International Physics Olympiad
«Formula of Unity» / «The Third Millennium»
Year 2020/2021. 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, 2020**.
All the information about the Olympiad and the instructions for participants: formulo.org/en/olymp/2020-phys-en/.

8.1. In the Rheomur alcohol thermometer the interval between the temperature of melting ice ($0°\mathrm{Re} = 0°\mathrm{C}$) and boiling water ($80°\mathrm{Re} = 100°\mathrm{C}$) is divided into 80 parts instead of 100 parts in the Celsius thermometer.
What is the normal temperature of 36.6°C of the human body in °Re? Give the answer rounded to tenth. (*Folklore*)

8.2. A car has an efficiency factor 0.2 and consumes 8 liters of gasoline with a density of 700 kg/m^3 and a calorific value of $4 \cdot 10^7$ j/kg per 100 km of road. It is known that the drag force for a car increases in direct proportion to the speed: $F = bv$, where $b = 16\ \frac{\mathrm{N}}{\mathrm{m/s}}$.
Calculate the speed value for such vehicle characteristics. Give the answer in km/h, rounded to an integer. (*A. Minarsky*)

8.3. A meteorite with a mass of 22.5 billion tons falls at 20 km/s into an ocean with the initial temperature of 20°C. The ocean area is 350 million km^2, the average ocean depth is 3 km, the specific heat capacity of water is $4200\ \frac{\mathrm{J}}{\mathrm{kg \cdot deg}}$, the specific heat of water vapor generation is $3{,}3 \cdot 10^6$ J/kg.

[1] By how many «milli-degrees» (0,001°C) will the ocean temperature increase if all the heat is distributed evenly?

[2] What maximum mass (in billions of tons) of water could evaporate with uneven heat distribution?

For both questions give the answers rounded to an integer. (*A. Minarsky*)

8.4. An ice cube with a mass $m = 0.1$ kg with a lead pellet inside floats in a heat-insulated container full of water. The cube began to sink when 20 kJ was supplied to it. Ice density is 0.9 g/cm^3, ice melting heat is 340 kJ/kg, lead density is 11.3 g/cm^3.
What is the mass of the pellet? Give the answer in grams, rounded to an integer. (*Folklore*)

8.5. There is a boat with a man and several massive cannonballs of the same size in a pool. The man starts throwing cannonballs out of the boat. The first cannonball falls into the water. The second one falls somewhere outside the pool. By lifting the first cannonball with an oar, the man gets it from the water back into the boat.
Answer for each of these 4 time periods how the water level in the pool has changed (1 = remains the same, 2 = increases, 3 = decreases):

[1] The level after the fall of the first cannonball into the pool.

[2] The level after the fall of the second cannonball outside the pool.

[3] The level after lifting the first cannonball back into the boat.

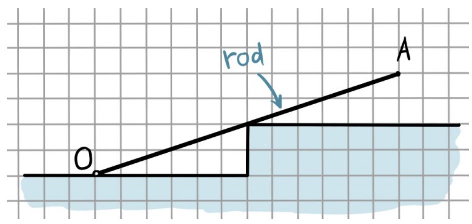
[4] The final level according to the initial one. (*A. Sokol, A. Minarsky*)

8.6. Two boys run one after another in a circle on a sports ground with constant speed. Every 12 minutes the first runner overtakes the second one. The dog Rex runs towards the runners and meets the second runner every 3 minutes.
What is the period of time between Rex' meetings with the first runner? Give the answer in seconds, rounded to an integer. (*Folklore*)

8.7. Two connected identical containers are filled with water and installed on a horizontal table. A cube is placed on the bottom of one of the containers so it is completely covered with water. The mass of the cube is $m = 100$ g and its density is $d = 2.5$ g/cm^3. The area of the bottom of each vessel is 20 cm^2.
[1] How will the pressure of the first vessel on the surface of the table change?
[2] How will the pressure of the second vessel on the surface of the table change?
Give both answers in Pa, rounded to an integer.
Remark: take the acceleration of gravity as equal to 10 N/kg. (*A. Sokol, A. Minarsky*)

