Physics Competition

For each problem the recommended grades are specified in the parentheses (a student is allowed to solve the problems for older grades; if a student solves a problem intended for younger grades, the solution will be ignored)

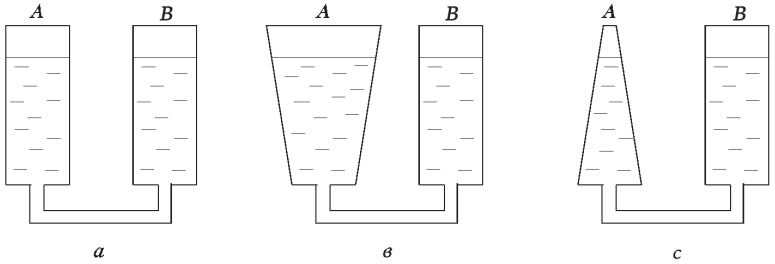
1. *(5–7)* A lollipop is transparent, and different objects can be seen through it. While granulated sugar is a white opaque powder, and the bottom of the sugar-bowl can not be seen through it. Why? *(5 points)*

2. *(5–8)* A housewife should add to the dish 0,1 g of chili pepper (this spice is a fine powder). Her kitchen scales allow to weigh an object heavier than 10 g with an accuracy of 1 g (lighter objects can't be weighed, the mechanism doesn't react). How can she measure the right amount? She has various (other) item of kitchenware. *(5 points)*

3. *(5–9)* How many tracks are left behind the bicycle after a turn — one or two? Does the rear wheel follow the same track as the front? If not, where does the rear wheel pass — closer to the centre of the turn or further away? Explain. *(5 points)*

4. *(8–10)* There are three communicating vessels of different shapes (a, b, and c). Vessels are filled with a homogeneous liquid. Will the level in vessel B change if the liquid in vessel A is warmed up? If it changes, will it raise of fall? Give an answer in all three cases. The liquid in vessels expands when heated.

(7 points)



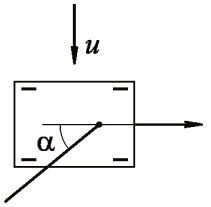
5. *(8–10)* Let's take very long metal tube and submerge in into the ocean (in the place where it is deep enough) so that the top of the tube protrudes slightly above the water. Then we will pump the water from the tube until it is filled with water from the deep layers. If we stop pumping and wait for a while — the water will begin to fountain by itself!

This experiment was conducted by American physicists in the Atlantic ocean several decades ago. The fountain was 60 cm high (the length of tube was 1000 m).

Why does the fountain appear? Will it exist forever? How long will it work if the ocean is isolated from all the influence except the gravitation of the Earth? *(7 points)*

Note. Close to the surface water is warm (due to the sun heating) and very salty (due to the evaporation). In the deep layers it's colder and less salty.

6. *(9–11)* An iceboat is a light platform with a sail set on runners (skate blades). It's able to slide on ice almost without friction. Suppose the sail is set at an angle α to the direction in which the iceboat moves. The wind is perpendicular to this direction, its velocity is u. What is the maximum velocity the iceboat can reach in this situation? *(7 points)*



7. *(10–11)* **A water rocket.**

This toy is a light plastic "rocket", empty inside and with a hole in the bottom. It's filled with water (not entirely), the hose of the air pump is tightly inserted in the hole. After this the rocket is placed vertically. Then the air is pumped into the rocket. After some time the pressure inside rises so much that the mounting of the hose cannot withstand the pressure and it is pushed out. The expanding air extrudes water from the hole in the rocket (the hole is playing a role of a nozzle) and the rocket blasts off.

Estimate the maximum height this rocket can reach. Assume its mass of 100 g, internal volume — 0,5 l. Water occupies the half of the volume. A reasonable estimate of the pressure inside before the start — 2 atm (2×10^5 Pa). *(10 points)*

8. *(10–11)* Read the text titled «Handling the electric locomotive». Answer the questions:

a) Define a as acceleration of locomotive at the beginning of stage 1. What is the acceleration in the beginning of stage 2? Stage 3?

b) Define v as steady velocity in the end of stage 1. What is the velocity in the end of stage 2? Stage 3?

c) The text claims that a real electric locomotive cannot be accelerated this way. Why? Which technical problem should be considered? What ideas can you offer to solve it?

The electric locomotive moves along the horizontal rails, all the resistant forces are negligible. The wheels of the locomotive roll on the rails without slipping. The voltage of contact network is approximately constant. *(12 points)*

9. *(10–11)*

a) A long vertical tube is submerged into an open swimming pool. Let's pump water in it using a piston, which is level with the surface of the

water. How high the piston can be lifted before the water starts to boil? Experiment is conducted at room temperature and the pressure of water vapour is negligible.

b) Capillary with an internal radius of $0,7\,\mu m$ is made of glass wettable by water. It's dipped into the open vessel with water. How high should the water rise according to the capillary formulas? Surface tension coefficient of water is $\rho = 0,07\ \mathrm{J/m^2}$, wetting is complete.

c) Compare answers to a) and b). How high actually will rise the water in this capillary? Explain your answer.

(12 points)

10. *(9–11)* Read the text titled «Expansion of the Universe». Do the tasks:

a) Using the astrophysical data provided in the text, estimate the age of our universe (considering that it expands with constant velocity). Provide the answer in years.

b) Using the same model find the dependence of Hubble constant on time.

c) Estimate how much the Hubble constant has changed since the discovery of Hubble's law (Georges Lemaître, 1927). In your opinion does the accuracy of modern astrophysical methods allow to detect such a change?

