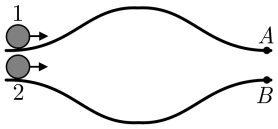
International Physics Olympiad
«Formula of Unity» / «The Third Millennium»
Year 2022/2023. Qualifying round

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**.
All the information about the Olympiad and the instructions for participants: formulo.org/en/olymp/2022-phys-en/.
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. (2 points) Two identical circular gingerbread buns («kolo-boks») roll at the same velocity along parallel horizontal tracks. On the way of the first gingerbread bun there is a hill, on the way of the second one there is a hole (see pic.). The height of the hill and the depth of the hole are the same. Both gingerbread buns overcame their obstacles and ended up at points A and B, respectively.

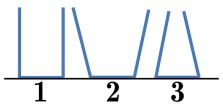


[1] Compare the velocities of the gingerbread buns at points A and B:
A) $v_1 > v_2$, B) $v_1 = v_2$, C) $v_1 < v_2$.

[2] Compare the times it took the gingerbread buns to overcome obstacles:
A) $t_1 > t_2$, B) $t_1 = t_2$, C) $t_1 < t_2$.

There is no slippage while the buns are moving. In both questions give only **the letter** of the correct answer from those given. (*S. Starovoytov*)

8.2. (3 points) An equal volume of water was poured into three glass cups, the axial sections of which are shown in the picture, in the way so that the water did not spill out of the cups.



[3] Choose from the suggested answers the correct one for the hydrostatic pressures of water (p_1, p_2, p_3) on the bottoms of the cups:
A) $p_1 = p_2 = p_3$, B) $p_2 > p_1 > p_3$, C) $p_3 > p_1 > p_2$.

[4] Choose from the suggested answers the correct one for the pressure forces (F_1, F_2, F_3) of the cups with water in them on the horizontal surface of the base:
A) $F_1 = F_2 = F_3$, B) $F_2 > F_1 > F_3$, C) $F_3 > F_1 > F_2$.

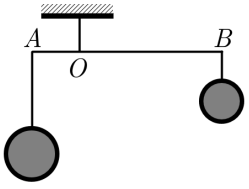
The height of the cups, the diameter of the base and the thickness of the glass walls are equal. The angle of inclination of the side walls is more than 45°. In both questions give only **the letter** of the correct answer from those given. (*S. Starovoytov*)

8.3. (3 points) Tourist Nikolai Petrovich was 5 minutes late to the departure of his cruise ship, which went down the river. Fortunately, the owner of the speedboat agreed to help Nikolai Petrovich. Having caught up with the cruise ship and left the unlucky tourist on board of it, the speedboat immediately set off back on the return journey.

[5] How long did it take from the moment the speedboat started until it returned? Give the answer in minutes.

Assume that the speed of the cruise ship in relation to the water is 3 times bigger than the speed of the river current, and the speed of the boat is 5 times bigger than that of the river. (*S. Starovoytov*)

8.4. (4 points) Balls made of different materials are balanced on a lever. The volume of the left ball is 1.25 times bigger than the volume of the ball on the right, and the arm AO is 2.5 times less than the arm OB.



[6] By how much should the volume of the right sphere be increased so that when the entire system is placed in water, the balance will not get disturbed provided the system density is twice as big as that of water? Give your answer as a percentage, rounded to integers. (*M. Krupina*)

8.5. (2 points) The boys (triplets) built a raft. When they climbed onto the raft all together, the raft sank completely into the water. But if only two of them ride it, then the raft is immersed in water for $\eta = 0.8$ of its thickness.

[7] Find out the density of the wood from which the raft is made. Give your answer in kg/m^3 rounded to integers.

Remark. The density of water is 1000 kg/m^3, the thickness of the raft is $h = 20$ cm.

(*T. Vorobyeva, S. Starovoytov*)

8.6. (3 points) Having opened a jar of condensed milk and eaten the half of it, Slavik thought that it would be nice to cook the rest. Having dipped the jar into boiling water, Slavik noticed that the jar was immersed in water for 5/6 of its volume. Time has passed but the milk hasn't turned dark, so Slavik has eaten a quarter more of the milk in the jar. Now the jar started floating being immersed in water on its half only.

