;

(2) Comparing the intensity of background radiation outside and inside a building as well as in a well- and badly- ventilated room;

(3) Comparing the quantity of radon in the air in different parts of a building.

We shall describe the last of these experiments in more detail.

Comparing the Quantity of Radon in the Air in Different Parts of a Building

(Experiment taken from the Physics Laboratory course of the Faculty of Physics, University of Warsaw)

In this experiment, we count the number of α particles from the radioactive decay of radon and its products, a part of a decay chain of uranium -238: $^{222}\text{Ra} \rightarrow {}^{218}\text{Po} \rightarrow {}^{214}\text{Pb}$.

Its didactic aims include:

(1) Making students acquainted with the operating principle of a scintillation counter;

(2) Comparing the quantity of radon and the products of its decay in different locations in a building.

Experiment set-up. The experiment set-up is shown in Figure 1.

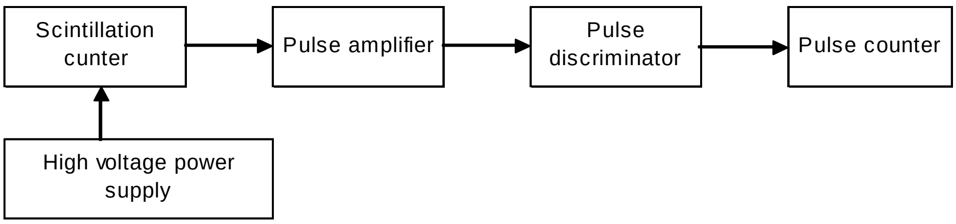

Figure 1. Experiment set-up.

Additional equipment. To carry out the experiment, we also need a vacuum cleaner, filter, stopwatch and computer software permitting to plot diagrams and to fit a trend line.

Procedure. The procedures are as follows:

(1) After setting the apparatus, adjust the working voltage so that the input from background radiation amounts to a few counts per minute;

(2) Put a fresh filter on the nozzle of the vacuum cleaner and operate the vacuum cleaner for three minutes. Aerosols from the air, including radioactive elements and decay products, will be stopped by the filter;

(3) Put the filter in the scintillation counter and register the readings of the pulse counter at minute intervals, starting six minutes after switching on the vacuum cleaner;

(4) Repeat procedure in different locations (laboratory, cellar in a basement, attic and open air);

(5) Draw your students' attention to the fact that the pulse registration must always start when the same number of minutes have elapsed since the onset of each operation;

(6) Use a computer to plot a diagram basing on the obtained measurements, remembering to adjust the registered numbers so as to eliminate the input from background radiation;

(7) Fit trend lines.

