LET'S BUILD PARTICLE PHYSICS!

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ABSTRACT

Particle physics is one of the fastest developing areas of science in the world. High schools do not have time to deal with this topic, so the students can get to study it after the regular lessons only. The students consider this topic too difficult. There are many unknown terms, they are hard to imagine, because particles are very-very small, they are invisible and their size is below 10^{-18} meters. I have developed a low-cost educational material on particle physics for teachers and students. It is easy to make and students can learn with them while playing with paper cubes.

INTRODUCTION

Having taught physics for several years at secondary level I realized that one of the areas of the subject that is very difficult for students to comprehend is particle physics. The main reason for this is that the sizes of the particles are below10^{-18} meters so they are very hard to imagine as they are invisible. Although particle physics in not yet part of the curriculum, I feel it is vital to deal with this topic as this is one of the fastest developing fields of science in the 21st century.

Students like doing experiments, but unfortunately, there are no good tools for explaining the particles. I have developed a tool and a method for this using paper cubes. My goal is to introduce the basics of particle physics with the help of an easily made and cheap instrument, to help to understand the structure of the small particles and their behaviour in different reactions. At the same time I want to help other teachers to deal with this topic.

THE TOOL

The basic set (Fig.1.) consists of

- 15 cubes of size 5x5 cm,
- 4 small cubes of size 2x2 cm,
- 2 large cubes of size 12x12 cm,
- 1 tetrahedron of 10 cm edge size and
- a lot of Styrofoam filling material.

The cube was chosen as it has six surfaces, and we know six kinds of quarks with antiquarks and six leptons with antileptons.

At present this programme is recommended to be implemented in extracurricular study circles as it is not part of the regular curriculum and unfortunately there is not enough time for this during regular classes. Preparing the cubes will take about two hours and understanding and effectively using it about five to six. As for the age group of the students: I have used the tool from the age of 13-14 upwards.

Fig.1. The basic set

PEDAGOGICAL ASPECTS

Students like playing and in my opinion we must teach them while playing, because as I see it, the motivation of the students to study natural sciences is very low. Numerous studies have shown that knowledge is best retained when students not only verbally or visually receive information but also have a chance to actively participate in the learning process. Besides it also meets the requirements of visual and kinaesthetic learners. So in this project the most important part is the „hands on, mind on" method. The teacher is not an authority figure but rather the facilitator in this process, so students feel they play an equally important role, thus become more motivated to learn. I experienced with my students that they were very open to this new method. During the work they also learn the basics of particle physics.

GETTING TO KNOW THE QUARKS

First students need to make quark and antiquark cubes. For that we need red, blue and green cardboard paper. The sides of the cubes will have the signs and charges of the quarks. While making the cubes the students will memorize the signs of the quarks and their unnatural charges. In the beginning the emphasis is on getting to know the quarks, but even at this stage we emphasize the three colours for the quarks and the complementary colours for the anti-quarks (Fig.2).

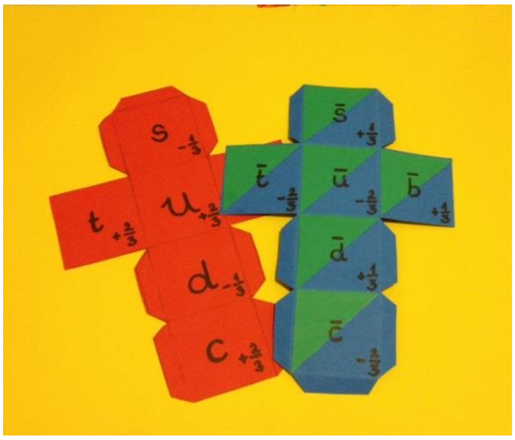

Fig.2. Quark and antiquark cubes

For example if one of them is red, the other cubes will have blue and green colours. This expresses quantum colour dynamics. In nature there is just white colour. The colour white consists of red, blue, green, or colour-anticolour pairs. Those particles which contain quarks are called hadrons. Inside the baryons there are three quarks, their colours are red, blue and green. Inside the mesons there is one quark and one antiquark, colour-anticolour pair.

