International Physics Olympiad
«Formula of Unity» / «The Third Millennium»
Year 2026/2027. 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 — **November, 29**.
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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. (4 points) At a furniture factory, parts are joined using dowels, special cylindrical wooden fasteners driven into slots in the parts with a hammer of mass $M = 0.500$ kg. The hammer is raised to a height $h = 0.200$ m and released from rest. After the hammer strikes, the dowel moves a distance $s = 0.500$ cm farther into the slot.

[1] Calculate the average impact force if the mass of the dowel is $m = 5.00$ g.

Comment. Take the acceleration due to gravity to be $g = 9.80\,m/s^2$. (*Cherenkov A.A.*)

8.2. (5 points) Before being installed in a light aircraft, a piston aircraft engine is tested on a test stand. In steady-state operation, the engine delivers a mechanical power of 110.0 kW. To cool the engine, water is continuously pumped through it via a pipe with an internal diameter of 40.0 mm. The mean speed of the water in the pipe is 1.25 m/s. As it passes through the engine cooling system, the water warms by 25.0^oC.

[2] Determine the efficiency of the engine as a percentage.

Comment. Assume that all the energy not converted into mechanical work by the engine is transferred to the cooling water. Take the density of water to be 1000.0 kg/m^3 and its specific heat capacity to be 4200.0 J/(kg · °C). (*Cherenkov A.A.*)

8.3. (5 points) A magician visited a school physics lesson. Demonstrating his magical abilities, he performed a trick in which water instantly turned into ice. To do this, he took an ordinary bottle of water, carefully placed it on a table and gently flicked the bottle with his finger. After this, 10.0 % of all the water rapidly turned into ice. Petya watched the trick closely and realised that the entire secret lay in the temperature of the water.

[3] Calculate the initial temperature of the magician's water in degrees Celsius.

Comment. The specific heat capacity of water is $c = 4.2$ kJ/(kg K), and the specific latent heat of fusion of ice is $\lambda = 0.34$ MJ/kg. (*Cherenkov A.A.*)

8.4. (6 points) During the repair of a city fountain, one of the pipes of the water supply system was left pointing vertically upwards. When the pump was switched on, a jet of water began to emerge from it. From the flowmeter readings, the workers determined that 97.5 litres of water passed through the pipe per minute. At a height of 2.00 m above the outlet, the diameter of the jet was 2.00 cm.

[4] Determine the area of the pipe outlet.

Comment. Assume steady water flow, and neglect air resistance and the viscosity of water. Take the acceleration due to gravity to be 9.80 m/s^2. Give your answer in square centimetres.
(*Cherenkov A.A.*)

8.5. (6 points) Sasha was going to make tea and poured $V_1 = 1.4$ litres of water into an electric kettle with a power of $P = 2400$ W. When the water boiled, the kettle switched off automatically, but Sasha was distracted and returned to it only after $\tau_1 = 50.0$ s. He switched the kettle on again, and after $\tau_2 = 10.0$ s the water boiled again, whereupon the kettle switched

off automatically. Immediately afterwards, Sasha removed the lid from the kettle, became lost in thought, accidentally switched it on again and went into the next room. Since the kettle was open, the automatic switch-off did not operate.

[5] Calculate the mass of water remaining in the kettle if Sasha returned and switched it off after $\tau_3 = 230$ s.

Comment. Assume that the rate of heat loss to the surroundings remains constant throughout the experiment. Neglect the heat capacity of the kettle. The density of water is $\rho = 1000.0$ kg/m, and its specific latent heat of vaporisation is $L = 2.3$ MJ/kg. (*Cherenkov A.A.*)

8.6. (7 points) While repairing a boat, a worker accidentally dropped overboard a sealed toolbox with a total mass of 5.0 kg. The box is a rectangular parallelepiped with dimensions of 20.0 cm $\times$15.0 cm $\times$10.0 cm. The box sank to the bottom, and its centre came to rest at a depth of 3.0 m. The worker attached a cable to the box and used a winch to raise it slowly vertically upwards. During the lift, the box remained horizontal, with its 10.0 cm edge oriented vertically. The lift continued until the centre of the box was 0.80 m above the water surface.

[6] How much work did the winch do in raising the box?