8.8. In a workshop for quenching parts there is a big tank with 100 l of water at temperature $T_1 = 30$°C. An iron billet with weight of 10 kg and temperature of 500°C is put inside this tank so that some of the water evaporates and the water temperature becomes $T_2 = 34$°C.
How much water has evaporated? Give the answer in grams, rounded to an integer.
Remark: the specific heat capacity of water is 4200 $\frac{\text{J}}{\text{kg}\cdot\text{deg}}$, its specific heat of steam generation at a boiling point is 2.3 MJ/kg, and the specific heat capacity of iron is 460 $\frac{\text{J}}{\text{kg}\cdot\text{deg}}$. (*A. Sokol*)

8.9. A massive homogeneous rod with mass 20 kg, connected to the point O and freely rotating around it, lies on a stair (see the figure with a cell grid).
What is a minimum force required to apply to the end of the rod A in order to lift it up? Give the answer in newtons, rounded to an integer.



Remark: take the acceleration of gravity as equal to 10 N/kg. (*I. Demidov*)

8.10. Three friends: Winnie-the-Pooh, Piglet and the donkey Eeyore decide to take a trip from the Owl house to the High-Above Oak. Each of them goes at a constant speed. Eeyore walks slowly, so he has decided to start before the others and reaches the oak tree in exactly 3 hours. When the donkey has passed one third of the way, he is overtaken by Piglet, and another half an hour later he is overtaken by Winnie. It is known that Winnie and Piglet started at the same time and Piglet ran during the entire trip so he was 1.5 times faster than Winnie-the-Pooh.
[1] How many times faster did Piglet run than Eeyore?
[2] How much time (in hours) did it take Winnie-the-Pooh to get to the Oak?
[3] How long (in hours) did Piglet have to wait for Eeyore under the Oak?
Give all the answers rounded to tenth. (*A. Minarsky, N. Bogoslovsky*)

International Physics Olympiad
«Formula of Unity» / «The Third Millennium»
Year 2020/2021. Qualifying round

Problems for grade R9

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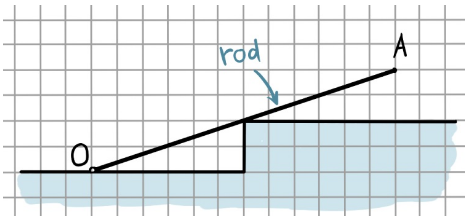
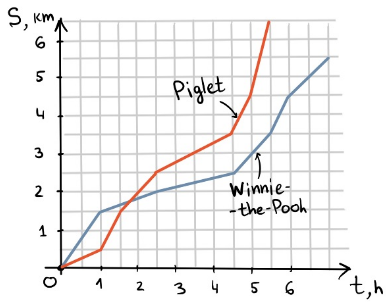
9.1. A massive homogeneous rod with mass 20 kg, connected to the point O and freely rotating around it, lies on a stair (see the figure with a cell grid).
What is a minimum force required to apply to the end of the rod A in order to lift it up? Give the answer in newtons, rounded to an integer.
Remark: take the acceleration of gravity as equal to 10 N/kg. (*I. Demidov*)



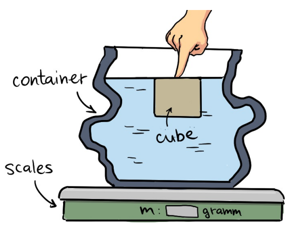
9.2. There are 2020 identical numbered balls with temperatures changing in the arithmetic progression of $T_1 = T$, $T_2 = 2T$, $T_3 = 3T$, …, $T_{2020} = 2020T$ (the value of T is measured in Celsius). All the balls were placed in a heat-insulated container with a negligible heat capacity.
What temperature will the balls have after a sufficiently long period of time, if it is known that if there were only two balls with the numbers 1000 and 2000 in the container, they would have a steady temperature of 1800 C? Give the answer rounded to an integer. (*I. Demidov*)