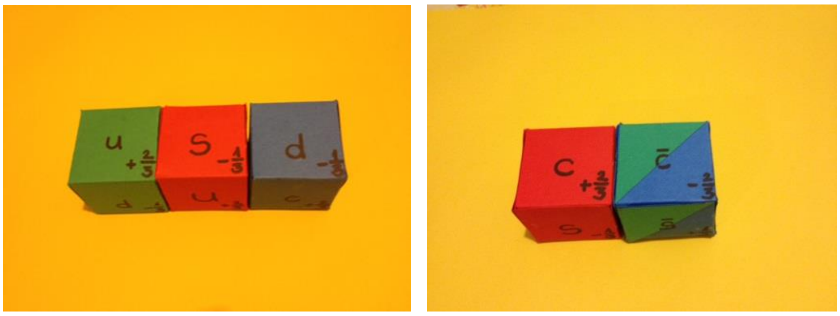

Fig.3. Left panel: baryon; Right panel: meson

The students make different hadronic particles, baryons and mesons (Fig.3.), and they write the signs and charges of quarks on the surfaces. So they can check the sum of the charges. In these examples they will learn expressions which are quite far from everyday life, and they can observe the systematics of particle physics.

THE STRUCTURE OF A PROTON

Unfortunately, in chemistry, while studying the atomic structure the students meet just the names of the electron, proton and neutron and most of the textbooks call all of them elementary particles. In order to fight this misconception I apply a very demonstrative method. In a large cube we place 3 quark cubes, a pair of quark+anti-quark cubes and many little coloured Styrofoam "worms" representing the gluons (Fig.4). This shows that the proton consists of three quarks, gluons, and sea quarks.

Fig.4. Composition of the proton

The electric charges of the nucleons, the protons and neutrons are generally known, but the cubes help students to understand how they are composed of the fractional charges of the quarks.

Fig.5. The charge of the proton

In this way it is easy to remember that the proton is a hadron, a baryon, because it contains three quarks, two up-quarks and one down-quark. The electric charge of the proton is plus one. The charges of quarks are 2/3 and minus 1/3 (Fig.5.).

ELEMENTARY QUANTUM NUMBERS OF THE QUARKS

The quarks are presented in the chart of Fig.6. There are the names, signs, charges and other parameters. Using that table the students can prepare their own quark cubes.

English name	Sign	Rest mass (GeV/c²)	Electric charge (e)
Up	***u***	0,0016-0,003	2/3
Down	***d***	0,0045-0,0051	-1/3
Charm	***c***	1,25-1,3	2/3
Strange	***s***	0,09-0,1	-1/3
Top	***t***	165-180	2/3
Bottom	***b***	4,15-4,21	-1/3

Fig.6. The chart of quarks

THE GLUONS

The gluons, the bosons mediating the strong interaction, carry two colours actually, but they are painted white here. While painting the gluons the students learn the basics of quantum chromodynamics. As they are painted white they should carry a colour and an anti-colour, although not necessarily of the same kind. The fact that of the 9 possible colour+anti-colour combinations allowed only 8 gluons exist belongs the group theory, well over the high school level.

FURTHER USES OF THE TOOL

Having learnt the basics, it is interesting to know what else the cube set can be used for. During my research work I regularly participate with a group of high school students in the development of gas-filled detectors for the detection of cosmic muons at the laboratory of the High Energy Physics Department of the Wigner Research Centre for Physics. During this work we study the various production reactions of those particles. There are detailed explanations in the literature, but in my experience the students cannot understand them. For a demonstration I developed the following method.

HADRONIZATION

Using quark cubes the process of hadronization can be well demonstrated. In Fig.7. you can see how the pions are generated. A proton collides with a nucleus, say, of an oxygen atom (as depicted by the quarks, gluons and sea quarks in Fig.7). During the collision one of the quarks is separated from the others and produces a gluon string. One of the gluons splits into a quark+anti-quark pair and the anti-quark creates a meson with the distant quarks. The pion, the lightest meson, is produced in the simplest picture this way.

