International Physics Olympiad
«Formula of Unity» / «The Third Millennium»
Year 2024/2025. Qualifying round

Problems for grade R8

The qualifying round is **an online-test** (in other words, **only answers** are required). The last day to send your answers is — **December, 7**.
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The number in square brackets (for example, **[3]**) indicates the number of the field in which the answer to this question should be entered. You must not enter dimensions in any answer.

8.1. (7 points) There are two steel cubes placed on each other at the bottom of the aquarium filled with water. Lengths of edges of cubes are $L_1 = 10$ cm and $L_2 = 5$ cm, depth of aquarium is H = 30 cm, density of steel is $\rho = 7900\ kg/m^3$, density of water is $\rho_0 = 1000\ kg/m^3$ Calculate the pressure force of the structure on the bottom of the aquarium when

[1] the first cube lies on the bottom

[2] the second cube lies on the bottom.

Comment. Assume that the acceleration of free fall is 9.8 m/s^2 (*Cherenkov A.A.*)

8.2. (6 points) Vadim experiments with communicating vessels, which have diameters of $D_1 = 15$ cm and $D_2 = 10$ cm. At first Vadim fills the vessels with water and measures the level of liquid in them. Then he puts a wooden cube of m = 500 g mass into the first vessel and measures the liquid level again. Then Vadim puts the cube into the second vessel and repeats the measurements. By how much will these measurements differ from the original level of water in the vessels

[3] in the first case,

[4] in the second case?

Comment. The density of water is $\rho = 1000\ kg/m^3$. (*Cherenkov A.A.*)

8.3. (6 points) Cold and warm water are separated by a partition in a calorimeter. The mass of cold water is $m_1 = 200$ g and its temperature is $t_1 = 3^o$ C. The warm water has a mass of $m_2 = 300$ g and its temperature is $t_2 = 10^o$ C. At some point, the partition is removed.

[5] By how many percent will the total volume occupied by the liquids change after the temperatures equalize?

Comment. Assume that the coefficient of thermal expansion is $\alpha = 0.0002\ K^{-1}$. The density of water under normal conditions is $\rho = 1000\ kg/m^3$. (*Cherenkov A.A.*)

8.4. (7 points) The engine of a Lada Vesta car has power of N = 90 horsepower and efficiency of $\eta = 25\%$.

[6] What is the minimum number of liters of petrol to be poured at a petrol station so that the car could drive s = 200 km with a constant speed of v = 72 km/h?

Comment. The density of petrol is $\rho = 0.76\ g/cm^3$, specific heat of combustion of petrol is q = $4.6 * 10^7\ J/kg$. Assume that one horsepower is equal to 735 W. (*Cherenkov A.A.*)

8.5. (5 points) The equilibrium of solids in liquids is studied in a school laboratory. The teacher took an empty cylindrical glass and carefully immersed it upwards with the bottom and released it. The glass occurred to be in the state of equilibrium.

[7] What is the volume of water poured into the glass?

Comment. The glass has height H = 15 cm, diameter D = 5 cm and mass m = 0.1 kg (*Cherenkov A.A.*)

8.6. (7 points) A hollow aluminum ball (outer radius is R = 10 cm, inner radius is r = 9 cm) floats on the surface of water.

[8] What is the maximum density of matter that can be filled inside the ball so that it still floats in the liquid?

Comment. Density of aluminum is $\rho_1 = 2700\ kg/m^3$, density of water is $\rho = 1000\ kg/m^3$.

(*Cherenkov A.A.*)

8.7. (7 points) During an extra physics lesson, pupils studied the phenomenon of heat balance by conducting experiments. They placed a piece of ice with a mass of m = 150 g at a temperature of $T_1 = -10^o$ C in a vessel with water, which has a total heat capacity of C = 1550 J/K and temperature of T = 25^o C.

[9] What will be the temperature in the vessel after the system comes to equilibrium?

Comment. Latent heat of fusion of ice is $\lambda = 0.33$ MJ/kg, its specific heat capacity is c = 2.1 $kJ/kg*$K.

(*Cherenkov A.A.*)

8.8. (6 points) In a school laboratory, experiments are carried out to demonstrate heat transfer between bodies. There is an aluminum cube heated to a certain temperature. This cube is placed on a piece of ice at a temperature of $t_2 = -20^o$ C.

[10] What must be the minimum temperature of the cube so that it could completely immerse in ice?

Comment. The specific heat capacity of aluminum is $c_1 = 836\ J/kg*$K, density is $\rho_1 = 2700\ kg/m^3$. Latent heat of fusion of ice is $\lambda = 0.33$ MJ/kg, its specific heat capacity is c = 2.1 $kJ/kg*$K and density is $\rho_2 = 920\ kg/m^3$.

