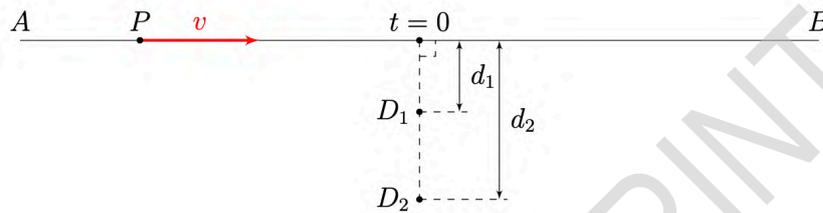
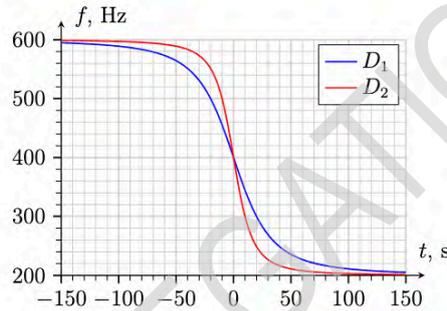


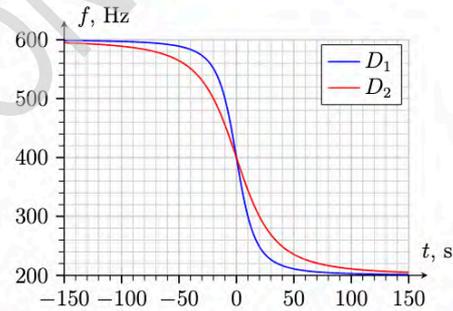
**P.1** During flight tests, aircraft  $P$  moves along a straight line  $AB$  with a constant speed  $v < c$ , where  $c$  is the speed of sound. Throughout the flight, the aircraft emits sound signals at a constant frequency. During the tests, the frequency of the sound is measured by two detectors  $D_1$  and  $D_2$ . The detectors are located at distances  $d_1$  and  $d_2 > d_1$ , respectively, from the straight line  $AB$  on a single perpendicular to it (see figure).



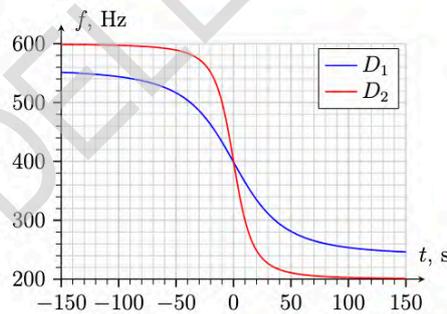
Select the answer option that correctly shows the dependence of the frequency  $f$  of the received signal on time  $t$ . The moment when the aircraft is at the minimum distance from the detectors is considered the time origin ( $t = 0$ ). The blue curve corresponds to detector  $D_1$ , the red curve to  $D_2$ .



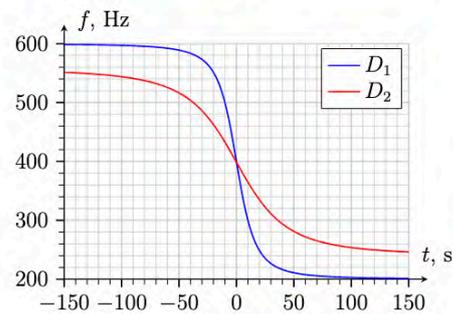
(A)



(B)



(C)



(D)

- A. Fig. (A)
- B. Fig. (B)
- C. Fig. (C)
- D. Fig. (D)

- P.2** A fidget spinner is an entertaining spinning toy. There is a bearing in the center of the spinner, and several blades with weights are arranged radially. In the video clip provided, you can see the spinner spinning rapidly at the beginning. The video was filmed with a smartphone camera at a frame rate of 30 frames per second. What is the rotation period  $T$  of the spinner at time  $t = 48$  s in the video? Watch the video and select the closest answer.



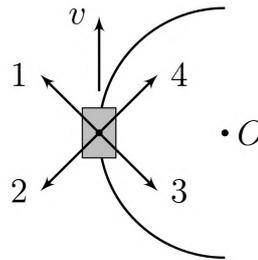
video:

- A.  $T \approx 0.033$  s;  
 B.  $T \approx 0.1$  s;  
 C.  $T \approx 0.2$  s;  
 D.  $T \approx 0.4$  s.

- P.3** A snail is attached to the inside of the vertical wall of the aquarium filled with water. There is no air between the snail's body and the glass. The area of the dry contact spot (where the snail contacts the glass) is  $S$ , and the volume of the snail is  $V$ . The snail's center of gravity is at a depth  $h$  below the water surface. The density of water is  $\rho_0$ , the free-fall acceleration is  $g$ , the atmospheric pressure is  $p_0$ . Neglect the change in hydrostatic pressure over the area of the spot. Find the total force exerted by the water on the snail.

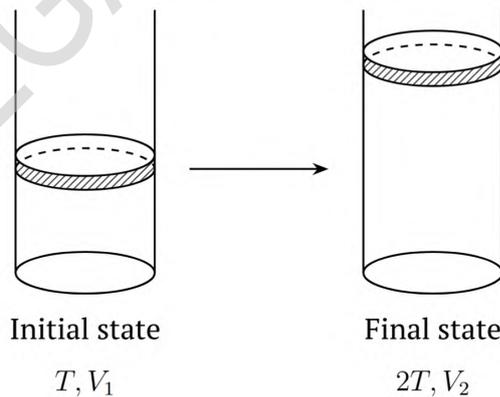
- A.  $F = \rho_0 g V$ ;  
 B.  $F = \rho_0 g V - \rho_0 g h S$ ;  
 C.  $F = \sqrt{(\rho_0 g V)^2 + (\rho_0 g h S)^2 + (p_0 S)^2}$ ;  
 D.  $F = \sqrt{(\rho_0 g V)^2 + ((\rho_0 g h + p_0) S)^2}$ .