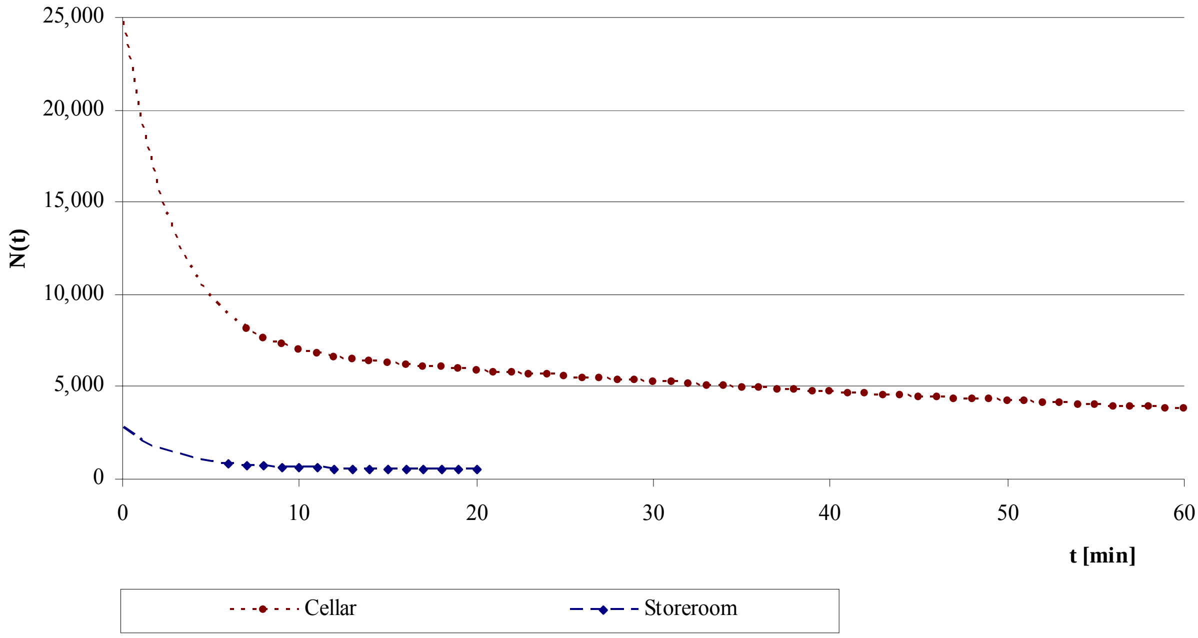

Figure 2. Comparison between the numbers of counts N(*t*) registered for the air taken from a cellar and from a storeroom in the building of Faculty of Physics, Warsaw.

Figure 2 presents the results of an experiment conducted by the authors in the building of Faculty of Physics of the Warsaw University (Giembicka, 2009). The air has been taken from a storeroom and a closed cellar in the basement. Registered number of counts (corrected for the presence of background radiation) has been plotted on the diagram and trend lines extended to the onset of each operation ($t = 0$).

Discussions

A discussion is an exchange of arguments by two or more parties having differing opinions. Its aim is to view an issue from every available standpoint and work out a compromise which is acceptable to all parties

(Okoń, 2007).

Taking part in a discussion requires a certain maturity on the part of the students, who have to gather enough information on a given subject to be able to formulate their own opinion and prepare arguments to support it. Participants are obliged to give their statements in a concise and coherent manner, respect their opponents and seek compromise. This type of activity is very useful when working with teenage students who have already mastered some of the art of logical thinking and, at the same time, feel a strong need to voice their opinions. Moreover, making a good appearance in a discussion can be a source of satisfaction for students and enhance their self-respects.

With multiple controversies pertaining to it, the subject of radioactivity is one well suited for discussions. Following is a list of issues which can be discussed during a physics class in a secondary school.

Topic 1: Radiation—The Threats It Poses and How to Defend Ourselves (Group of Experts)

This discussion could take the form of "questioning the expert". The class chooses a group of experts, each of whom is assigned a topic to research and one additional student, who is to prepare a short lecture on radiation. After the lecture is delivered, the discussion is opened to the public who will ask the experts pertaining questions. The discussion could include such topics as (Jaracz, 2001):

(1) Sources of radiation (natural and human-made), average annual doses and types of radiation;

(2) Biological effect of radiation (depending on exposure time, type and intensity of radiation and the organ in question);

(3) Ways of calculating the absorbed and equivalent dose, radiation absorbed in the course of medical diagnosis and therapy and background radiation;

(4) The possibility of being exposed to "remnants" of radiation used in food conservation;

(5) Radiation protection and types of shielding.

Topic 2: Should Poland Build a Nuclear Plant? (Decision Tree)

In this case, we propose the class to be divided into smaller groups. Within these, students can discuss the advantages and disadvantages of nuclear power versus other sources of energy, taking into account such aspects as cost, availability, reliability, environmental contamination, etc.. Groups draw their own decision trees, which are then compared and discussed by the class as a whole.

Topic 3: Nuclear Power as a Source of Future Prosperity (Debate for and Against)

The disputants are divided in two groups, one of which supports and the other is against the proposed motion. An exchange of arguments takes place justifying each standpoint, following which the discussion is passed to observers (i.e., the rest of the class) who put questions to the disputants. The debate ends with a final voting.

Topic 4: Energy Sources—Conventional, Renewable, or Nuclear? (Panel Discussion)

Members of the panel are assigned their roles and given time to gather information and prepare their arguments. The first phase of the discussion takes part among members of the panel, later it is passed to the audience who can put questions to the panel, comment on their statements and voice their own opinions.

Topics 2 to 4 are interchangeable. It is up to the teacher to choose the option best suited to their class, depending on the number of students, their knowledge and general maturity. The topic of these discussions is an interesting and controversial one and will in all probability arouse the students' interest. Since the knowledge required to take part in such a discussion does not strictly belong to the realm of school physics (i.e., one does not need to remember formulas and equations or to solve problems), every student in the class can become a participant.