9.3. The figure shows a graph of the paths taken by Winnie-the-Pooh and Piglet versus time.
[1] Who of them was able to achieve a higher average speed during the walk? If it was Winnie, type «W», otherwise — «P».
[2] What is this maximum value of the average speed? Give the answer in km/h, rounded to tenths. (*I. Demidov*)



9.4. Lazy Dunno is travelling in a cart (by inertia only) with two equal bags of apples. The cart moves relatively slowly at a speed of 3 m/s. Dunno is too lazy to push the cart, so he comes up with the idea to throw out some of the apples, thereby reducing the total weight of the cart (he would not be able to eat so many apples anyway) and, according to the conservation of momentum law, increasing its speed. So he takes one bag of apples and throws it perpendicularly to the cart's direction.
How long will it take for Lazy Dunno to reach the final destination 12 km ahead? Give the answer in seconds, rounded to an integer.
Remark: the total mass of the Dunno and the cart is 25 kg, one bag of apples weighs 5 kg. There is no friction. (*I. Demidov*)

9.5. A container of some shape with some water and a floating wooden cube inside is placed on a scale. The density of water is 1 g/cm^3, the density of wood is 0.7 g/cm^3, the side of the cube $a = 10$ cm.
How much will the scale measurement change if the cube is pushed that it completely drowns? Give the answer in kg, rounded to tenths. (*I. Demidov*)



9.6. Paul went camping and brought a tent and a sleeping bag with him. The evening was rather warm so he fell asleep outside. At night the temperature dropped so much that at $T_1 = 18$ C Paul felt cold and moved inside the tent but without the sleeping bag. When the temperature outside dropped even more to $T_2 = 14$ C, he felt cold again so he found his sleeping bag and fell asleep back in it outside the tent. Finally at the air temperature $T_3 = 10$ C he got so freezing cold that he went inside the tent in the sleeping bag.

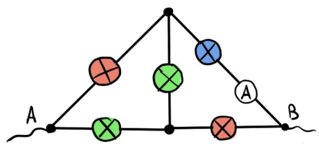
[1] At what air temperature T_4 will Paul start freezing in his sleeping bag inside the tent? Give the answer rounded to an integer.

[2] How many people should sleep in such sleeping bags inside the tent so they do not freeze at the outside temperature $T_0 = 0$?

Consider that any person, while sleeping, emits heat at a certain constant rate, and this speed does not depend on the outside temperature. (*A. Minarsky, N. Bogoslovsky*)

9.7. Let M be the mass of the Moon, R — its radius, and $G = 6.67 \cdot 10^{\ 11}\ \mathrm{N \cdot m^2/kg^2}$ — the gravitational constant. What formula can be used to estimate the pressure in the center of the Moon?
A: $p \approx G/MR^2$; B: $p \approx R/GM$; C: $p \approx GM^2/R^4$; D: $p \approx GM/R^2$; E: $p \approx GMR^2$.
(*I. Demidov*)

9.8. Dunno made a short chain of lights (see the picture). The red lamp's resistance is twice as big as the green one's, and the blue lamp's resistance is 2 times bigger than the red one's. When the circuit was connected to a constant voltage source of 120 V, an ideal ammeter showed 0.1 A. Dunno went to put up the lights on his door and accidentally plugged it in another voltage source. Unfortunately, all the red lamps burned out and the ammeter began to show 2 times bigger value than before.

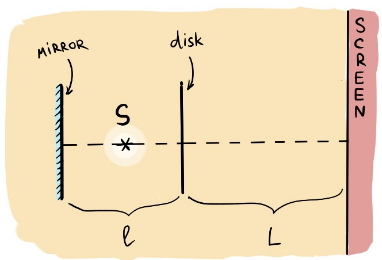


[1] What is the resistance of the green lamp (in Ohms)?

[2] What is this new voltage value (in Volts) that Dunno powered the circuit with?