- P.4** A car moves along a circular arc of radius  $R$  clockwise. The speed of the car increases during the motion along the arc. In the sealed interior of the car, a helium balloon is tied to the floor with a light, inextensible string. At rest, the balloon hangs in the air without touching the floor or ceiling. Determine in which direction the balloon may tilt relative to its state of rest (see figure):



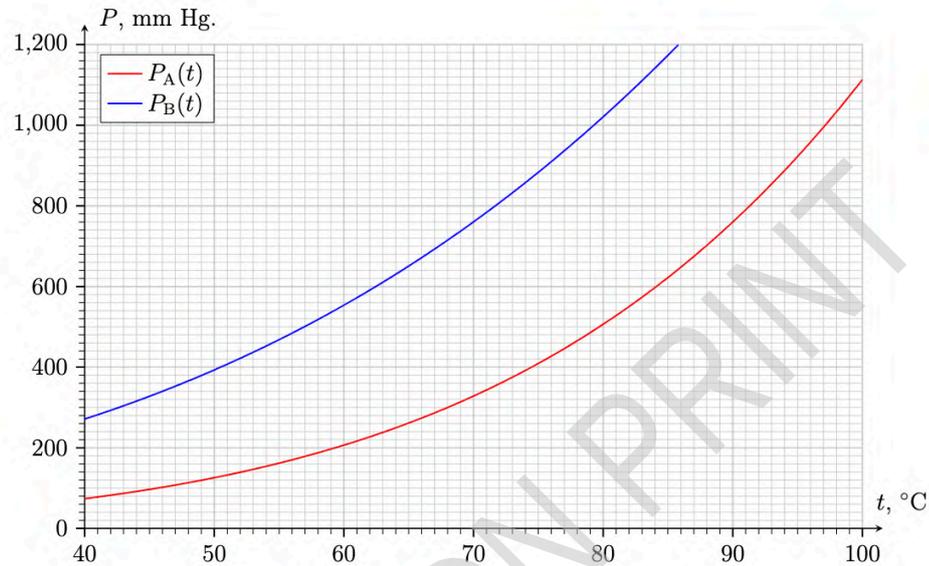
- A. in direction 1;  
 B. in direction 2;  
 C. in direction 3;  
 D. in direction 4.

- P.5** In a cylindrical vessel under a freely movable piston, there is carbon dioxide. When the absolute temperature of the gas doubled, half of the initial carbon dioxide molecules dissociated into carbon monoxide (CO) and molecular oxygen. Assuming that the piston moved slowly and without friction, determine by what factor the volume of gas increased. All the gases can be considered ideal.



- A. 1.5 times;  
 B. 2.5 times;  
 C. 3 times;  
 D. 4 times.

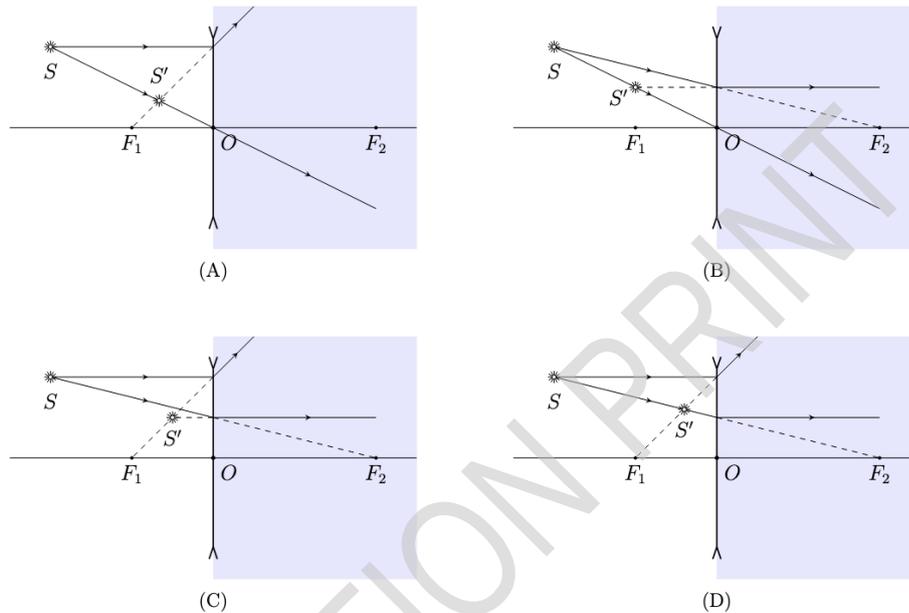
**P.6** The figure shows graphs of the temperature dependence of saturated vapor pressure for two immiscible liquids A and B.



Boiling is a process that occurs when the pressure of saturated vapor of a liquid equals the external pressure. If both liquids are in the same container, boiling will begin at their interface when heated. Given an air pressure of 760 mm Hg, determine the boiling temperature of the mixture. Neglect hydrostatic pressure.

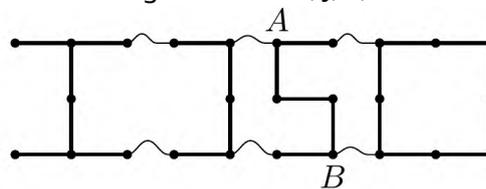
- A. 60 °C;
- B. 70 °C;
- C. 80 °C;
- D. 90 °C

**P.7** A thin diverging lens is located at the boundary between two media of different refractive indices ( $n_1$  and  $n_2$  where  $n_1 \neq n_2$ ). Due to the difference in refractive indices, the front and rear focal lengths of such a lens are not equal. Figures A-D show possible constructions of the image of a point source  $S$ . Select the correct construction.