(*Cherenkov A.A.*)

8.9. (5 points) At a children's camp the counsellors decided to teach the children how to build a small electric power station. To do this, they went to the Chernaya River, which forms a waterfall with a height of h = 2 m.

[11] The river flows at a speed of v = 3 m/s, and the cross-section of the stream is s = 3 m^2. How much power can this waterfall develop?

(*Cherenkov A.A.*)

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Problems for grade R9

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9.1. (6 points) During a practical physics lesson, pupils conduct experiments in a laboratory. They have a calorimeter in which there is a piece of ice with a mass of m = 150 g at temperature of t_0 = 0^o C , as well as a machine that supplies steam at temperature of t_1 = 100^o C into the calorimeter.

[1] What is the minimum mass of vapor to be injected into the calorimeter to obtain water at temperature t = 20^o C?

[2] What will be the mass of obtained water?

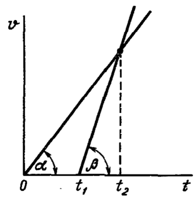
Comment. Latent heat of fusion of ice is λ = 0.33 MJ/kg, latent heat of vaporization of water is l = 2.26 MJ/kg, specific heat capacity of water is c = 4200 $J/kg * K$. Neglect heat capacity of the calorimeter. (*Cherenkov A.A.*)

9.2. (5 points) In a school laboratory, experiments are carried out to demonstrate heat transfer between bodies. There is an aluminum cube heated to a certain temperature. This cube is placed on a piece of ice at a temperature of $t_2 = -20^o$ C.

[3] What must be the minimum temperature of the cube so that it could completely immerse in ice?

Comment. The specific heat capacity of aluminum is c_1 = 836 $J/kg*$K, density is ρ_1 = 2700 kg/m^3. Latent heat of fusion of ice is λ = 0.33 MJ/kg, its specific heat capacity is c = 2.1 $kJ/kg*$K and density is ρ_2 = 920 kg/m^3. (*Cherenkov A.A.*)

9.3. (5 points) Two toy trains move along the same straight tracks, from the same initial position. Figure shows the graphs of velocities of the trains. It is known that t_1 = 5 s, t_2 = 10 s.



[4] At what moment of time t_3 will the trains meet?

(*Cherenkov A.A.*)

9.4. (6 points) Petya was gifted a radio-controlled car that can accelerate or decelerate with the same magnitude constant acceleration a = 10 m/s^2 and continues to move uniformly afterwards.

[5] Petya wants to find out what maximum velocity V the car must develop to get from one end of the room to the other in the shortest possible time, provided that it stops at the end of the journey.

Comment. The length of the room is L = 5 m. (*Cherenkov A.A.*)

9.5. (8 points) An air balloon descends to the Earth with a constant velocity of u = 2 m/s. At some moment of time a stone with initial velocity of v_0 = 10 m/s relative to the Earth is thrown vertically upwards from this balloon.

[6] What will be the distance L between the balloon and the stone, at the moment when the stone reaches the highest point relative to the Earth?

[7] What is the greatest distance L_{max} the stone will move away from the balloon?

[8] At what time T after the throw will the stone align with the balloon?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

9.6. (5 points) During a practical physics class Vanya was studying parallel and series connection of resistors. Unfortunately, he got a set in which two resistors had their nominal value erased. However, Vanya was not confused and connected them first in parallel and then in series to a battery with a voltage of 70 V. In the first case it turned out that the total current flowing was I_1 = 49 A, and in the second case - I_2 = 10 A.

[9] What are the resistances of the resistors?

Comment. Give your answers separated by semicolons, starting with the smallest.

(*Cherenkov A.A.*)

9.7. (6 points) A hollow aluminum ball (outer radius is R = 10cm, inner radius is r = 9cm) floats on the surface of water.

[10] What is the maximum density of matter that can be filled inside the ball so that it still floats in the liquid?

Comment. Density of aluminum is $\rho_1 = 2700\ kg/m^3$, density of water is $\rho = 1000\ kg/m^3$.

(*Cherenkov A.A.*)

9.8. (6 points) In a physics class at school electric circuits are studied. A resistor of R = 4 Ohm was connected to a source with internal resistance of r = 2 Ohm, having EMF of 10 V. Then a second resistor of the same value was connected. At first it was connected in parallel and then in series.

[11] Find the ratio of powers released on the first resistor in the first and second cases.

(*Cherenkov A.A.*)

9.9. (7 points) A straight piece of wire of 30 cm length (straight line segment AB) with specific resistance of $3 * 10^{-8}\ Ohm/m$ is divided by points C, D, E, F so that CD=DE=EF=FB, AC=2CD. Points C, D, E, F, B are connected to point A by segments of wires with different specific resistances so that their resistances are equal to the resistance of the section AC.