Projects

The project method is an educational technique relying on the students' individual work. The aim of this method is to produce a tangible result, which in this case will take the form of a presentation on a topic related to nuclear physics. In the course of their work, students decide on the form the outcome of their research should take, on how to achieve the desired final effect and on how to organize their efforts. The teacher's role is limited to defining (frequently only in general terms) the topic of the project, offering help and encouragement in the process of its execution and later assessing the final result.

The project method supports the students' individuality and sense of self-dependency, at the same time teaching them to assume responsibility for their own work. In the case of larger projects, an ability to cooperate also becomes a prerequisite, coupled with the skill to coordinate the efforts of many individuals.

The fact that the final outcome, i.e., the presentation itself, is put on public display is also an important psychological factor. Winning the approval of one's peers can be a source of well-earned pride and enhance the student's self-respect.

There are a number of topics related to nuclear physics which can constitute a leading theme for a presentation as follows:

(1) Nuclear energy worldwide;

(2) Nuclear power—its history and future;

(3) Practical uses of radioactivity and radioactive isotopes;

(4) Biological effects of radiation;

(5) Nuclear arms;

(6) International Atomic Energy Agency and institutions overseeing nuclear safety in Poland;

(7) Uranium ore deposits in Poland.

The above list is a varied one with regard to the size of the potential outcome. Some of those projects would be better carried out by a group of students and others are well suited for individual work. Likewise, the form of the presentation can vary, depending on the theme and the authors. It can be a lecture prepared by one student or by the members of a physics circle, to be presented to class during lesson. It can also take the form of a series of short oral or multimedia presentation, a poster, or even an exhibition on nuclear physics.

Portfolio

In this method, students create their own portfolios on a given subject. Each portfolio contains all the relevant materials a student has managed to gather from different sources. The introduction to nuclear physics is a subject well suited for presentation in the form of a portfolio since:

(1) It constitutes an integral with rather limited contents, which means that even students who have not hitherto carried out projects by themselves will be able to control their work;

(2) Many interesting and controversial topics stem from it—This can encourage students to study the subject in more depth and formulate their own opinions which they can subsequently present in their portfolios;

(3) Many topics are perforce discussed in class in only a very general way, giving ample space for individual research, reflecting a student's ability to seek out information, their curiosity and concern about the

world around them;

(4) In Poland, this subject is usually taught in the last year of secondary school, in spring, when students are preoccupied with final exams and eager to start their holidays and designing a portfolio is more inspiring and creative than ordinary class work.

The contents of a portfolio evidence a student's commitment and the effort devoted to their work, therefore, being a good foundation for an assessment of their overall achievements. It is all the more valuable, since it permits the students to display skills which differ from those usually required in their physics class (seen by the students as consisting mainly of ability to memorize a certain amount of data and solve problems). In creating a portfolio, students get an opportunity to prove their diligence and inventiveness as well as an ability to present a piece of work executed with care, accuracy and aesthetic taste. In this way, students who are not perhaps scientifically gifted but conscientious and industrious obtain a chance to improve their marks.

A typical portfolio will contain:

(1) Basic information provided by the teacher during lessons;

(2) Reports on class excursions;

(3) Reports on own experiments;

(4) Results and inferences from discussions, didactic games and presentations given by other students;

(5) Information collected by the student from encyclopedias, books, the Internet, etc.;

(6) Student's own opinions on a number of issues, such as nuclear power and nuclear arms, multiple uses we have for radioactive isotopes, using carbon dating in scientific research, methods of protecting oneself from the effects of radiation and the lives and achievements of prominent scientist.

It is also important for the teacher to draw the students' attentions to the fact that a well designed portfolio ought always to contain a list of references and sources.

Didactic Games

Games are used in order to achieve predefined didactic aims, therefore, they are considered to be an instrument for teaching (Okoń, 2007). Didactic games are employed by teachers with the aim of putting the school discipline in abeyance and producing a more relaxed atmosphere among the students, thus increasing their activity. The elements of rivalry, existent in every game, also have a very stimulating effect, giving the students an opportunity to present their skills and knowledge and gain an advantage over their peers. By eliminating the tension in class, games create a friendlier environment in which those retiring and self-conscious students can achieve astonishingly good results. Additionally, didactic games are a useful tool for a teacher who desires to assess how well the students have understood a lesson. The easiest method of achieving this aim is to arrange a quiz. We would like to describe two other games designed by the authors with the aim of being used during a lesson on nuclear physics.