[8] How much did the full jar weigh provided its volume is 300 ml? Give the answer of the mass in kilos rounded to hundredths.

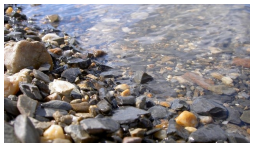
Remark. Consider that the jar is thin-walled. (*T. Andreeva*)

8.7. (2 points) Three cylindrical communicating vessels in the form of the cyrillic letter «Ш» are filled with oil of 900 kg/m^3 density and are shut with weightless thin pistons. The cross section of each of the vessels makes 60 cm^2. A weight of 600 g is being placed over the piston that shuts the middle vessel.

[9] What height (in relation to their initial level) will the side pistons rise at after this? Give the answer in millimeters, rounded to integers.

Remark. The friction of the pistons over the vessel walls should be neglected. (*S. Starovoytov*)

8.8. (4 points) Mother took her baby to the river shore. The sun heated the stones by the shore up to 40°C, but the water remained cold (18°C). To bathe the baby, mother got 5 L of water into a small bucket and started heating it by placing the stones in the bucket. Not to spill the water over, she put only one stone in the bucket and then waited until the temperatures of water and a stone equalized. Then she took the stone out and placed in a new one.



[10] How much will the temperature of water be after the fourth stone is out of it?

[11] Up to what temperature could the water heat up if all the four stones had been possible to be placed in it at once?

Give both answers in degrees Celsius, rounded to integers (but only round up the final results). The mass of each stone is 2.8 kg, the heat capacity of them is 900 $\frac{\text{J}}{\text{kg}\cdot\text{K}}$, and the specific heat capacity of water is 4.2 $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$. (*T. Andreeva*)

8.9. (3 points) The initial temperature of water of 20°C in the boiler of the steam locomotive is heated up until it boils and evaporates. And then it is heated up to 300°C in the superheater. Superheated vapor goes into the steam engine the efficiency of which makes 30%.

[12] How much is the power of the steam engine, provided its water consumption is 7.2 m^3/h? Give the answer in MW, rounded to integers.

Remark. The specific heat capacity of water is 4.2 $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$, the specific heat of water vaporization is 2.3 MJ/kg, the average heat capacity of water vapor in the range 100–300°C is 4.2 $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$.

(*T. Andreeva*)

International Physics Olympiad
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Year 2022/2023. Qualifying round

Problems for grade R9

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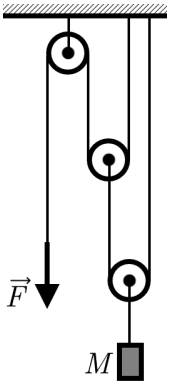
The number in square brackets (for example, **[3]**) indicates the number of the field in which the answer to this question should be entered. You must not enter dimensions in any answer.

9.1. (3 points) The train that started from Kings Cross railway station has travelled 1/8 of its way at the speed of $v_1 = 52$ km/h. The average velocity of the train on its whole way has made $\langle v \rangle = 34$ km/h.

[1] At what speed has the train made the rest of its way if we know that 1/10 of the whole time it took him to make its way the train has been stopped to let the Hogwarts Express go? Give the answer in km/h, rounded to tenths. (*T. Andreeva*)

9.2. (3 points) The load of $M = 10$ kg in mass has been lifted using the block system shown in the picture. The constant force of 50 N has been applied to the tightrope within 2 sec and then the tightrope has been dropped by accident and it could only get back under control 4 sec later. It afterwards took 5 sec more to get the load to the necessary level with the same force applied.



[2] At what level has the load been lifted from its initial position? Give the answer in meters.