(12 points)

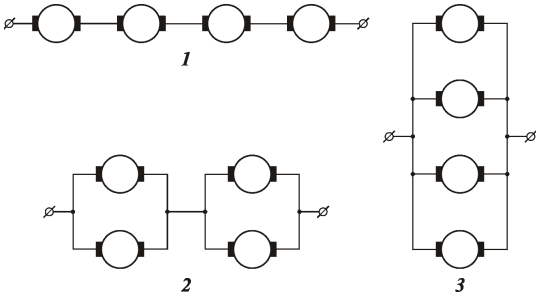
Supplementary materials for physics competition

Handling the electric locomotive

(Text for the task 8)

Electric locomotive usually has several traction electric engines (from four to eight). Each shaft is rigidly connected with driving wheels. Using a special switch (controller) the driver can connect engines with the supply voltage (contact network) in various ways – in series, parallel or in some other more complicated ways.

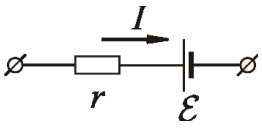
Let's consider, for example, a simple model and see such a locomotive is handled. Let us assume that there are 4 equal traction engines in our locomotive. The controller has 4 positions: 0 (all the engines are disconnected from the supply), 1, 2 and 3 in which the engines are connected as it is shown on the picture:



First, the locomotive is at rest, and then controller is switched to position 1. The locomotive begins to accelerate, with time its velocity grows slower and finally is ceases to increase at all. This is stage 1. After this, the driver switches the controller to position 2, the locomotive starts to accelerate again, and its velocity reaches new steady value (stage 2). And when controller is switched to position 3, yet another cycle of acceleration takes place (stage 3). (Remember that we are talking about a simplified electric locomotive — a real locomotive cannot be accelerated this way).

To understand what is happening it is very important to keep in mind the following. The principles of work of a constant voltage electric engine (not every one, but this specifically) can be described by this simple model:

a) An equivalent schematic of the electric engine (which determines its behaviour in an electric circuit) includes a resistor r (the resistance of engine's winding) and so-called counter EMF (electromotive force) E (it appears due to the electromagnetic induction in the windings of coil). If the engine works "normally" counter EMF always directed against the current. (*see the fig.*).



b) The value of counter EMF is proportional to the angular velocity of the engine's rotor, and is doesn't depend on the value of the current.

c) The momentum applied to the wheels is proportional to the value of the consumed electric current, and it doesn't depend on the angular velocity.

Using this model try to figure out how the processes in the described method of accelerating the electric locomotive

The expansion of the Universe

(Text for the task 9)

The movement of the galaxies is a well-known phenomenon to amateur astronomers. As observations show, galaxies that are stationary on the celestial sphere are moving away from us and each other in space. Furthermore, methods of astrophysics allow us to measure the velocity of that movement: for every pair of objects in the Universe this velocity is proportional to L — the distance between the objects: $v = HL$. objects in the Universe this velocity is proportional to L - the distance between the objects: v = HL. For this reason, such movement of the stars in our galaxy is practically unobservable - they are too close, so velocity is too small. It is only possible to notice the effect by observing other galaxies - they are far away from us, so the velocity becomes measurable. And the furthest galaxies, at the margins of observable Universe are moving away from us at the speeds approaching the speed of light! This notable rule is known in Astrophysics as *the Hubble's Law*, and the coefficient H is called *the Hubble constant*. It equals (according to the latest data) $H \approx 2,2 \cdot 10^{-18} c^{-1}$.

According to modern Cosmology, it is not the galaxies that move, but the points in our three-dimensional space. This statement sums the famous phenomenon of the expansion of the Universe. It can be understood with a simple analogy. Imagine that the galaxies are drawn on a rubber balloon. Its surface is a (two-dimensional) space where they exist. If someone starts to blow the balloon up, increasing its radius, how will the galaxies move? First of all, they don't move within the rubber, and the angle by with each pair of galaxies can be seen from the centre of the balloon will remain constant. But their rubber space stretches out and the length of the arc connecting this pair will increase! And the length of this arc is, as it can easily be understood, the distance between points in our model two-dimensional space. The relative speed of the point is indeed proportional to the distance between them (prove it yourself). Hubble's law works! Actually, the analogy is quite adequate despite the fact that our Universe is closer to *a three-dimensional* surface of *a four-dimensional* «baloon». It is *the space itself*, that changes, and the dependence of geometric parameters (curvature, for example) on time is governed by *the laws of general theory of relativity* (GTR).

Is the speed by which the radius of our 'spherical Universe' grows constant? This is a difficult question. The form of the aforementioned equations of GTR and, consequently, the law of the evolution of space can dramatically change with the properties of matter in the Universe. In the most naïve model the Universe expands with constant speed - due to inertia; in the next model the velocity depends on time according to the power law; while in the majority of models used this function is quite complex. In particular, the expansion of the Universe can accelerate (which corresponds with current data), slow down, or even, after some time, turn to contraction and collapse — «End of the World». The attempts to put the observed velocities in compliance with the available data on the properties of matter in space have led to the hypotheses of the existence of *dark matter* and *dark energy* in the Universe.

It is interesting that even the simplest of models predict «the Beginning of Times»: the all state that our space had evolved from a single point in finite time («Big Bang»). This time is nothing else than the age of the Universe in this particular model. It can be measured.

The idea is that the Hubble constant is constant versus the distance to a galaxy, however it is a function of time! If we assume a model law of evolution of space with time, than, using the Hubble constant acquired with astrophysical observations, we can estimate the age of the Universe.

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^{th}.