Time Line

A suitably enlarged timeline is placed in front of the class. The unmatched events (see Figure 3) are printed on cards which can be attached to the time line. By means of discussion, the students decide where to place each of these cards, thus, completing the diagram.

Decay Chains

In order to use this game in class, the teacher must prepare a suitable number of diagrams presenting the four decay chains in which some of the symbols and mass and atomic numbers have been removed (see Figure 4). The class is then divided in pairs and each pair is handed an incomplete diagram. The objective of the game is to fill in the blank spaces with appropriate symbols and numbers.

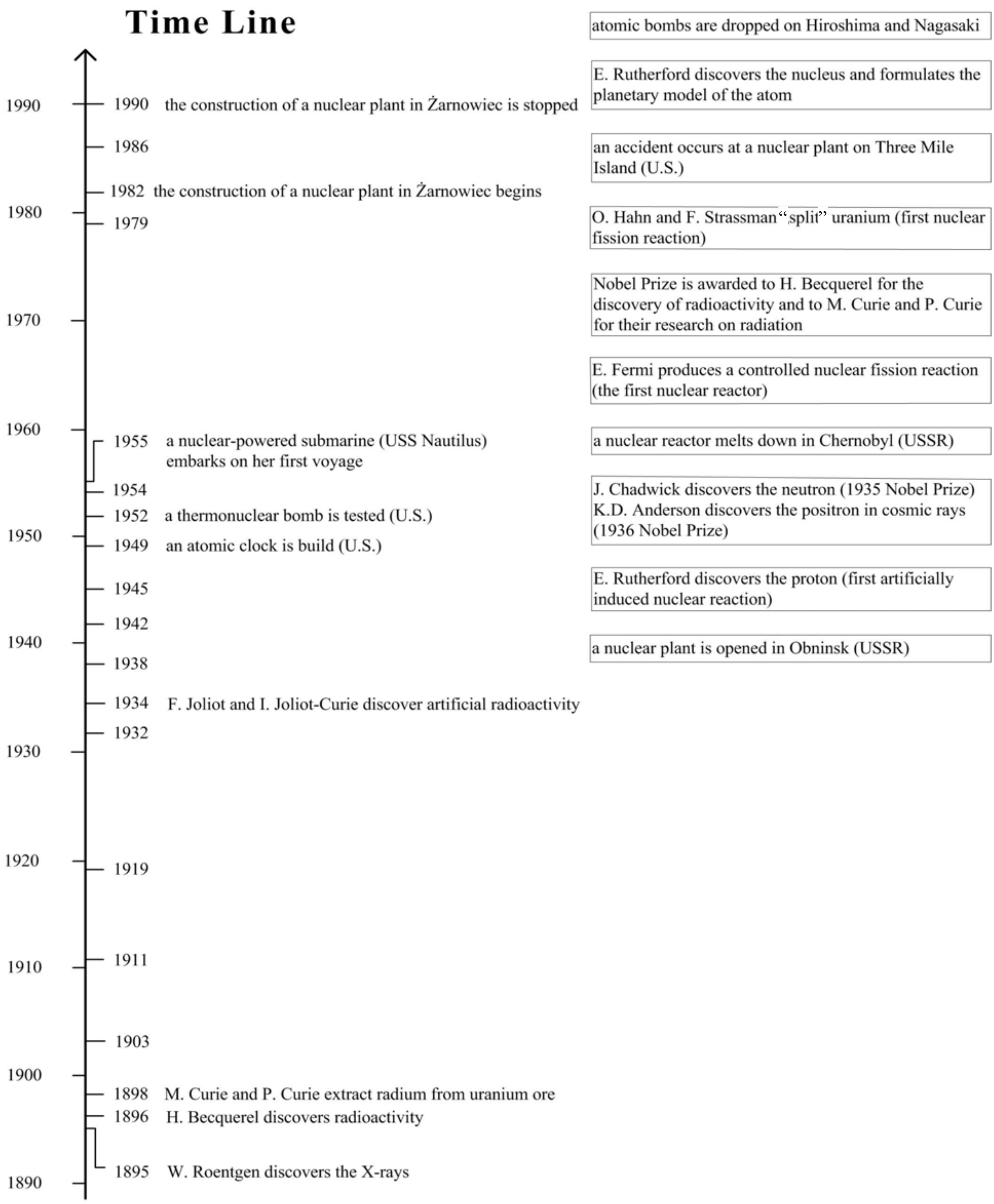

Figure 3. Time line diagram.

