Additional materials for task 10.

THE QUARKS

In 1964 American physicist M. Gell-Mann proposed a hypothesis that all particles capable of strong (intranuclear) interaction (*hadrons*) are not truly elementary, but consist of several subelementary particles. He named these particles quarks. This hypothesis allowed to describe all the variety of hadrons known at that time and also explained many of their properties.

The main feature of quarks is that they can't leave the particle they make a part of. Therefore they can't be observed separately (in a free state). Only the particles consisting of quarks can be observed but not the quarks themselves. This phenomenon is called *confinement*. Some physicists consider it to be a postulate of quark theory (see below); the others think it has a theoretical explanation. But nobody had succeeded in this explanation yet.

The original version of Gell-Mann theory stated that there are only three different "sorts" of quarks (they are called flavours). But later, when new particles with very unusual properties were discovered, three new flavours had to be added to the theory. Since we are not going to consider these particles we will talk only about the first three ("Hell-Mann") quarks.

There is a list of the main points of the quark model:

1. **a.** Quarks belong to three different "flavours", called: **u**-quark (up), **d**-quark (down) and **s**–quark (strange).

   b. Quarks of the same flavour have same masses and electrical charges.

   c. Any quark can be one of three "colours": **r** (red), **g** (green) and **b** (blue).

   Therefore a flavor, an electrical charge and mass are the inherent features, while a color may be various.

2. For any quark there is an antiquark which:

   a. Has a corresponding "antiflavour": $\overline{\mathbf{u}}$, $\overline{\mathbf{d}}$ or $\overline{\mathbf{s}}$.

   b. Has an electrical charge of equal module but opposite sign.

   c. Can be one of three complementary colours. Complementary color for red **c** (cyan), for green — **m** (magenta), for blue — **y** (yellow).

3. **a.** The color of a composite particle appears to be a "sum" of its parts' colors following the rule of visual perception: a sum of any two colours is a complementary color to the third one: $\mathbf{rg} = \mathbf{y}$, $\mathbf{rb} = \mathbf{m}$, $\mathbf{gb} = \mathbf{c}$. A sum of a color and its complementary gives (**w**, white) color:
   $\mathbf{rc} = \mathbf{gm} = \mathbf{by} = \mathbf{rgb} = \mathbf{w}$.

   b. The color of any observable particle is — **w** (white).

   It means, in particular, quarks can be observed only in different combination with each other but not separately. Any *baryon* (a particle consisting of three quarks like proton and neutron) has to consist of quarks of different colours to make a particle white. The same way *meson* (a particle consisting of two quarks) has to include quark and antiquark of complementary colours.

   c. An electrical charge of composite particle is a sum of quark charges.

To learn more about quark theory, its theoretical and experimental basis and other amazing chapters of particle physics read:

Okun Lev «$\alpha\ \beta\ \gamma$ … Z. An elementary introduction to the quark theory". "Kvant" library, edition 45.

Don't forget to **sign** your work (please, write the card number, your last name, school and grade) before **submitting** the work. You do not have to submit the sheet with the tasks. The tasks, their solutions and the results of the competition will be published at *http://turlom.olimpiada.ru* after November 20.