Give both answers rounded to an integer. (*I. Demidov*)

9.9. A point light source S is placed in the middle between an opaque disk with the radius $R = 10/\sqrt{\pi}$ cm and a flat circle mirror of the same radius (see the picture).



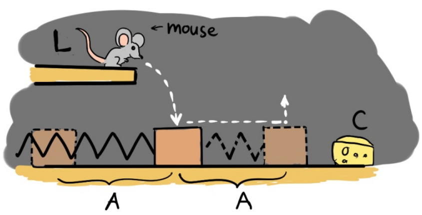
[1] Find the area of the full shadow on the screen (in cm^2) if the distance between the disk and the screen is $L = 15$ cm and between the disk and the mirror is $l = 5$ cm.

[2] Find the area of the part of the screen (in cm^2) where only the source image is visible in the mirror (but the source itself is invisible).

Give both answers rounded to an integer.

Remark: both the disk and the mirror are parallel to the screen and its centers are perpendicular to the mirror (indicated by a dotted line in the drawing). (*I. Demidov*)

9.10. The mouse needs to get from the ledge L to the some cheese (point C, see the picture), but on its way there is a cube on a spring harmonically oscillating without any friction with an amplitude equal A. The mouse accelerated and jumped from the ledge onto the cube. At the moment of landing the cube was in its balance position and the horizontal projections of velocities of the mouse and the cube were equal. After that, when the cube reached its extreme position, the mouse slightly jumped up vertically and landed on the floor, continuing its way to the cheese.



[1] How did the total mechanical energy of the spring and the cube change (relatively its initial state when the mouse was on the ledge) right after the mouse landed on the cube?

[2] How did the total mechanical energy of the spring and the cube change (relatively its initial state when the mouse was on the ledge) right before the mouse jumped off?

[3] What will the amplitude of the cube be equal to after the mouse's visit, if A is equal to 8 cm, and the mass of cube is 80% of the mouse's. Give the answer in cm, rounded to 2 significant digits.

Answer to the first 2 questions as «remains the same» (1), «increases» (2) or «decreases» (3).
(*I. Demidov, A. Minarsky*)

International Physics Olympiad
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Year 2020/2021. Qualifying round

Problems for grade R10

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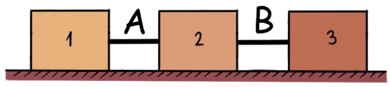
10.1. A glass of ice ($m = 308$ g) with its bottom down was placed in a deep pot with water. Knowing that the radius of the pot is 14 cm and the radius of the glass is 7 cm, answer the following questions:
[1] How much did the water level Δh_1 rise after the glass had been lowered into it (before the ice started to melt)?
[2] Some time later the glass completely melted so the water level rose by Δh_2 compared to the very beginning (even before the glass was placed). Find the difference $\Delta h_2 - \Delta h_1$.
Give both answers in cm, rounded to an integer.
Remark: water density is 1 g/cm^3. (*I. Demidov*)

10.2. The lift force of an aircraft wing is directly proportional to both square of the aircraft speed and area of the wing. One student made a 1:25 scale model of a plane so that all linear dimensions of the model are 25 times smaller than the original ones. Assume that the model and the plane are flying horizontally at the same height without any acceleration.
[1] Is the speed of the model bigger than the plane speed? If so, type «B», otherwise — «S».
[2] How many times will the speed of the model and the plane speed differ? Give the answer rounded to an integer.
Take densities of the model and the plane as equal. (*A. Minarsky, N. Bogoslovsky*)

10.3. If the average velocity of the molecules of an ideal gas is increased by 10 m/s, its pressure will increase by exactly 21%.
By how many percent (from the initial value) will the pressure in this gas increase if the average speed is increased by another 10 m/s? Give the answer rounded to an integer. Remark: take the gas volume as constant. (*A. Minarsky*)

10.4. Three bricks of the same mass $M = 1$ kg, connected by threads A and B, are lying on a horizontal table. The threads are torn by the tension force $T = 6$ N. The bricks are made of materials with different friction coefficients $\mu_1 = 0.1$, $\mu_2 = 0.3$ and $\mu_3 = 0.5$ for bricks 1, 2 and 3 respectively.