Comment. Take the density of water to be 1000.0 kg/m^3 and the acceleration due to gravity to be 9.8 m/s^2. Neglect water resistance and the mass of the cable. Give your answer in joules.
(*Cherenkov A.A.*)

8.7. (7 points) Preparing to go fishing on a river, Vanya decided to make his own float from a goose feather and a cork. He stripped the vane from the feather and weighed it: the mass of the feather was 0.20 g. Vanya fitted a cylindrical cork of height 15 mm and diameter 12 mm tightly onto the lower part of the feather. First, Vanya fixed the cork so that the distance from its lower edge to the lower end of the feather was 3.0 cm, attached a sinker with a mass of 0.50 g and placed the float in water. Once equilibrium was established, the water surface was 4.0 mm above the lower edge of the cork. Vanya did not like how the float sat in the water, so he moved the cork upwards: the distance from its lower edge to the lower end of the feather was now 5.0 cm. He also replaced the sinker with another with a mass of 0.78 g. When the float was placed in the water again, the water surface settled 3.0 mm above the lower edge of the cork.

[7] Determine the density of the cork material.

Comment. Take the density of water to be 1.0 g/cm^3 and the acceleration due to gravity to be $g = 9.8 m/s^2$. Assume that the lower part of the feather is cylindrical. Neglect the volumes of the sinkers and the fishing line. Give your answer in grams per cubic centimetre. (*Cherenkov A.A.*)

International Physics Olympiad
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Year 2026/2027. Qualifying round

Problems for grade R9

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9.1. (4 points) There is an elevator in an old coal mine. When the workers called the elevator to the top, it began to rise with a constant acceleration of $a = 1.2$ m/s^2. Some time after the motion began, severe shaking caused a screw that held a lamp to start falling from the ceiling.

[1] Calculate the total time taken by the screw to fall if the height of the elevator is $h = 2.7$ m.

Comment. Take the acceleration due to gravity to be $g = 9.8\,m/s^2$. Neglect air resistance. (*Cherenkov A.A.*)

9.2. (4 points) A batch of cartridges was tested in a ballistics laboratory. During the test, a lead bullet is fired, giving it an initial speed of 400.0 m/s, after which it strikes a massive steel wall. The investigation showed that only 62.5% of the kinetic energy acquired by the bullet upon firing was converted into its internal energy. Immediately after firing, the temperature of the bullet was 33.0^oC.

[2] What fraction of the bullet's mass melted on impact?

Comment. The melting point of lead is 327^oC, its specific heat capacity is 125 J/(kg · °C), and its specific latent heat of fusion is 25.0 kJ/kg. Neglect heat exchange with the surroundings during the impact. Give your answer as a percentage. (*Cherenkov A.A.*)

9.3. (5 points) At a sawmill, a tree trunk of radius $R = 20.0$ cm is fed into a debarking machine. The trunk is held between two parallel moving belts, one above it and one below it. The belts move in the same direction at speeds $v_1 = 1.5$ m/s and $v_2 = 0.50$ m/s. To remove all the bark, the trunk must make 5 complete revolutions about its axis.

[3] Determine the time required to debark one trunk.

Comment. There is no slipping between the trunk and the belts. (*Cherenkov A.A.*)

9.4. (5 points) During a winter physics laboratory session, students were asked to determine the coefficient of friction between a sledge and snow. The sledge was set in motion at the foot of a straight snow-covered slope inclined at an angle $\alpha = 10.0^o$ to the horizontal. After moving uphill, the sledge stopped and slid back down. The ascent and descent times were measured with a stopwatch and found to be $t_1 = 3.0$ s and $t_2 = 4.0$ s, respectively.

[4] Determine the coefficient of friction between the sledge runners and the snow.

(*Cherenkov A.A.*)

9.5. (6 points) On a sunny, windless day, Masha was playing in a sandpit at a playground and built a tall mound of dry sand. After the sand had slid down, the slope of the mound made an angle of 35^o with the horizontal. A horizontal wind then began to blow, and some of the sand was blown away. Masha began building the mound again, carefully adding more sand.

[5] What is the greatest possible angle that one of the slopes of the mound can make with the horizontal if the wind exerts a force on each surface grain equal to one tenth of its weight?