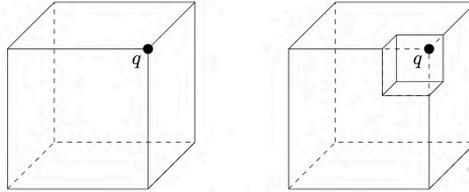
- A. Fig. (A)
- B. Fig. (B)
- C. Fig. (C)
- D. Fig. (D)

**P.8** Determine the resistance of the wire grid shown in the figure between contacts  $A$  and  $B$ . The resistance of each conductor between the nodes it is connected to is  $R$ . The resistance of the wires connecting the letters I, J, S, O is zero.



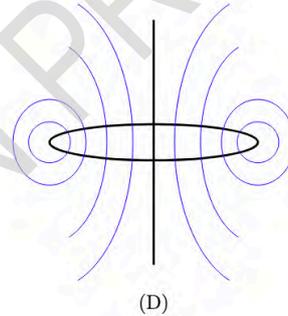
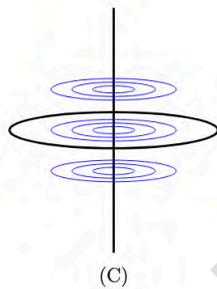
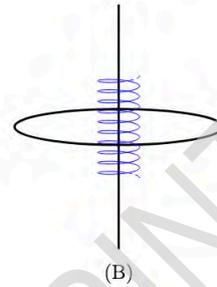
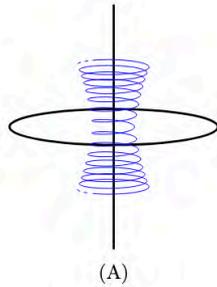
- A.  $3R$
- B.  $\frac{15}{17}R$
- C.  $\frac{17}{15}R$
- D.  $\frac{15}{11}R$

- P.9** A positive point charge  $q$  is held at a fixed point near the vertex of a uniformly charged cube with edge length  $a$  and volume charge density  $\rho > 0$ . The charge is released at zero initial velocity, resulting in a velocity of  $v_1$  at infinity. The experiment is repeated, but a smaller cube with edge length  $a/3$  is removed from the original cube, adjacent to the same vertex where the charge was located (see figure). What will be the velocity  $v_2$  of the charge at infinity if it is released at zero initial velocity from the same position?



- A.  $v_2 = \frac{8}{9}v_1$ ;  
B.  $v_2 = \sqrt{\frac{2}{3}}v_1$ ;  
C.  $v_2 = \frac{2\sqrt{2}}{3}v_1$ ;  
D.  $v_2 = \frac{2}{3}v_1$ .

**P.10** A straight infinite wire passes through the center of the ring perpendicular to its plane. Current  $I_1 \geq 0$  is in the straight wire, and current  $I_2 \geq 0$  is in the ring. Select the figure that shows the magnetic field lines (blue lines) that are impossible given the described mutual arrangement of the wires.



- A. Fig. (A)
- B. Fig. (B)
- C. Fig. (C)
- D. Fig. (D)

**C.1** Octane number is a measure of the performance of engine fuel which indicates the resistance of a motor fuel to knock. Octane numbers are based on a scale on which 2,2,4-trimethylpentane (isooctane) is 100 (minimal knock) and heptane is 0 (maximum knock). The addition of tetraethyl lead was found by Thomas Midgley in 1921 to boost a fuel's octane number ( $\text{Pb}(\text{C}_2\text{H}_5)_4$ , TEL). Currently, its usage has been gradually ceased in the majority of countries, primarily because it hinders catalytic converters and acts as a contributor to lead in the air. The maximum permissible concentration (MPC) of lead atoms in air is  $0.01 \text{ mg}\cdot\text{m}^{-3}$ . 1.0 L of gasoline with an octane number of 93 contains approximately 0.8 g of TEL. Assume that the combustion of 0.5 L of the mentioned fuel generates  $6.0 \text{ m}^3$  of gaseous products. Volumes of all gases measured under the same conditions. Estimate how many times the lead atoms concentration in a given volume of gaseous products exceeds the air's MPC for lead.

- A. 8500
- B. 4300
- C. 6600
- D. 3300

**C.2** Identify the correct ascending order of boiling points of the following compounds under the same conditions ( $P = 1 \text{ atm}$ ).

- 1) hydrogen chloride  $\text{HCl}$  ( $T_1$ )
- 2) methane  $\text{CH}_4$  ( $T_2$ )
- 3) water  $\text{H}_2\text{O}$  ( $T_3$ )
- 4) heavy water  $\text{D}_2\text{O}$  ( $T_4$ )

- A.  $T_2 < T_1 < T_3 < T_4$
- B.  $T_2 < T_1 < T_4 < T_3$
- C.  $T_1 < T_2 < T_3 < T_4$
- D.  $T_2 < T_3 < T_4 < T_1$

- C.3** A and B are elements that exist as diatomic molecules in a gaseous state. Energy changes for the reaction  $A_{2(g)} + B_{2(g)} \rightleftharpoons 2AB_{(g)}$  at standard temperature and pressure can be shown using the following potential energy profile (Fig. 1). Determine the molar enthalpy change ( $\text{kJ}\cdot\text{mol}^{-1}$ ) for the decomposition of AB into  $A_2$  and  $B_2$  under the same conditions.