[1] If someone starts to pull the first block to the left with slowly increasing force F, which one of the threads will break first? Give «A» or «B» as the answer.
[2] At what value of the force F will this happen? Give the answer rounded to an integer.
[3] If someone starts to pull the third block to the right with slowly increasing force F, which one of the threads will break first? Give «A» or «B» as the answer.
[4] At what value of the force F will this happen? Give the answer rounded to an integer.
Remark: take the acceleration of gravity as equal to 10 m/s^2. (*A. Minarsky, N. Bogoslovsky*)

10.5. In a large Christmas garland, 44 light bulbs burned out and connecting wires were inserted instead. After that, the power of each of the remaining lamps increased by 44%.
How many working lights are there in the garland? Consider that the resistance of each bulb does not depend on its brightness, and the resistance of the wires is negligible. (*A. Minarsky*)

10.6. Paul went camping and brought a tent and a sleeping bag with him. The evening was rather warm so he fell asleep outside. At night the temperature dropped so much that at $T_1 = 18$ C Paul felt cold and moved inside the tent but without the sleeping bag. When the temperature outside dropped even more to $T_2 = 14$ C, he felt cold again so he found his sleeping bag and fell asleep back in it outside the tent. Finally at the air temperature $T_3 = 10$ C he got so freezing cold that he went inside the tent in the sleeping bag.

[1] At what air temperature T_4 will Paul start freezing in his sleeping bag inside the tent? Give the answer rounded to an integer.

[2] How many people should sleep in such sleeping bags inside the tent so they do not freeze at the outside temperature $T_0 = 0$?

Consider that any person, while sleeping, emits heat at a certain constant rate, and this speed does not depend on the outside temperature. (*A. Minarsky, N. Bogoslovsky*)

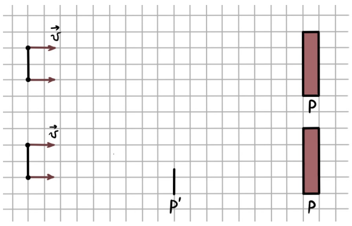
10.7. A glass of water with some 10 mm^3 gas bubble at the bottom was placed on an accurate digital scale with a fast response and a stationary bowl. The scale showed 100,000 mg. At some moment, the bubble started floating up.

[1] How did the scale measurement change while the bubble was floating? If increased, type «B», otherwise — «S».

[2] What is the scale measurement when the acceleration of the bubble was 6 m/s^2? Give the answer in mg, rounded to an integer.

Remark: take the acceleration of gravity as equal to 10 m/s^2. (*S. Sashov, A. Minarsky*)

10.8. Two very small massive balls are connected by a weightless rigid rod of length $L = 2$ m. Two experiments are performed in a vacuum with zero gravity.



In the first case, the balls are simultaneously given the same speed $v = 1$ m/s in the direction perpendicular to the rod. After some time t_1, the balls simultaneously hit a stationary wall P.

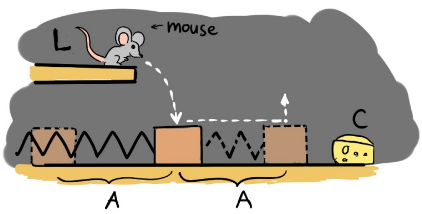
In the second case, a thin (with negligible thickness) rigid absolutely elastic wall P^0 is rigidly installed in the middle of the trajectory of the lower ball, so this time the balls reach P after time t_2.

Calculate $\Delta t = t_2 - t_1$. Give the answer in seconds, rounded to hundredth. (*S. Sashov, A. Minarsky*)

10.9. A small ball moves counterclockwise along a wire bent in the shape of an ellipse* (see the picture). The speed modulus of the ball is 10 cm/s.