Comment. Assume that the wind blows without gusts and does not change direction or speed. Take the acceleration due to gravity to be 9.8 m/s^2. Give your answer in degrees. (*Cherenkov A.A.*)

9.6. (6 points) Dasha decided to assemble a mechanical model of a snake from 11 identical wooden blocks, each with a mass of 300.0 g. The blocks are arranged in a row on a horizontal table and connected in sequence by 10 light springs. The spring constants, in order from the "tail" to the "head", are k, $2k$, $3k$, ..., $10k$, respectively, where $k = 100.0\ N/m$. To set her snake in motion, Dasha tied a string to its "head" and pulled it with a constant horizontal force $F = 33.00$ N. The coefficient of kinetic friction between each block and the table is 0.2000.

[6] By how many centimetres will the total length of the mechanical snake increase once motion is established in which all the blocks move with the same acceleration?

Comment. Before the motion began, all the springs were undeformed. (*Cherenkov A.A.*)

9.7. (7 points) At a physics club session, Anton investigated the operation of an electric immersion heater. He placed 600.0 g of water and 80.0 g of ice in a vessel, which were in thermal equilibrium at a temperature of 0.00^oC. The heater was connected to a direct-current source with an EMF of $\mathcal{E}$ =220 V and an internal resistance of $r = 8.00\Omega$. The current–voltage characteristic of the heater is described by the relation $I = 2.5\sqrt{\frac{U}{200}}$, where U is the voltage across the heater, expressed in volts, and I is the current through it, expressed in amperes.

[7] How long after the heater is switched on will the water in the vessel reach its boiling point?

Comment. Neglect the heat capacities of the vessel and the heater, as well as heat losses to the surroundings. Take the specific heat capacity of water to be 4200 J/(kg · °C) and the specific latent heat of fusion of ice to be 340 kJ/kg. Take the boiling point of water to be 100.0^oC.

(*Cherenkov A.A.*)

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Problems for grade R10

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10.1. (5 points) At the construction site of a new bridge, workers were moving a horizontal concrete slab vertically upwards at a speed $u = 0.450$ m/s. A hooligan passing by threw a ball vertically downwards onto the slab with an initial speed $v = 2.00$ m/s.

[1] How long will it take for the ball to strike the slab for the second time if the initial distance between the slab and the ball is $h = 2.45$ m?

Comment. Assume that the collisions between the ball and the slab are perfectly elastic. Take the acceleration due to gravity to be $g = 9.80\ m/s^2$. Neglect air resistance. (*Cherenkov A.A.*)

10.2. (5 points) During a lesson on the construction of piston engines, students were shown how a piston air pump works. As a practical exercise, they were asked to calculate how many working strokes the pump piston must make to evacuate air from a sealed vessel with a volume of $V = 4.00$ litres and reduce its pressure from $p_0 = 100.00$ kPa to $p = 51.2$ kPa. The swept volume of the pump per stroke is $\Delta V = 1.00$ litres.

[2] Determine the required number of piston strokes.

Comment. Assume that the air temperature remains constant. After each stroke, all the air that has entered the pump is discharged to the outside. (*Cherenkov A.A.*)

10.3. (5 points) A laboratory is developing a prototype trapped-ion quantum processor. Four identical singly ionised atoms each have a charge $q = 1.6 \cdot 10^{-19}\ C$. In the initial configuration, the ions are held along a straight line, with the distance between adjacent ions equal to $r = 6.0\ \mu m$. The control electrodes of the trap are then slowly reconfigured so that the ions occupy the vertices of a regular tetrahedron with an edge length of $6.0\ \mu m$.

[3] How much work must be done to change the ion configuration in this way?

Comment. Give your answer in millielectronvolts. Assume that the process is sufficiently slow and that the change in the kinetic energy of the ions can be neglected. (*Cherenkov A.A.*)

10.4. (6 points) Petya went to a clinic to be vaccinated against tick-borne encephalitis. Before giving the injection, the nurse expelled all the air from a syringe of diameter $d = 1.6$ cm by pressing its plunger with a force of $F = 2.0$ N. The air is expelled until a jet of the active substance emerges from the needle.

[4] What is the maximum horizontal range of the jet if the nurse holds the syringe at a height of $h = 1.0$ m above the floor?