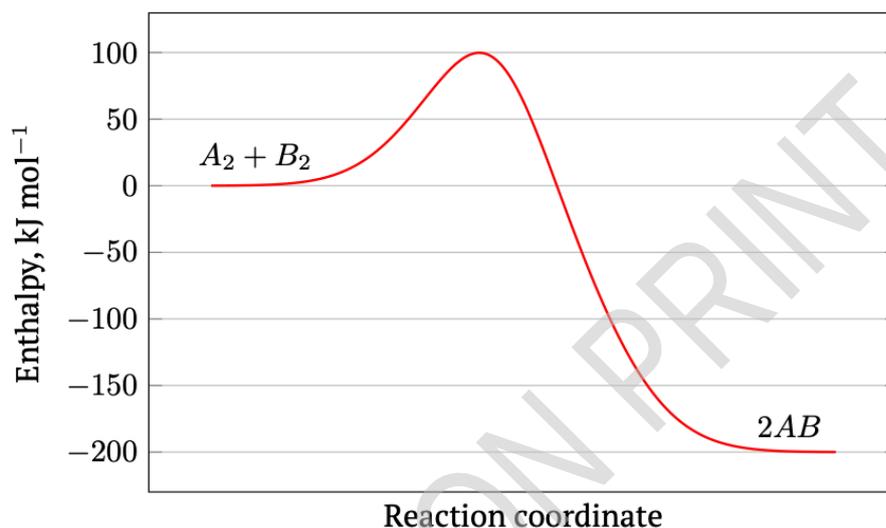


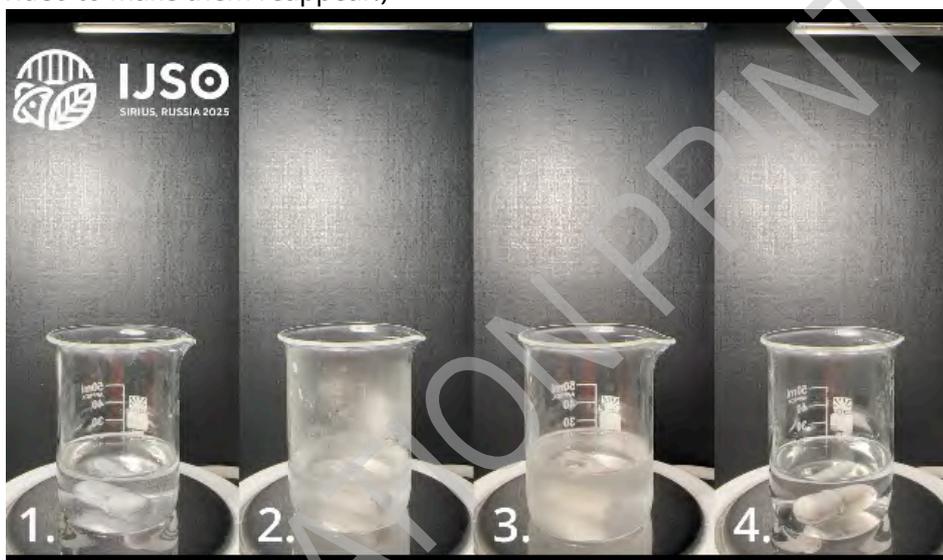
Fig. 1: Potential energy profile.

- A. -100  
 B. +100  
 C. -200  
 D. +200

- C.4** Rank the first dissociation constants ( $K_{a1}$ ) of the following acids in decreasing order.  
 1) fluorosulfonic acid ( $\text{HSO}_3\text{F}$ )  
 2) chlorosulfonic acid ( $\text{HSO}_3\text{Cl}$ )  
 3) methanesulfonic acid ( $\text{HSO}_3\text{CH}_3$ )  
 4) sulfurous acid ( $\text{H}_2\text{SO}_3$ )

- A. 1, 2, 3, 4  
 B. 3, 4, 1, 2  
 C. 4, 1, 3, 2  
 D. 4, 3, 1, 2

- C.5** A student qualitatively estimated the molar enthalpy of solution of electrolytes by observing changes when 0.05 mol each of four substances were fully dissolved in a distilled water under the same conditions. The following video demonstrates the results of four experiments. When the substances 1, 2, 3 and 4 are arranged in order of increasing molar enthalpy of solution values at 298 K, what is the correct order? (You may wish to use the slider when watching a video. Click and drag the handle on the progress bar to scrub through the video, or use your cursor to click a new point to jump to that part of the video. If the controls are hidden, move your cursor over the video to make them reappear.)



Video 1.

- A. 4, 2, 3, 1  
 B. 4, 2, 1, 3  
 C. 3, 1, 2, 4  
 D. 1, 3, 2, 4

- C.6** The redox reaction between potassium iodide and copper (II) sulfate is used to determine the concentration of copper in a solution and is accompanied by the formation of a copper (I) iodide precipitate ( $K_{sp} = 1.27 \cdot 10^{-12}$ ). The excess iodide ion leads to the dissolution of precipitate by forming soluble complexes, such as  $[\text{CuI}_2]^-$ . The equilibrium constant ( $K_{stab}$ ) of the following reaction:  $\text{Cu}^+_{(aq)} + 2\text{I}^-_{(aq)} \rightleftharpoons [\text{CuI}_2]^-_{(aq)}$  is  $5.75 \cdot 10^8$ . Calculate the minimal volume (in L) of solution containing 20% by mass of potassium iodide ( $\rho = 1.166 \text{ g}\cdot\text{ml}^{-1}$ ) required to completely dissolve 0.95 g of copper (I) iodide. Ignore disproportionation processes. Assume that copper (I) compounds are found as  $\text{CuI}$  and  $[\text{CuI}_2]^-$  only, with no additional compounds being formed.

- A. 4.88  
 B. 5.67  
 C. 6.40  
 D. 6.83

- C.7 The potential difference between electrodes results from the different chemical reactions occurring at their surfaces. Therefore, the magnitude of the electrode potential is affected by both the concentration of the reactants and the temperature. For iron electrodes in iron (II) chloride solution it can be determined by the Nernst equation:

$$E_{\text{Fe}^{2+}/\text{Fe}}(T) = E_{\text{Fe}^{2+}/\text{Fe}}^0(T) + \frac{RT}{2F} \ln[\text{Fe}^{2+}],$$

where  $E^0(T)$  grows with higher temperature.