Find the component of the speed of the ball along the y axis when the ball is at the point P. Give the answer in cm/s, rounded to hundredth. (*S. Sashov, A. Minarsky*)

10.10. The mouse needs to get from the ledge L to the some cheese (point C, see the picture), but on its way there is a cube on a spring harmonically oscillating without any friction with an amplitude equal A. The mouse accelerated and jumped from the ledge onto the cube. At the moment of landing the cube was in its balance position and the horizontal projections of velocities of the mouse and the cube were equal. After that, when the cube reached its extreme position, the mouse slightly jumped up vertically and landed on the floor, continuing its way to the cheese.



[1] How did the total mechanical energy of the spring and the cube change (relatively its initial state when the mouse was on the ledge) right after the mouse landed on the cube?

[2] How did the total mechanical energy of the spring and the cube change (relatively its initial state when the mouse was on the ledge) right before the mouse jumped off?

[3] What will the amplitude of the cube be equal to after the mouse's visit, if A is equal to 8 cm, and the mass of cube is 80% of the mouse's. Give the answer in cm, rounded to 2 significant digits.

Answer to the first 2 questions as «remains the same» (1), «increases» (2) or «decreases» (3). (*I. Demidov, A. Minarsky*)

* An ellipse is a circle evenly stretched in one direction.

International Physics Olympiad
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Year 2020/2021. Qualifying round

Problems for grade R11

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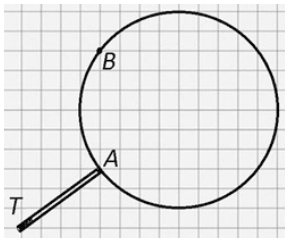
11.1. Two endless columns of athletes run side by side in opposite directions. The first column runs from left to right with a speed of each athlete equal to $v_1 = 5$ m/s and a distance between runners equal to $l_1 = 10$ m. The second column runs from right to left with a speed $v_2 = 3$ m/s and a distance between runners $l_2 = 20$ m. When two athletes meet each other, they pass a baton.
What is the average speed of the baton for a long period of time? Give the answer in m/s, rounded to 2 significant digits. Take the direction from left to right as positive.
Remark: an average speed of rectilinear movement is a ratio of the coordinate change to the time spent on this change. (*S. Sashov*)

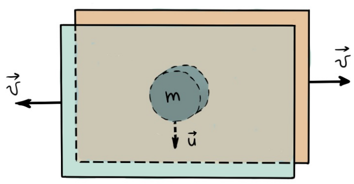
11.2. A small ball moves counterclockwise along a wire bent in the shape of an ellipse* (see the picture). The speed modulus of the ball is 10 cm/s.
Find the component of the speed of the ball along the y axis when the ball is at the point P. Give the answer in cm/s, rounded to hundredth. (*S. Sashov, A. Minarsky*)

11.3. In a vacuum, a ball made of homogeneous rubber is inflated through a fixed tube T of a very small diameter with the end at the point A. The air is fed into the ball through the tube in such a way that the volume of the ball increases by 2 cm^3 per second.
Find the value of the instantaneous velocity of a point B on the ball. Give the answer in cm/s, rounded to 3 significant digits.
Remark: A side of a cell on the picture is equal to 1 cm. (*S. Sashov*)



11.4. In zero gravity there is a fixed (motionless) concave conical surface (the interior of the cone) with a small angle $\alpha = 0.001$ radian between the axis and the generatrix. A small ball rolls on this surface freely without any friction (there is no air resistance either). At the initial moment of time, the ball is located at a distance $L = 10$ m from the top of the cone. Its velocity is perpendicular to the generatrix and equals $v = 1$ m/s.
What is the acceleration component of the ball along the axis of the cone? Give the answer in m/s^2, rounded to 3 significant digits. (*S. Sashov*)

11.5. A washer with a mass $m = 10$ g is clamped with a force $F = 100$ N between two vertical planes («millstones»). The coefficient of friction between the washer and each of the planes equals to $\mu = 0.5$. Take the acceleration of gravity as equal to $g = 10$ m/s^2. The planes move horizontally in opposite directions with the same speed $v = 1$ m/s.