Comment. Take the density of the drug solution to be $\rho = 1200\ kg/m^3$. Neglect plunger friction, pressure losses as the liquid flows through the needle, and air resistance. Assume that the speed of the liquid inside the syringe barrel is small compared with the speed of the jet. Take the acceleration due to gravity to be $g = 9.8\,m/s^2$. (*Cherenkov A.A.*)

10.5. (6 points) Vasya assembled a spring toy from a construction set: two small carts of masses 200 g and 600 g are connected by a light spring. The boy placed the toy on a smooth horizontal table, with the first, lighter cart resting against a fixed stop. Vasya moved the second cart towards

the first, compressing the spring by 4 cm, and held it in this position. He then carefully released the second cart from rest.

[5] What will be the maximum extension of the spring, in centimetres, after the cart is released?

Comment. Neglect the mass of the spring and resistance to the motion of the carts.

(*Cherenkov A.A.*)

10.6. (6 points) During a school physics lesson, students carry out an experiment with a light cylindrical vessel of length 60.0 cm that can move without friction along a horizontal guide. A partition fixed relative to the vessel divides it into two equal parts. Oxygen is to the left of the partition and nitrogen to the right. Before the experiment begins, both gases have the same temperature and the vessel is at rest. The partition is then made permeable to the gases. Once equilibrium is established, the vessel is found to have moved 5.0 cm towards the half that initially contained nitrogen.

[6] Determine the ratio of the initial nitrogen pressure to the initial oxygen pressure.

Comment. Take the molar masses of oxygen and nitrogen, respectively, to be $\mu_{O_2} = 32\ g/mol$,$\mu_{N_2} = 28\ g/mol$. Neglect the masses of the vessel and the partition. Treat the gases as ideal.

(*Cherenkov A.A.*)

10.7. (7 points) A projectile is fired from a cannon at the Earth's surface at an angle $\alpha = 60.0^o$. The initial speed of the projectile is $v = 200.0$ m/s. Upon reaching the highest point of its trajectory, the projectile explodes into three fragments with masses of $m_1 = 1.0$ kg, $m_2 = 2.0$ kg and $m_3 = 3.0$ kg. In the reference frame attached to the centre of mass of the system, the velocity vectors of the fragments are at angles of 120^o to one another.

[7] Determine the maximum possible speed of one of the fragments if the energy released in the explosion is $Q = 25$ kJ.

Comment. Take the acceleration due to gravity to be $g = 9.8\,m/s^2$. Neglect air resistance.

(*Cherenkov A.A.*)

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Problems for grade R11

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11.1. (4 points) Masha is assembling a prototype gas-based temperature-difference indicator for a scientific conference. She connected two sealed chambers of volumes 300.0 cm^3 and 500.0 cm^3 with a horizontal transparent tube with a length of 2.00 m and cross-sectional area of 1.00 cm^2. The tube contains a light, gas-tight, thermally insulating partition that can move without friction. Initially, it is located exactly at the midpoint of the tube. The same ideal gas is present on both sides at a temperature of 27.0^oC, and the system is in mechanical equilibrium. The left chamber, together with the gas inside it, is then heated to 57.0^oC, while the right chamber is cooled to 7.00^oC.

[1] By how many centimetres will the partition move once a new equilibrium is established?

Comment. Neglect heat transfer through the partition and changes in the volumes of the chambers and the tube during heating and cooling. (*Cherenkov A.A.*)

11.2. (5 points) An old pendulum clock hung in the entrance hall of Danya's country house. The temperature in the hall was 10.0^oC, and the clock kept accurate time. Later, Danya's grandmother asked him to move the clock into the next room, where the stove had already been lit and a constant temperature of 25^oC was maintained. After 3.0 hours, Danya compared the clock reading with the correct time and found that it had lost 1.5 s. The pendulum rod is made of one of the following materials:

No.	Material	α, 10^{-6} K^{-1}
1	Steel	12
2	Copper	17
3	Brass	19
4	Aluminium	23

[2] Determine the material from which the pendulum rod is made, and give its number in the table as your answer.