The following cell was constructed: iron electrodes were placed in each beaker containing 1 M iron (II) chloride solution at 298 K and wired to a galvanometer (Fig. 2). A glass tube, equipped with cotton inserts at its extremities and containing KCl solution (2 M), served to connect the beakers. Subsequently, a hot plate raised the temperature of the beaker containing the electrode 1 to 318 K. After the cell ran in this mode for a 4 hours, the electrodes were taken out, dried and weighted. Select the option that correctly outlines the observations.

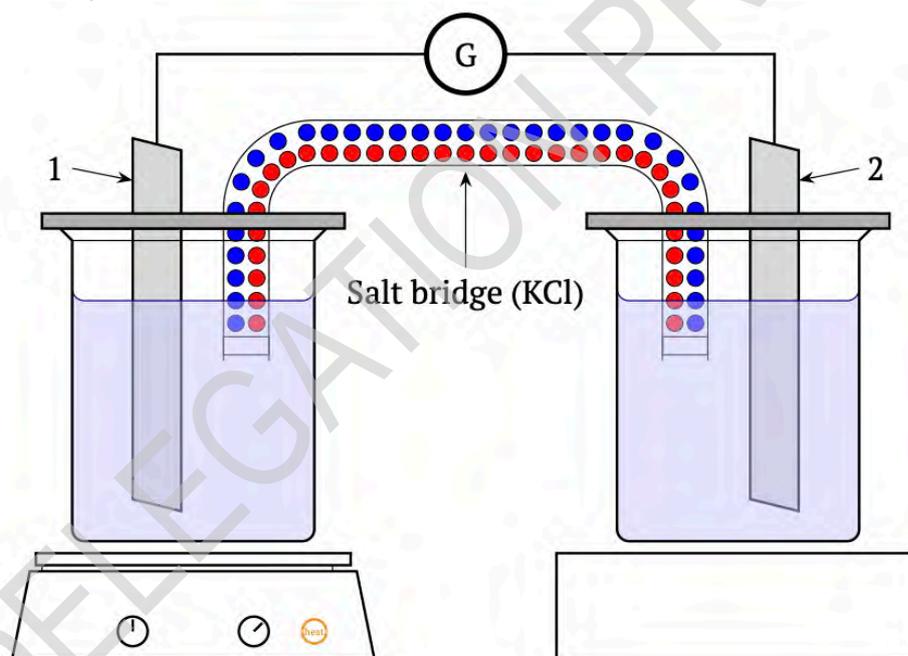


Fig. 2: Voltaic cell.

- A. The mass of the electrode 1 went up, and the mass of the electrode 2 went down  
 B. The mass of the electrode 1 went down, and the mass of the electrode 2 went up  
 C. Both electrodes experienced a mass increase  
 D. Both electrodes experienced a mass decrease

- C.8** A student decided to identify the monoprotic acid, HA, by determining an acid dissociation constant,  $K_a$ , through the osmosis phenomenon that is widely found in nature, particularly in biological systems and could be described through van 't Hoff's law:  $\Pi = CRT$ , where  $\Pi$  — osmotic pressure (Pa);  $C$  — molar concentration of a solute ( $\text{mol} \cdot \text{m}^{-3}$ ). In an experiment, 100 ml of distilled water was introduced into the left arm of a 1 cm diameter U-shaped tube (Fig. 3), which was separated by a water-only permeable membrane. Simultaneously, 100 ml of a 0.001 M HA solution was added to the right arm. Once equilibrium was established, the fluid level in the right knee was 26 cm higher than in the left knee. The experiment was conducted at a temperature of 25 °C. Determine the  $K_a$  of an unknown acid. Assume that the density of the solution is equal to the density of water.

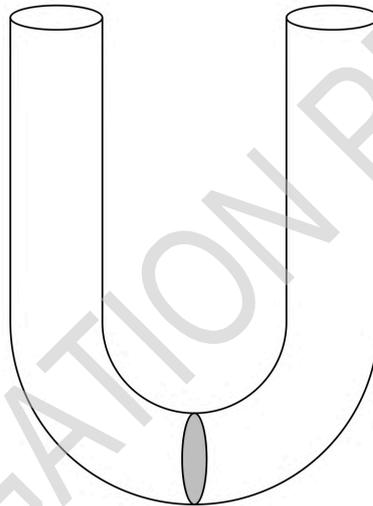


Fig. 3: Empty U-shaped tube with membrane.

- A.  $6.76 \cdot 10^{-5}$   
B.  $1.90 \cdot 10^{-5}$   
C.  $7.59 \cdot 10^{-7}$   
D.  $4.37 \cdot 10^{-6}$

- C.9** The potentiometric titration of a particular monoprotic acid solution with a potassium hydroxide solution of an unknown concentration was performed by a student, utilizing a homemade pH meter. The following graphs were drawn: calibration curve (Fig. 4) and titration curve (Fig. 5). Calculate the pH of the solution once the equivalence point is reached.

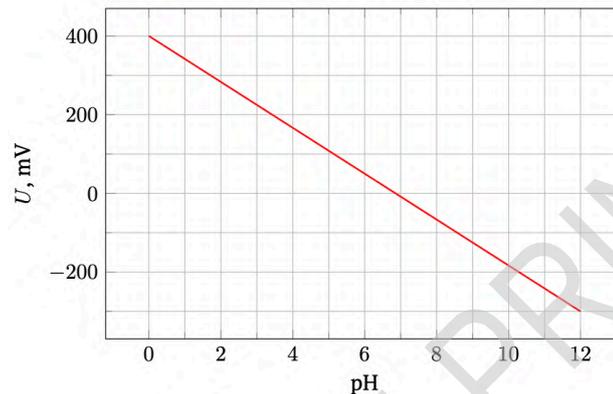


Fig. 4: Calibration curve.