Remark. Neglect the friction of pulleys and air resistance. Consider the pulleys as weightless, the ropes as light and inextensible, and the parts of ropes that are free of pulleys positioned vertically. Consider the acceleration of gravity to be 10 m/sec^2. (*M. Krupina*)

9.3. (3 points) The kids are sledging. Andrew is pulling the sledge with Mary by the rope at the angle $\alpha = 30°$ to the horizon while Pete is pushing the same kind of sledge with Daria on it directing the force of $F_2 = 140$ N downwards at the angle $\alpha = 30°$ to the horizon.

[3] What force F_1 should Adrew apply so that the girls moved with the same acceleration? Give the answer in Newtons, rounded to integers.

The mass of Mary together with her sledge makes $m_1 = 40$ kg, Daria weighs $m_2 = 35$ kg together with her sledge. Consider the acceleration of gravity to be 10 m/sec^2. Friction coefficient is $\mu = 0.20$. (*M. Krupina, S. Starovoytov*)

9.4. (3 points) Grandpa Mazai is saving seven hares in the spring floods. Frightened hares are sitting at the stern of the boat, and grandpa Mazai is standing on the bow. The boat is 3.4 m long and weighs 110 kg. The mass of grandpa in his sheepskin coat makes 90 kg.

Not far from the land, the boat stops and Mazai and the hares change their places: grandpa gats to the stern, and the hares get to the bow of the boat. As a result, the boat approaches the land by 1 m.

[4] Find out the average weight of a hare. Give the answer in kilos, rounded to tenths. (*T. Andreeva*)

9.5. (4 points) A thin-walled cylindrical glass filled with maple syrup to its quarter (1/4) is floating in a vessel of water, being immersed to its middle. The same glass, but filled with water to its half (1/2), is floating in a vessel with syrup, also being immersed to its middle.

[5] What part of the glass can be filled with syrup so that it does not sink in water?

[6] And what part of the glass can be filled with syrup so that it does not sink in syrup?

Give answers as decimals, rounded to thousandths. (*T. Andreeva*)

9.6. (3 points) Two satellites move in circular orbits in opposite directions around some planet with linear velocities $v_1 = 5$ km/sec and $v_2 = 8$ km/sec. The radius of the planet equals $R = 17.4$ thousand km and the acceleration of free fall on its surface makes $g = 14$ m/sec^2.

[7] Find out the time interval within which the satellites periodically approach each other at a minimum distance. Give your answer in hours, rounded to tenths.

(*M. Korobkov, T. Andreeva*)

9.7. (4 points) Ruth and Mary cooked 2 liters of cranberry juice. There was very little time left before the arrival of the guests, and the fruit drink was still warm (40°C). The girls wanted to cool it down quickly with the help of 20 plastic balls filled with ice (−20°C), but then they argued and divided the fruit drink and the balls equally between themselves. Ruth put all the balls into the fruit drink at once, and Mary poured her fruit drink into two identical jugs and put the balls into one of them, then waited, stirring the fruit drink, until the temperatures of the balls and the fruit drink got equal, and then replaced the balls to the second jug. When the temperatures equalized again, Mary poured the drink into one large jug.

[8] Whose drink turned out to be colder in the end? Put either **the letter** R if Ruth's drink is colder, or M if otherwise.

[9] By how many degrees that drink turned out to be colder? Round your answer to integers.

The mass of ice in a ball is 20 g.

Remark. The specific heat capacity of water (and the fruit drink) is 4.2 $\frac{\text{J}}{\text{kg}\cdot\text{K}}$, the specific heat capacity of ice is 2.0 $\frac{\text{J}}{\text{kg}\cdot\text{K}}$, and the specific heat of fusion of ice is 340 kJ/kg. (*T. Andreeva*)

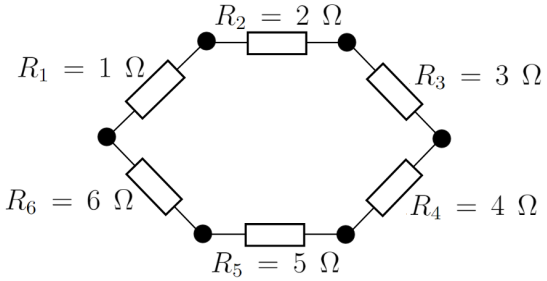
9.8. (2 points) The initial temperature of water of 20°C in the boiler of the steam locomotive is heated up until it boils and evaporates. And then it is heated up to 300°C in the superheater. Superheated vapor goes into the steam engine the efficiency of which makes 30%.