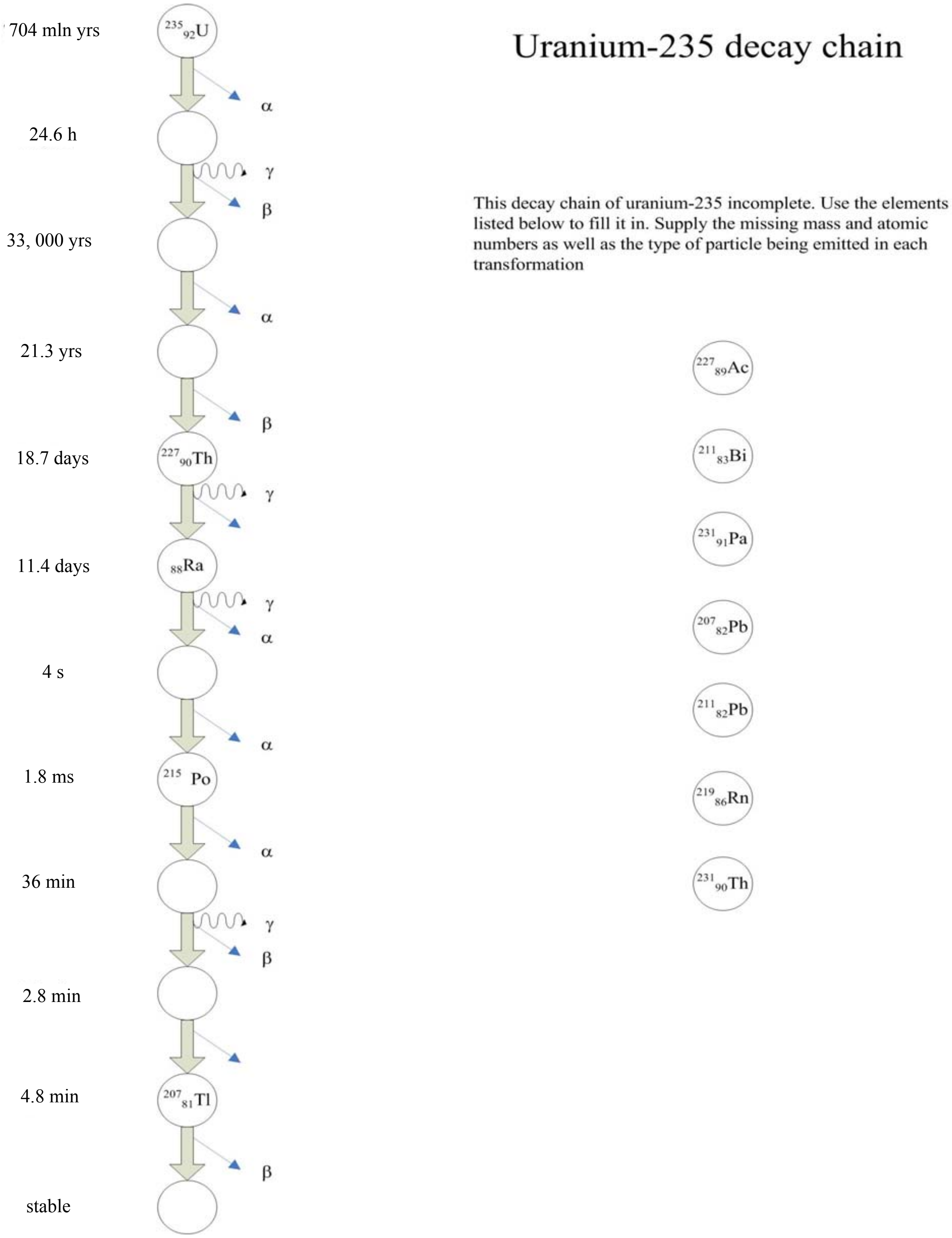

Figure 4. Diagram presenting the decay chain of uranium-235.

The decay chain diagrams can be also used to test the students' knowledge. In this case, each student receives a card on which a part of a decay chain has been printed (see Figure 5). The students' task is to supply the missing mass and atomic numbers as well as the symbols of emitted particles.