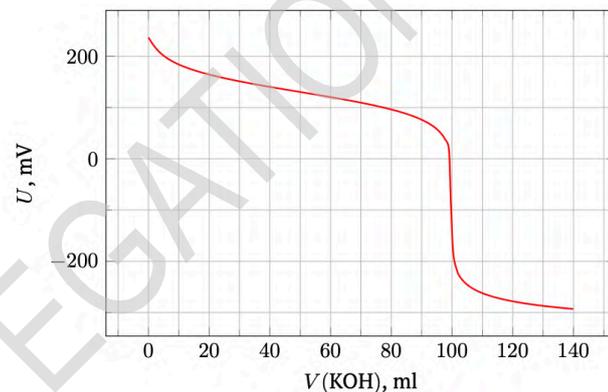


Fig. 5: Titration curve.

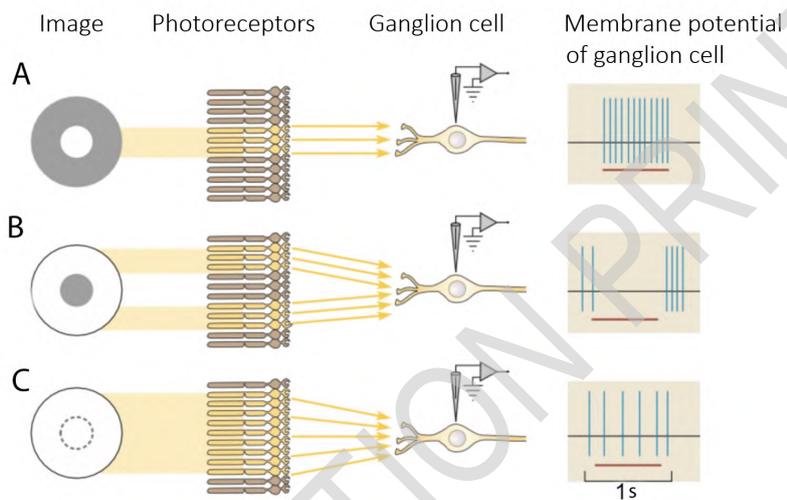
- A. 8.7  
 B. 7.0  
 C. 12.0  
 D. 4.8

- C.10** Select the correct sequence of missing fermions (notations for fermions: e — electron, p — proton, n — neutron) in the following nuclear reaction diagrams.

- 1)  $^{40}\text{K} + \dots \rightarrow ^{40}\text{Ar}$
- 2)  $^7\text{Li} + \dots \rightarrow 2^4\text{He}$
- 3)  $^{14}\text{N} + ^4\text{He} \rightarrow ^{17}\text{O} + \dots$
- 4)  $^6\text{Li} + \dots \rightarrow ^3\text{H} + ^4\text{He}$

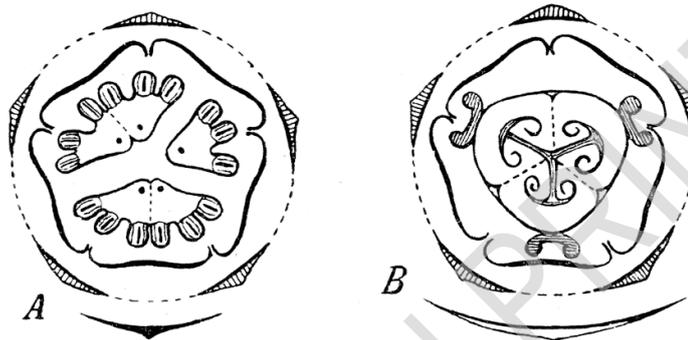
- A. e, p, n, p  
 B. p, n, p, n  
 C. e, p, p, n  
 D. e, e, p, n

- B.1** Human retina consists of a variety of specialized cell types. Photoreceptor cells (rods and cones) generate “input signals”, transducing light to nerve impulses, while ganglion cells generate “output signals” after visual information processing in the retina. A receptive field is a group of photoreceptors that transmit information to a single ganglion cell. Based on the provided diagram, which factor best explains the differences between the ganglion cell responses in cases (A), (B), and (C)?



- A. presence or absence of cones and rods in the receptive field
- B. opposite light responses of the receptive-field center and surround
- C. different conduction speeds in ganglion-cell axons
- D. increased excitation threshold during prolonged stimulation

- B.2** In the squirting cucumber (*Ecballium elaterium*), sex is determined by a gene that exists in three allelic forms:  $a^D$ ,  $a^+$ , and  $a^d$ . The  $a^D$  allele is dominant over the others and determines the development of male plants. The  $a^+$  allele is dominant over  $a^d$  and determines the development of hermaphroditic plants that bear both male and female flowers, while the  $a^d$  allele is recessive to all other alleles and determines the development of female plants.



diagrams of male (A) and female (B) flowers of *Ecballium elaterium*

Plants with following genotype are absent in nature

- A.  $a^D a^D$
- B.  $a^+ a^+$
- C.  $a^D a^d$
- D.  $a^+ a^d$

**B.3** According to the theory of symbiogenesis, plastids of higher plants and algae originated from prokaryotic ancestors. Figure 1 presents an evolutionary tree of various groups of algae, in which four organisms are labeled with the letters A–D. Examine Figure 2, which shows these organisms, and determine their positions on the phylogenetic tree. Choose the answer that correctly matches the numbers of the organisms with the letters on the phylogenetic tree.