[10] How much is the power of the steam engine, provided its water consumption is 7.2 m^3/h? Give the answer in MW, rounded to integers.

Remark. The specific heat capacity of water is 4.2 $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$, the specific heat of water vaporization is 2.3 MJ/kg, the average heat capacity of water vapor in the range 100–300°C is 4.2 $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$.

(*T. Andreeva*)

9.9. (3 points) Six resistors $R_1 = 1\ \Omega$, $R_2 = 2\ \Omega$, $R_3 = 3\ \Omega$, $R_4 = 4\ \Omega$, $R_5 = 5\ \Omega$ and $R_6 = 6\ \Omega$ are connected in series one by one and are closed in a ring. A constant voltage source was connected to two contacts of the circuit (black dots in the picture) so that the resistance of the circuit between these contacts is at **maximum**. The source voltage is $U = 36$ V.



[11] Find out the power P_3 produced in the resistor R_3. Give the answer in watts, rounded to integers. (*S. Starovoytov*)

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Problems for grade R10

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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.

10.1. (3 points) Sherlock Holmes and Professor Moriarty stepped out of the first and last doors of the arrived train of and headed towards each other at a constant speed. After the boarding of passengers was completed, the train began to move with constant acceleration of 1 m/sec^2, and in 12 sec the last train carriage passed Professor Moriarty, and then in 2 sec more it passed Sherlock Holmes as well. The length of the train and the platform makes 172 m.

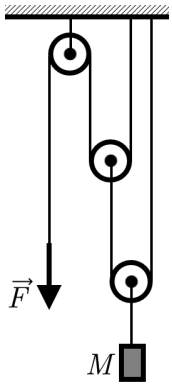
[1] How far apart were Sherlock Holmes and Professor Moriarty when the last train carriage left the station? Give your answer in meters, rounded to integers. (*T. Andreeva*)

10.2. (2 points) Cliff diver jumped into the water from a 29-meter high cliff. When he had flown the first 10 m, a spectator fell off the edge of the rock into the water.

[2] How high is the edge if the athlete and the spectator got to the water at the same time? Give the answer in meters, rounded to integers.

Remark. Cliff diving is jumping into the water from natural levels like rocks. Assume that the jumper's initial speed is zero. Consider the acceleration of gravity to be 10 m/sec^2. Ignore air resistance. (*T. Andreeva*)

10.3. (3 points) The load of $M = 10$ kg in mass has been lifted using the block system shown in the picture. The constant force of 50 N has been applied to the tightrope within 2 sec and then the tightrope has been dropped by accident and it could only get back under control 4 sec later. It afterwards took 5 sec more to get the load to the necessary level with the same force applied.



[3] At what level has the load been lifted from its initial position? Give the answer in meters.

Remark. Neglect the friction of pulleys and air resistance. Consider the pulleys as weightless, the ropes as light and inextensible, and the parts of ropes that are free of pulleys positioned vertically. Consider the acceleration of gravity to be 10 m/sec^2.
(*M. Krupina*)

10.4. (2 points) The kids are sledging. Andrew is pulling the sledge with Mary by the rope at the angle $\alpha = 30°$ to the horizon while Pete is pushing the same kind of sledge with Daria on it directing the force of $F_2 = 140$ N downwards at the angle $\alpha = 30°$ to the horizon.

[4] What force F_1 should Adrew apply so that the girls moved with the same acceleration? Give the answer in Newtons, rounded to integers.

The mass of Mary together with her sledge makes $m_1 = 40$ kg, Daria weighs $m_2 = 35$ kg together with her sledge. Consider the acceleration of gravity to be 10 m/sec^2. Friction coefficient is $\mu = 0.20$.