Comment. Assume that the pendulum's bob is a point mass, the rod is light, and the pendulum's oscillations are small. In your solution also assume that after being moved, the clock quickly reached room temperature and remained at a constant temperature throughout the observation period, and that only the rod undergoes thermal expansion. (*Cherenkov A.A.*)

11.3. (5 points) At a school tea party, Petya decided to perform a classic trick: pulling a tablecloth out from under a vase standing on it without tipping the vase over. The vase is cylindrical, with a height of $h = 15$ cm and base radius of $r = 5.0$ cm. The mass of the cylindrical wall of the vase is 5.0 times the mass of its base. Before performing the trick, Petya decided to determine the conditions under which the vase might begin to tip over rather than slide on the tablecloth.

[3] Find the minimum coefficient of static friction between the vase and the tablecloth for which tipping is possible.

Comment. Treat the walls and base of the vase as thin and uniform. The tablecloth moves horizontally with gradually increasing acceleration. Take the acceleration due to gravity to be $g = 9.8\,m/s^2$. (*Cherenkov A.A.*)

11.4. (6 points) During a physics lesson, Kolya carried out a laboratory experiment on hydrostatic phenomena. He took a vessel in the shape of a truncated cone with a height of 8.00 cm.

The areas of its bases are 108 cm^2 and 12.0 cm^2. One base of the vessel is open, and the other is closed by a light detachable bottom. Kolya immersed the vessel vertically in water and fixed it so that the detachable bottom was horizontal. First, Kolya gradually poured water into the vessel. When the mass of the added water reached 304 g, the detachable bottom fell off. Just before detachment, the water in the vessel had risen to a level at which the cross-sectional area was 48.0 cm^2. Kolya then replaced the bottom, leaving the vessel in the same position and at the same depth, poured out the water and placed a weight of mass 304 g on the bottom. This time, the bottom did not fall off. Finally, Kolya removed the weight and began gradually pouring oil into the vessel.

[4] What is the minimum mass of oil in the vessel at which the bottom will fall off?

Comment. Take the density of water to be $\rho = 1.00\ g/cm^3$, and the density of oil to be $\rho_m = 0.800\ g/cm^3$. (*Cherenkov A.A.*)

11.5. (6 points) For a physics lesson, Kolya made a model of a molecule. He attached four light, identical small balls representing atoms to a single central support using identical thin, light, non-conducting threads. During the demonstration of the model, each ball was given the same positive charge $q = 2.0 \cdot 10^{-7}\ C$, and, once equilibrium was established, all the balls were at equal distances $a = 30.0$ cm from one another.

[5] Determine the tensions in the threads of the model once equilibrium is established.

Comment. Take the Coulomb constant to be $k = 9.0 \cdot 10^9\ \frac{N \cdot m^2}{C^2}$. Give your answer in millinewtons. (*Cherenkov A.A.*)

11.6. (6 points) An insulating ring with a radius of $R = 10.0$ cm is fixed in a vertical plane. Two small positively charged balls, A and B, with charges q_A and q_B, respectively, are fixed at the upper-left and lower-left vertices of a square inscribed in the ring, so the side AB of the square is vertical. Two identical balls, C and D, each with a mass of $m = 0.90$ g and equal positive charges $q = 0.20 \mu C$, can move along the ring without friction. Balls C and D are in equilibrium at the upper-right and lower-right vertices of the square, respectively.

[6] By how many microcoulombs must the charge of the lower fixed ball B exceed that of the upper ball A?

Comment. Neglect the sizes of the balls. Take the Coulomb constant to be $k = 9.0 \cdot 10^9\ \mathrm{N \cdot m^2/C^2}$. Take the acceleration due to gravity to be $g = 9.8\, m/s^2$. (*Cherenkov A.A.*)

11.7. (7 points) During a physics lesson, students investigated the stability of bodies on an inclined plane. The teacher suggested making an unusual cylinder that could remain in equilibrium on an inclined board because of its displaced centre of mass. For the experiment, a uniform cylinder of radius $R = 6$ cm was taken, and a cylindrical cut-out of radius $r = 3$ cm was made in it, with its axis parallel to the axis of the original cylinder. The cylinder is placed on a board, one end of which is slowly raised. The coefficient of friction between the cylinder and the board is $\mu = 0.2$.

[7] Determine the greatest possible angle of inclination of the board to the horizontal at which the cylinder remains in equilibrium.

(*Cherenkov A.A.*)