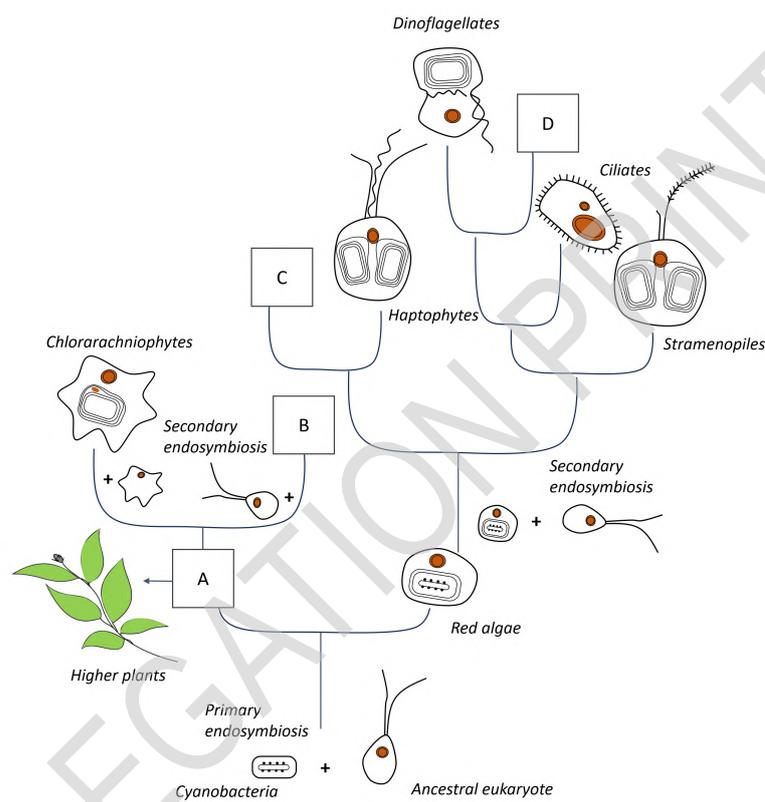


Figure 1

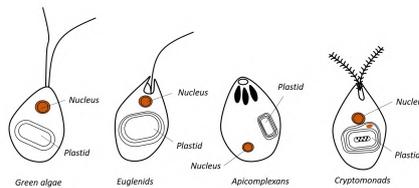
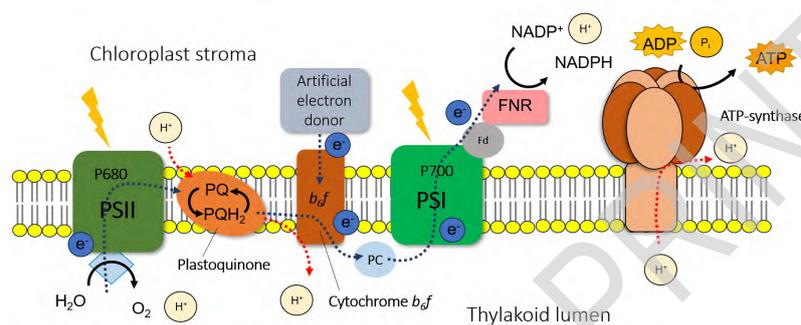


Figure 2

- A. (A) Apicomplexans; (B) Euglenids; (C) Green algae; (D) Cryptomonads  
 B. (A) Green algae; (B) Cryptomonads; (C) Apicomplexans; (D) Euglenids  
 C. (A) Green algae; (B) Euglenids; (C) Cryptomonads; (D) Apicomplexans  
 D. (A) Euglenids; (B) Cryptomonads; (C) Apicomplexans; (D) Green algae

- B.4** The electron transport chain (ETC) of chloroplasts uses light energy to create a proton gradient, which is then used for ATP synthesis. The cytochrome  $b_6f$  complex plays a key role in this process. One of the electron carriers in the ETC, plastoquinone (PQ), functions as a “proton pump” because, when it accepts electrons, it captures protons ( $H^+$ ) from the stroma, and when it donates electrons to the cytochrome  $b_6f$  complex, it releases these protons into the thylakoid lumen.



Imagine that, in an experiment with isolated thylakoids, the functions of Photosystem II and plastoquinones were “blocked”. No light was supplied to the system. Then, a reduced artificial electron donor capable of passing electrons **directly** to the cytochrome  $b_6f$  complex—bypassing plastoquinone—was added to the medium, and the system was illuminated.

Which of the following events under these conditions will be significantly reduced according to the diagram above?

- A. Electron transfer from the cytochrome  $b_6f$  complex to Photosystem I
- B. Light absorption by chlorophyll
- C. ATP synthesis
- D. Reduction of  $NADP^+$  to  $NADPH$

- B.5** On a hot, sunny day, a leaf is actively photosynthesizing. Let’s consider the diffusion of  $CO_2$  molecules from the stomatal pore into the leaf toward the chloroplasts, and the diffusion of  $O_2$  molecules from the chloroplasts toward the stomatal pore. Diffusion occurs mainly through the air spaces of the intercellular spaces.

Which of the two processes —  $CO_2$  uptake or  $O_2$  release—proceeds more slowly, and why?

- A.  $CO_2$  uptake proceeds more slowly because the  $CO_2$  molecule has a greater molecular mass (44 g/mol) than  $O_2$  (32 g/mol)
- B.  $O_2$  release proceeds more slowly because its high concentration in the leaf creates osmotic pressure that hinders its exit
- C.  $CO_2$  uptake proceeds more slowly because its inward movement is opposed by a simultaneous counterflow of  $O_2$  molecules, which, under active photosynthesis, is more intense
- D. Both processes proceed at the same rate, since both gases move through the same air channels and obey the same laws of diffusion

- B.6** The researcher studied the influence of the group of cortical neurons on the motor activity of mice. To do this, he injected a virus containing the light-driven ion cation channel gene into the motor cortex. After the injection, the researcher installed a fiber optic cable for stimulation. The mouse was placed in an experimental arena, and the movements of the rodent were recorded on camera. Initially, the mouse was allowed to move freely in the arena, after which the light in the fiber optic cable was turned on. The results of the experiment are presented in Video 1. In addition to the experimental mouse, a control mouse was used—this mouse was injected with a virus that did not contain the light-driven ion cation channel gene. The results of the control experiment are presented in Video 2. Please review both videos and answer the question below.