(*M. Krupina, S. Starovoytov*)

10.5. (3 points) A thin-walled glass cup is floating in a vessel filled with water. The syrup is being slowly poured into it until the glass is immersed in water exactly to its middle. It appears that a quarter of the glass got filled with syrup. The second glass of the same type, filled up to half with water, is floating in the syrup, immersed to its middle.

[5] What part of the second glass will be immersed in the syrup if the contents of the first glass are poured into it? Give your answer as a decimal with an accurancy of hundredths.

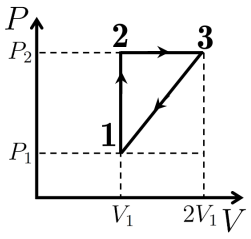
(*T. Andreeva*)

10.6. (3 points) Two satellites move in circular orbits in opposite directions around some planet with linear velocities $v_1 = 5$ km/sec and $v_2 = 8$ km/sec. The radius of the planet equals $R = 17.4$ thousand km and the acceleration of free fall on its surface makes $g = 14$ m/sec^2.

[6] Find out the time interval within which the satellites periodically approach each other at a minimum distance. Give your answer in hours, rounded to tenths.

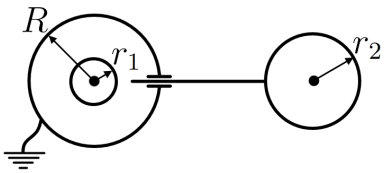
(*M. Korobkov, T. Andreeva*)

10.7. (3 points) The figure shows a cycle carried out with a monatomic ideal gas. it is known that the efficiency of the Carnot cycle carried out in the same temperature range is 64%, and with isobaric expansion the volume of the gas increases by 2 times.



[7] Find out the efficiency of the cycle. Give the answer in percentages with an accuracy of tenths. (*S. Starovoytov*)

10.8. (4 points) Charges of $q_1 = 0.6$ μC and $q_2 = 1.5$ μC were imparted to two metal balls with radii $r_1 = 10$ cm and $r_2 = 20$ cm respectively, and then they were connected with a thin wire. After that, a ball with radius r_1 is placed inside a metal sphere with a radius $R = 3r_1$ and this sphere is grounded.

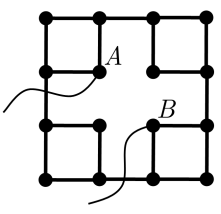


[8] What charge will pass through the connecting wire when the sphere is being grounded? Give the answer in μC, rounded to tenths.

Remark. The distance between the centers of the balls is much greater than their radii.

(*M. Krupina*)

10.9. (3 points) An electrical circuit consists of identical conductors with a resistance of $R = 10$ Ω forming a grid (see pic). An ohmmeter is connected to the nodes A and B.



[9] Find out what the ohmmeter reads. Give your answer in Ω with an accuracy of integers. (*M. Korobkov, T. Andreeva*)

International Physics Olympiad
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Year 2022/2023. Qualifying round

Problems for grade R11

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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.

11.1. (3 points) Sherlock Holmes and Professor Moriarty stepped out of the first and last doors of the arrived train of and headed towards each other at a constant speed. After the boarding of passengers was completed, the train began to move with constant acceleration of 1 m/sec^2, and in 12 sec the last train carriage passed Professor Moriarty, and then in 2 sec more it passed Sherlock Holmes as well. The length of the train and the platform makes 172 m.

[1] How far apart were Sherlock Holmes and Professor Moriarty when the last train carriage left the station? Give your answer in meters, rounded to integers. (*T. Andreeva*)

11.2. (3 points) An athlete — a shot putter, standing on a horizontal surface, pushed the shot at a speed of 12 m/sec at an angle of 30° to the horizon.

[2] What will be the radius of curvature of the shot trajectory in 1 sec after the throw? Give your answer in meters with an accuracy of tenths.

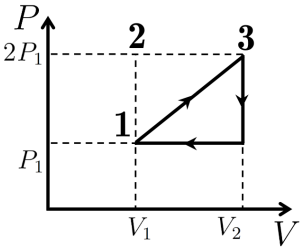
Remark. Consider the acceleration of gravity to be 10 m/sec^2. Ignore air resistance.