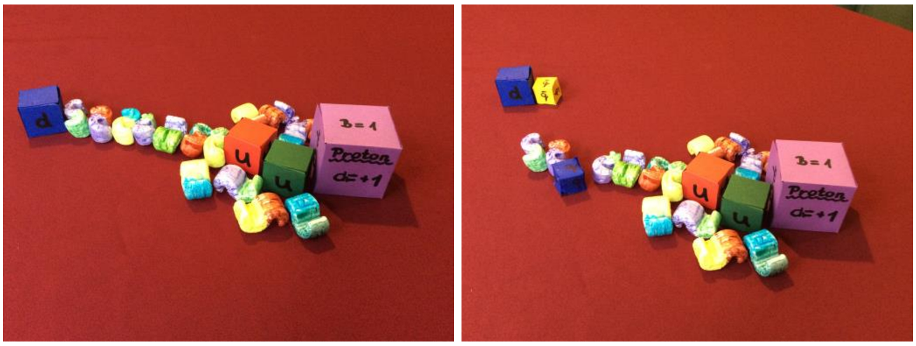

Fig.7. The creation of a meson

THE PROCESS OF BETA DECAY ON QUARK LEVEL

There is another field of particle physics the processes of which can be demonstrated using the cubes: the beta decay. Here the rotation of the cubes can be used when different properties are depicted on the different sides. Teachers teach beta decay in high school and the students use the reaction formulas, but they do not understand the essence of the process. Actually, in the beta decay the type of one quark is changed, the d-quark of the neutron becomes a u-quark. The d-quark decays into a u-quark plus a W^--boson and that in turn decays into an electron and an electron antineutrino [1-4] (Fig.8.)