[12] Find the total resistance of the circuit between points A and B.

Comment. Give the answer in microOhms. (*Yakovlev A.B.*)

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Problems for grade R10

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10.1. (7 points) At the factory a test is carried out to check the gas flow sensor. It is known that methane flows through a gas pipeline with cross-section of S = 5 cm^2 at pressure of p = 7 atm and temperature of T = 15^o C.

[1] What speed of gas flow should the serviceable sensor display, if a mass of m = 15 kg of methane flows through the cross-section of the pipe in t = 10 min?

Comment. Assume that the molar mass of methane to be M = 16.04 g/mol. (*Cherenkov A.A.*)

10.2. (5 points) Two vessels of equal volume are filled with oxygen and connected by a tube. The whole system is at temperature of T = 17^o C. At some moment of time one of the vessels is heated to the temperature of T_1 = 27^o C, and the temperature of the second vessel is kept the same.

[2] In how many times will the pressure in the system change?

Comment. Neglect the volume of the tube. (*Cherenkov A.A.*)

10.3. (6 points) A straight piece of wire of 30 cm length (straight line segment AB) with specific resistance of $3 * 10^{-8}$ Ohm/m is divided by points C, D, E, F so that CD=DE=EF=FB, AC=2CD. Points C, D, E, F, B are connected to point A by segments of wires with different specific resistances so that their resistances are equal to the resistance of the section AC.

[3] Find the total resistance of the circuit between points A and B.

Comment. Give the answer in microOhms (*Yakovlev A.B.*)

10.4. (7 points) Pavel conducts an experiment where he drops two identical balls from a height of H = 15 m with no initial velocity, measuring their speeds at the end of the fall and the times taken. One ball hits a platform at a height of h = 10 m, inclined at an angle of α = 30^o to the horizontal and rebounds elastically, while the other ball falls freely.

[4] How do their speeds differ at the moment of impact with the ground?

[5] How do their fall times differ?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2 (*Cherenkov A.A.*)

10.5. (6 points) Petya has a dream in which he is on a desert island. To get food, he goes hunting with a bow. Walking into the jungle, Petya notices a tree at a distance of L = 10 m from him, with a monkey sitting on a branch at a height of H = 5 m. Drawing the bowstring, Petya shoots an arrow. The monkey, who was resting on the tree, started to fall down from fright at the same moment.

[6] What should be the minimum speed of the arrow so that Petya hits the monkey?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

10.6. (7 points) Sasha invented a method which calculates the velocities of bodies. For this purpose he took an inclined plane and put a notch on it, at a distance of L = 10 cm from the base. Then he rolled the ball from bottom to top and measured the times t_1 = 2 s and t_2 = 5 s from the beginning of movement, when the ball passed the notch. Thus he was able to find out what velocity the ball had at the beginning of the motion.

[7] What was this velocity equal to?

[8] At what minimum angle in degrees of inclined plane Sasha's method fails if the position of the notch and the initial velocity are the same?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

10.7. (5 points) Petya was invited to go karting for his friend's birthday. Karting cars reach a maximum speed of 50 km/h. Petya drove the first part of the track, accelerating to 25 km/h. The rest of the track Petya covered after accelerating to the maximum speed.

[9] In how many times the work of the engine during acceleration on the second part of the track is greater than on the first part?

Comment. Consider the acceleration time and the drag force to be the same in both cases.

(*Cherenkov A.A.*)

10.8. (6 points) At the construction site of a kindergarten a rope of length L = 5 m was hanging on a pin. One of the workers, passing by, accidentally touched it, and the rope began to move.

[10] What speed will the rope have when it slips completely off the pin, if rope's ends had been at the same level before it started to move?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

10.9. (7 points) The sled slides down a mountain with an inclination angle $\beta = 30^o$, and moves sequentially along a horizontal section of length $s_1 = 7$ m, through a hill of h = 3 m height and inclination angle of $\alpha = 60^o$ and again along a horizontal section. The coefficient of friction on horizontal sections is $\mu_1 = 0.1$, on inclined sections - $\mu_2 = 0.3$.

[11] Determine the height from which the sled should start so that it would travel along the second horizontal section at least $s_2 = 15$ metres.

(*Cherenkov A.A.*)

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Problems for grade R11

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11.1. (6 points) . In the school physics circle Petya was charged to construct temperature dependences in the temperature range from $T_1 = 20^o$ C to $T_2 = 50^o$ C for a system, consisting of a coal rod of length $l_1 = 3$ cm and radius of r = 1 mm and a metal rod of the same radius and length $l_2 = 20, 60, 80, 90$ cm.