(*M. Krupina*)

11.3. (2 points) Two acoustic systems were installed at the edges of the open-air stage at the distance of 6 m. Due to a mistake by the sound engineer, they «buzzed». The viewer, who was opposite the center of the stage at the distance of 20 m from it, found out that if he moved from his initial position 2 m either to the left or right, then the sound volume turned out to be the smallest.

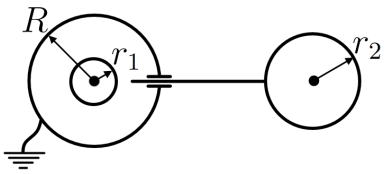
[3] At what frequency did the speakers buzz? Give the answer in Hz, rounded to integers. The speed of sound in air was 345 m/sec. (*T. Andreeva*)

11.4. (3 points) The figure shows a cycle carried out with a monatomic ideal gas. it is known that the efficiency of the Carnot cycle carried out in the same temperature range is 64%, and with isobaric expansion the volume of the gas increases by 2 times.



[4] Find out the efficiency of the cycle. Give the answer in percentages with an accuracy of tenths. (*S. Starovoytov*)

11.5. (4 points) Charges of $q_1 = 0.6$ μC and $q_2 = 1.5$ μC were imparted to two metal balls with radii $r_1 = 10$ cm and $r_2 = 20$ cm respectively, and then they were connected with a thin wire. After that, a ball with radius r_1 is placed inside a metal sphere with a radius $R = 3r_1$ and this sphere is grounded.



[5] What charge will pass through the connecting wire when the sphere is being grounded? Give the answer in μC, rounded to tenths.

Remark. The distance between the centers of the balls is much greater than their radii.

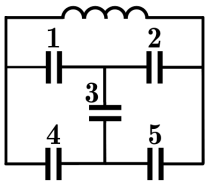
(*M. Krupina*)

11.6. (3 points) Having obtained a barrel of potassium dicyanoaurate on a captured ship, Jack the Sparrow decided to make several hundred fake gold coins from copper coins of some ancient forgotten country that had long been lying in an abandoned chest. He carefully measured the coins — they all had a diameter of 22 mm and the thickness of 1.5 mm. As a current source for electroplating coins with gold Jack took 11 giant electric stingrays, who could give the current of as much as 50 mA for 2 hours each.

[6] How many coins did Jack manage to gild if the layer of gold applied by him was 4.5 μm thick? Give the answer as an integer.

Remark. The electrochemical equivalent of gold in this process is 2.04 mg/C, the density of gold makes 19.3 g/cm^3.

11.7. (4 points) A coil with a number of turns $N = 1000$ and the diameter $d = 1$ cm is placed in a uniform magnetic field parallel to its axis. The field induction increases uniformly with the speed $B_0 = 0.01$ T/sec. The ends of the coil are closed to a battery of five identical capacitors, with a total capacity of $C = 1$ μF.



[7] Find out the charge Q_5 on the fifth capacitor. Give your answer in nC with accuracy of hundredths. (*V. Kuzmichev, S. Starovoytov*)

11.8. (3 points) α-particle flying at a speed of $V_x = 2 \cdot 10^5$ m/sec along the axis OX, enters the region of space where there are uniform electric and magnetic fields, and both the electric field strength and the magnetic field induction are directed along the axis OY. $E = 1000$ V/m, $B = 0.5$ T.

[8] In how many times will the particle's velocity change when it makes $N = 20$ full turns around the OY axis? Give your answer as a number with an accuracy of tenths. (*S. Starovoytov*)

11.9. (3 points) A flat thin object was placed parallel to the plane of a thin divergent lens with a focal length of 10 cm. The lens was replaced with a converging lens with the same focal length.

[9] Where should the object be moved along the main optical axis so that the size of its image does not change? Give only one **symbol**: either «+» if the object should be moved to the lens, or «−» if otherwise.

[10] What distance should the object be moved along the main optical axis so that the size of its image does not change? Give your answer in centimeters with an accuracy of integers.

(*S. Starovoytov*)