At what steady speed will the washer slide down? Give the answer in m/s, rounded to 3 significant digits. (*S. Sashov*)

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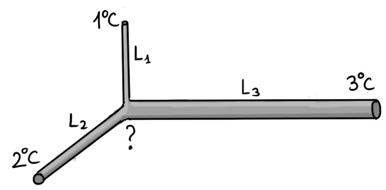
* An ellipse is a circle evenly stretched in one direction.

11.6. A spherical planet without any atmosphere has a radius $R = 1000$ km. A small thing falls without initial velocity on this planet from the same height R above the surface.
How long does it take for the thing to fall to the surface of the planet? The acceleration of gravity on the surface of the planet is $g = 1$ m/s^2. Give the answer in seconds, rounded to 3 significant digits. (*S. Sashov*)

11.7. Paul went camping and brought a tent and a sleeping bag with him. The evening was rather warm so he fell asleep outside. At night the temperature dropped so much that at $T_1 = 18°$C Paul felt cold and moved inside the tent but without the sleeping bag. When the temperature outside dropped even more to $T_2 = 14°$C, he felt cold again so he found his sleeping bag and fell asleep back in it outside the tent. Finally at the air temperature $T_3 = 10°$C he got so freezing cold that he went inside the tent in the sleeping bag.
[1] At what air temperature T_4 will Paul start freezing in his sleeping bag inside the tent? Give the answer rounded to an integer.
[2] How many people should sleep in such sleeping bags inside the tent so they do not freeze at the outside temperature $T_0 = 0°$?
Consider that any person, while sleeping, emits heat at a certain constant rate, and this speed does not depend on the outside temperature. (*A. Minarsky, N. Bogoslovsky*)

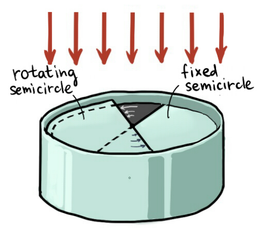
11.8. Three rods of the same material have lengths L_1, $L_2 = 2L_1$, $L_3 = 3L_1$ and diameters of the circular cross section D_1, $D_2 = 2D_1$, $D_3 = 3D_1$, respectively. All three rods are connected at one point by one of their ends. Temperatures at the free ends of the rods are $t_1 = 1°$C, $t_2 = 2°$C and $t_3 = 3°$C, respectively.



What temperature will be established at the point of connection of the rods after a long time? Give the answer in °C, rounded to 3 significant digits.
(*S. Sashov, A. Chudnovsky*)

11.9. A cube frame with an edge length $a = 40$ cm was made of $m = 89$ g of copper wire. The wire segments have good electrical contact at the vertices of the cube.
What is the resistance R of the cube between its opposite vertices (lying on a straight line through the center of the cube)? Give the answer in mΩ, rounded to 2 significant digits.
Remark: use the following copper parameters in calculations: its resistivity is $\mu = 0{,}017\ \Omega \cdot \text{mm}^2/\text{m}$, its density is $\rho = 8900$ kg/m^3. (*A. Chudnovsky*)

11.10. A light with an energy flux density (power per unit surface) of 1 mW/cm^2 falls on the circular entrance hole with a diameter of 2 cm of a light-sensitive detector. A device («curtains») made of 2 semicircles is installed on the hole. One of the semicircles is fixed, covering half of the entrance hole of the detector, while the other one continuously rotates at a constant angular velocity — when both semicircles are in the same position, the detector receives the maximum luminous flux, and in the opposite position, the luminous flux is completely blocked.



What is a total energy of the light entering the detector in $T = 10$ s? Give the answer in MJ, rounded to 3 significant digits.
Remark: take that the moving semicircle makes several full rotations in this period of time. (*S. Sashov*)