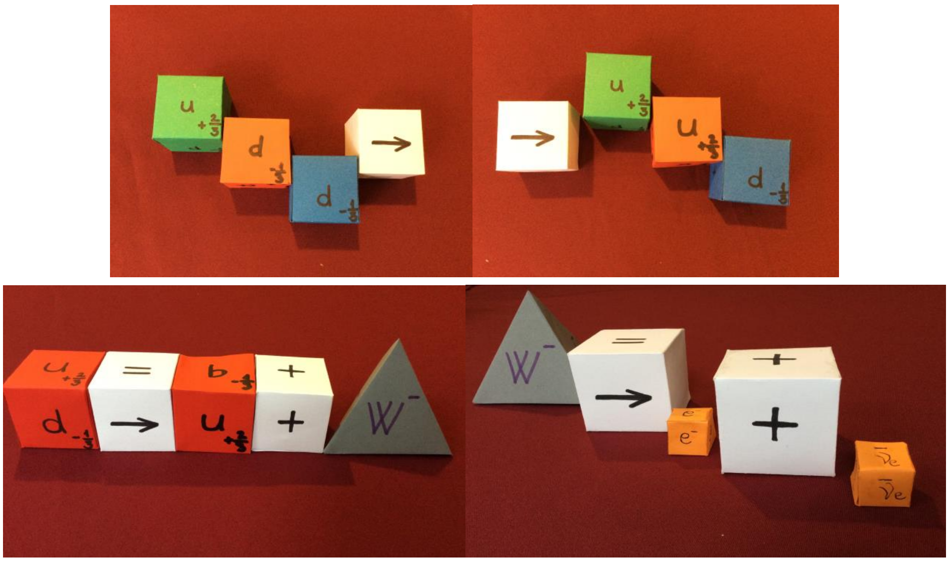

Fig.8. The process of beta-decay

DECAY OF THE NEUTRON

Using the cubes the students understand the beta decays. In this exercise every cube represents one particle with its conserving quantities on the sides; by turning the cubes the students themselves find out the kinds of beta decay. They have to apply the conservation laws. They check the conservation of charge, baryon number, lepton number etc. If they turn the cubes, they see different conservation laws. The sums standing on the left and right side of the equation are equal. In Fig.9. the neutron decay to proton, electron and electron anti-neutrino is presented. Under the names of the particles there are their electric charges. By comparing the sums on the two sides the students can think that the equality is fulfilled without the anti-neutrino cube. If now we rotate all cubes the same direction to see their baryon numbers (introduced by the teacher beforehand as +1 for baryons, -1 for anti-baryons and 0 for all others) which are also conserved without the anti-neutrino cube. However, with the next turn of the cubes the lepton numbers (to be also introduced) show up. As all leptons have a lepton number L = +1, while for anti-leptons L = -1, the antineutrinos are necessary to keep the conservation of lepton number. The other conserving quantities, like energy, are more complicated to account for, so they are shown on the cubes just for completeness.

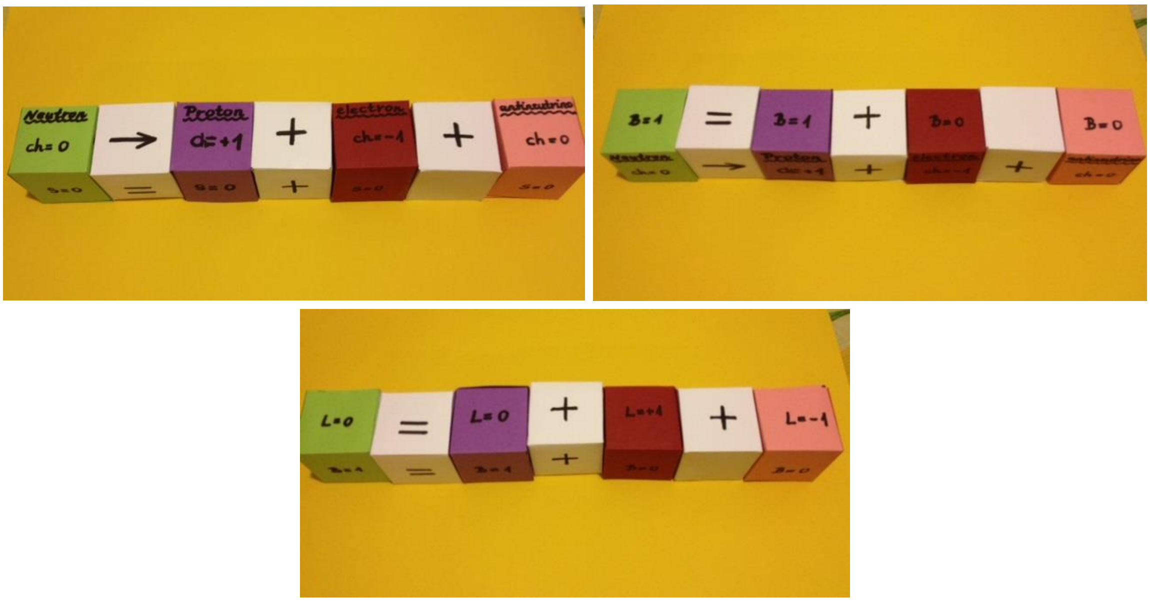

Fig.9. The decay of the neutron

The other two kinds of beta decay can also be demonstrated with the cubes, and the students will learn the essence of nuclear reactions while rotating the cubes. During this "discovery learning" with my students they also contributed to the project. It was their idea to add the Higgs boson with its decay modes to the set as the Nobel Prize was awarded for it in those days.

CONCLUSIONS

I experienced that students are very enthusiastic when they have to work on tools that will eventually help them discover the wonders and secrets of the micro world. While working, they get familiar with previously unknown terms and expressions, and through games understand the basic ideas of a very complex subject, particle physics. It was a great experience for me to do it together with the students as they contributed quite a few ideas to the project. I have made several presentations to fellow physics teachers with the cubes, giving methodical help to deal with modern physics in this unusual way and already in several school were similar cube sets made.

ACKNOWLEDGMENTS

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