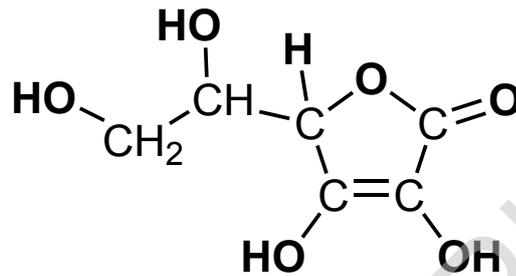
What hypotheses can the researcher propose to explain the results of the conducted experiment:

- A. Stimulation of motor cortex neurons leads to the initiation of exploratory behavior
- B. The group of neurons studied are inhibitory and connected by their synaptic terminals with neurons that suppress motor activity
- C. The group of neurons studied are excitatory and connected by their synaptic terminals with neurons that inhibit motor activity
- D. In the absence of the light-driven cation channel, motor cortex neurons respond to light

- B.7** Scientists discovered a new cell population in the mouse brain. They made following experiments. They injected nucleotide analogue A into the mouse. After 2 hours second nucleotide analogue B was injected. In the discovered cell population, they found 300 cells labeled ONLY with analogue A and 100 cells labeled with BOTH analogues. Based on this experimental data determine the length of DNA-synthesis phase (S-phase) for this group of cells.

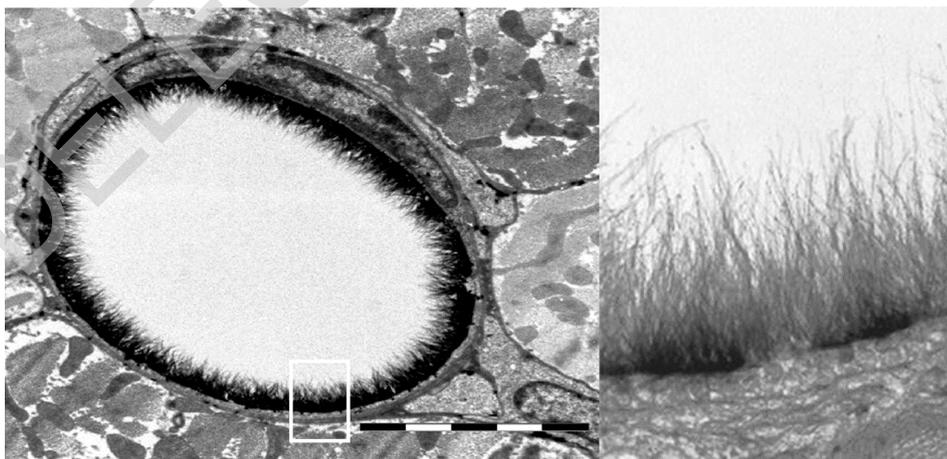
- A. 640 minutes
- B. 160 minutes
- C. 16 minutes
- D. 480 minutes

- B.8** The figure shows the formula of a substance that is not synthesized by the human body but serves as a cofactor for some important enzymatic reactions. Many mammals, however, are capable of synthesizing this compound. They use the following as a direct precursor for biosynthesis:



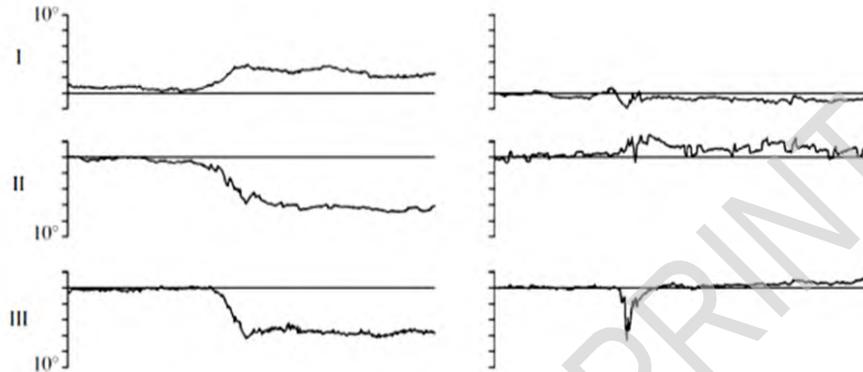
- A. nucleotides  
 B. amino acids  
 C. lipids  
 D. monosaccharides

- B.9** The figure shows an image of a capillary section obtained using transmission electron microscopy (TEM), as well as an enlarged section of this image. The scale bar is 2 micrometers. The image reveals that the inside of the capillary is covered with long filamentous structures, the length of which is several times greater than the thickness of the cells lining the capillary. Most likely, these filamentous structures represent:



- A. extracellular polysaccharides  
 B. basal lamina  
 C. collagen fibers  
 D. intracellular microtubules

**B.10** Cosmonauts on the International Space Station often experience difficulties in visually focusing on an object. To study the response of their visual analyzer to head tilts, an experiment is conducted, as shown below:



Recording of an cosmonaut's eye movement when tilting the head toward the right shoulder on Earth (left) and in space (right). On the X-axis: time in milliseconds; on the Y-axis: angle of eye rotation in degrees.

I – vertical displacement of the eye (“up-down” axis); II – horizontal displacement of the eye (“right-left” axis); III – rotation of the eye around its own axis (“clockwise/counterclockwise”).

Analyze the experimental data and answer which of the following statements is correct:

- A. In weightlessness, the receptors of the semicircular canals stop functioning
- B. When the head is tilted to the right, the eyes rotate counterclockwise
- C. The neurons that control eye movements are located in the spinal cord
- D. In weightlessness, an astronaut will experience problems following objects by eyes without head movement