[1] Petya found out that in one of these cases there is no temperature dependence. What is the length of the metal rod in centimeters in this case?

Comment. Temperature coefficients and resistivity at 0^o C for coal and metal are equal to $\alpha_1 = -0{,}8 * 10^{-3}$ K^{-1}, $\varrho_1 = 4 * 10^{-5}$ Ohm*m, $\alpha_2 = 6 * 10^{-3}$ K^{-1}, $\varrho_2 = 2 * 10^{-7}$ Ohm*m. (*Yakovlev A.B.*)

11.2. (9 points) A cannon fires a projectile at an angle of $\alpha = 30^o$ to the horizon with an initial velocity of v = 20 m/s. At the peak of its trajectory, projectile explodes into fragments flying in all directions, each having the same relative speed $v_0 = 5$ m/s with respect to the projectile.

[2] Find the volume bounded by the fragments $t_0 = 1$ s after the explosion.

[3] What will be the maximum velocity,

[4] minimum velocity of the fragments relative to the Earth after t_0?

Comment. Neglect the air resistance. Assume that the acceleration of free fall is 9.8 m/s^2.

(*Cherenkov A.A.*)

11.3. (5 points) Danya has a toy railway on which a train can travel at a speed of 25 km/h. He has attached a voltmeter to the rails.

[5] What will be the reading of the voltmeter when the train approaches it if the distance between the rails is d = 10 cm?

Comment. Consider that the normal component of the Earth's magnetic induction $B_n = 4 * 10^{-5}$ Tesla. (*Cherenkov A.A.*)

11.4. (9 points) Petya is going to take part in a rocket-building championship. The boy has built a test model of a rocket with mass of M = 2 kg and decided to test it. The rocket is launched from the ground with an initial velocity of $v_0 = 25$ m/s at an angle of $\alpha = 30^o$ to the horizon. Three times at equal intervals of time $\Delta t = 0.3$ s a mass of $\Delta m = 0.5$ kg is ejected from the rocket with velocity of u = 5 m/s relative to the rocket.

[6] What speed will the rocket have when it approaches the Earth?

Comment. Neglect the air resistance. Assume that the acceleration of free fall is 9.8 m/s^2.

(*Cherenkov A.A.*)

11.5. (8 points) There are two ramps in a skatepark - one is fixed to the ground and stationary, and the other is on a movable support. Both ramps are of the same height h = 2 m. A local skateboarder first rolled down the first ramp and then down the second ramp.

[7] In how many times will the speed of the skateboarder change in the second case compared to the first case, if the mass of the skateboarder is twice less than the mass of the ramp?

Comment. Neglect friction. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

11.6. (7 points) The equilibrium of solids in liquids is studied in a school laboratory. The teacher took an empty cylindrical glass and carefully immersed it upwards with the bottom and released it. The glass occurred to be in the state of equilibrium.

[8] What is the depth of immersion of the glass?

Comment. The glass has height of H = 15 cm, diameter of D = 3 cm and mass of m = 0.1 kg. Assume that atmospheric pressure is $p_0 = 10^5$ Pa and acceleration of free fall is g = 9.8 m/s^2. The density of water is $\rho = 1000\ kg/m^3$. (*Cherenkov A.A.*)

11.7. (7 points) Petya read in the textbook a method of determining the charge of a drop. It is needed to take a flat capacitor and measure the times of drop falling from one plate of capacitor to the other at different potential differences. The first time Petya applied a potential difference of 100 V and the second time - 200 V. The times he measured were $t_1 = 2$ s $t_2 = 3$ s.

[9] What is the modulus of charge of a drop if its mass m = 50 mg?

Comment. Assume that the acceleration of free fall is 9.8 m/s^2. (*Cherenkov A.A.*)

11.8. (5 points) A copper ball of radius 1 mm is suspended on a string over a grounded unbounded flat metallic surface. The distance between the ball and the surface is l = 5 cm. The ball is given some charge.

[10] In how many times will the interaction force between the plate and the ball change, if the distance between them is increased by $l_0 = 2$ cm.

(*Cherenkov A.A.*)

11.9. (7 points) Pupils of one school were invited on a tour to a physics laboratory. At one of the installations, the children were shown an experiment demonstrating the impact of an electric field on an electron moving in it. An electron with an energy of 1000 eV flew into a flat capacitor at an angle of $\alpha_1 = 30^o$ to its plates, and flies out at an angle of $\alpha_2 = 60^o$.

[11] What was the voltage on the capacitor, if its length is l = 10 cm and the distance between the plates is d = 1 cm?

Comment. Neglect the effect of gravity. (*Cherenkov A.A.*)