> A part of the decay chain of uranium-238 is presented below. Supply the missing numbers A and Z next to the symbols of the chemical elements. Fill in the spaces above the arrows with information on the type of decay.
>
> $${}^{234}_{90}Th \xrightarrow{\beta} \ldots Pa \xrightarrow{\ldots} {}^{234}_{92}U \xrightarrow{\ldots} {}^{230}_{90}Th \xrightarrow{\alpha} \ldots Ra$$

Figure 5. A card to be used in a class-test on radioactive decay.

Excursions

Apart from its recreational value, the advantage of an excursion is that it permits to acquire knowledge at first hand. The relaxing of school discipline can have a positive effect on the students' activities, encouraging them to express their opinions and ask questions (Okoń, 2007).

We propose three types of class outings to be taken into consideration when scheduling lessons on nuclear physics, which is as follows:

(1) A visit to an exhibition;

(2) A visit to a research institute;

(3) A longer field trip.

Exhibitions

A museum dedicated to the life of Marie Curie is located in Warsaw. Additionally to housing a permanent exhibition, it holds lectures and screens films, including those related to nuclear physics. Attending such an exhibition can help students understand that scientific discoveries are made by actual people, each with their own history.

Research Institutes

The Andrzej Sołtan Institute for Nuclear Physics in Świerk hosts school visits to its research nuclear reactor and holds special lectures on different topics, such as radioactivity, nuclear reactors and the use of radioactive materials in medicine, technology and in everyday life. Students can also visit the laboratories and become acquainted with the apparatus used in actual research. The Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences in Krakow and the Heavy Ion Laboratory of the University of Warsaw also hold lectures for students and stage visits to their laboratories.

According to the National Atomic Energy Agency, there are currently 11 institutions in Poland conducting research in the field of nuclear physics and producing radioactive materials for different purposes. Depending on the location of the school, a visit to one of them can be arranged as a short one-day event or as a part of a longer school trip.

Field Trips

It is not commonly known that there are uranium ore deposits in the Świętokrzystkie and Sudety Mountains in Poland. Uranium ore from these deposits was already used before the Second World War by German scientists in their research on radioactivity. Later, uranium ore was mined and processed for the needs of the Soviet atomic bomb project. A part of an old uranium mine in Kowary was also used as an inhalation site in radon therapy.

During a field trip to the location of an old uranium mine, students can gain knowledge on a number of different topics, such as geology and history of the region, ecology (both regions now house National Parks), history of the nuclear arms race, use of radium and radioactive elements in medicine both now and at the beginning of the 20th century.

Old mines in Kowary and Kletno are open to visitors, and in several other towns, it is possible to see the remnants of the now disused uranium mines, many of which have been operated since the Middle Ages, yielding gold, silver, sulphur and iron ores. The fact that some of those mines have for many centuries been considered "unlucky" by the local people can be the starting point for a discussion concerning the biological effects of radiation.

Conclusions

In this paper, we present some techniques which can be used while teaching nuclear physics in secondary schools, comprising experiments, discussions, projects, portfolios, didactic games and class excursions. Each of these methods has been presented by means of specific examples which can be incorporated in any actual schedule, complementing the more traditional forms of teaching. Examples were chosen to assure diversity, offering the teacher a wide range of choice. They can all be easily modified and adapted to the specific needs and circumstances of any school.

Implementing some of the methods presented above can bring manifold advantages both for the teacher and the students, as they:

(1) Permit the students to prove their imagination and inventive skills as well as diligence and thoroughness;

(2) Permit the students to voice and defend their own opinions;

(3) Make the school environment friendlier and more exciting by introducing elements of play and of rivalry among students;

(4) Enhance the students' commitment to individual study and acquiring knowledge.

These qualities are conducive to stimulating the students' interest and involvement in the learning process, both matters of crucial importance while teaching nuclear physics, a subject that is difficult both from the academic and the human point of view. The results of research in this field, as well as their practical implementation, have a profound influence on contemporary society, at the same time, being a source of continuing controversy. It is, therefore, of great importance for the school to provide its students with knowledge necessary to formulate measured opinions and be able to defend them. Using active teaching methods can help to achieve this aim.

References

Giembicka, M. A. (2009). Methods of teaching nuclear physics in high schools (Bachelor's Thesis, University of Warsaw).

Jaracz, P. (2001). *Ionizing radiation in human environment: Physics, radiological effects, society*. Warsaw: Wydawnictwa Uniwersytetu Warszawskiego.

Okoń, W. (2007). *New dictionary of pedagogy.* Warsaw: Wydawnictwo Akademickie "Żak".