Physical and Technical Sciences: Second-round sample tasks for the Open Doors undergraduate track

You will be asked to complete 45 tasks, including:

- 27 entry-level tasks, each correct answer worth 1 point;
- 13 intermediate-level tasks, each correctly answered task worth 2-4 points;
- 5 advanced tasks (constructed response), each correctly completed task valued at 5–6 points.

Evaluation criteria and standard answers are provided for the advanced tasks requiring constructed responses.

Mechanics

Task 1
Entry level (1 point)

A truck and a car are travelling at speeds υ_1 = 36 km/h and υ_2 = 108 km/h, respectively. The weight of the truck is m=3000kg. What is the mass of the car if the truck's momentum is 15000 kg · m/s greater than that of the car?

1. 1000 kg
2. **500 kg**
3. 1500 kg
4. 2000 kg

Answer: 2.

Task 2
Entry level (1 point)

The boy launched the sled from the top of the slide, which stands at a height of 15 meters. At the bottom, the sled reached a velocity of 20 m/s. The friction between the sled and the snow is minimal. What was the sled's velocity right after the boy pushed it? The acceleration due to free fall is assumed to be 10m/s^2.

1. 20 m/s
2. 15 m/s
3. **10 m/s**
4. 25 m/s

Answer: 3.

Task 3
Entry level (1 point)

In rectilinear motion, the dependence of the body coordinate x on time t is as follows: $x= 5+3t+4t^2$. What is the velocity of the body at time t = 3 c in this motion?

1. **27 m/s**
2. 30 m/s
3. 20 m/s
4. 50 m/s

Answer: 1.

Task 4
Entry level (1 point)

A body is launched vertically upward with an initial velocity of 30 m/s. What is the modulus of the body's velocity 2.5 seconds after it was thrown? Ignore air resistance.

1. 10 m/s
2. **5 m/s**
3. 15 m/s
4. 20 m/s

Answer: 2.

Task 5
Entry level (1 point)

What will be the stretch of a spring with a stiffness of k = 103 N/m when a force of 10,000 N is applied?

1. 10 sm
2. 100 sm
3. **1000 sm**
4. 1 sm

Answer: 3.

Task 6
Entry level (1 point)

What is the distance between two identical balls, each with a mass of 10 tons, if the gravitational force acting between them is $6.67 \cdot 10^{-5}$ N? The universal gravitation constant $G = 6.67 \cdot 10^{-11}$ $N \cdot m^2/kg^2$.

1. 20 m
2. **10 m**
3. 15 m
4. 25m

Answer: 2.

Task 7
Entry level (1 point)

A pine bar with a volume of $V = 0.6$ m³ is floating in water, half submerged. What is the buoyant force acting on the bar? Assume the acceleration due to gravity is 10 m/s², and the density of water is $\rho = 1000$ kg/m³.

1. 30 kN
2. **3 kN**
3. 6 kN
4. 60 kN

Answer: 2.

Task 8
Intermediate level (3 points)

The body decelerated at a constant rate, and 100 seconds prior to coming to a stop, its velocity had decreased by 10 m/s. How far did the body travel during this period? Please provide your answer in meters.
Answer: 500 m.

Task 9
Intermediate level (3 points)

Two balls, with masses m1 = 1.5 kg and m2 = 2 kg, are approaching each other, both travelling at the same speed of v = 10 m/s. Determine the velocity of the balls after they undergo a completely inelastic collision. Please provide your answer in meters per second, rounded to the nearest hundredth.
Answer: 1.43 m/s

Task 10
Advanced level (5 points)

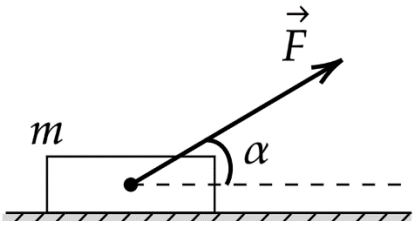
An object is launched from the Earth's surface at a 30^0 angle to the horizontal with an initial velocity of 10 m/s. Calculate the duration of the object's flight before it impacts the ground.

Note that the evaluation will consider how you solve the task; providing only the final answer is not sufficient.
Answer: 1 s

Evaluation criteria:
Criterion 1 – 2 points: The relevant theoretical principles and physical laws needed to solve the problem are clearly stated. All new symbols representing physical quantities introduced in the solution are explained.
Criterion 2 – 2 points: The mathematical manipulations and calculations have been performed accurately.
Criterion 3 – 1 point: The final answer is provided along with the appropriate units of measurement.

Task 11
Advanced level (5 points)

What is the modulus of the force F with which a block of mass m = 3 kg is moved, the coefficient of friction μ = 0.2 and the force F is directed at an angle α = 30^0 to the horizon (see figure). The modulus of the friction force acting on the block = 4 N.



Note that the evaluation will consider how you solve the task; providing only the final answer is not sufficient.
Answer: 20 N.

Evaluation criteria:
Criterion 1 – 2 points: The relevant theoretical concepts and physical laws required to solve the problem are clearly outlined. All new symbols representing physical quantities introduced in the solution are explained.
Criterion 2 – 2 points: The mathematical transformations and calculations have been executed accurately.
Criterion 3 – 1 point: The final answer is provided along with the correct units of measurement.

Thermodynamics

Task 12
Entry level (1 point)

To melt 200 g of ice, 900 g of water at a temperature of 20 ^{0}C was required. What was the initial temperature of the ice? The specific heat capacity of water is 4200 J/(kg•^{0}C), the specific heat capacity of ice is 2100 J/(kg•^{0}C), the latent heat of fusion of ice is 340 kJ/kg. Please select the answer that is nearest to your calculation.

1. -20 ^{0}C
2. -18 ^{0}C
3. -9 ^{0}C
4. -2 ^{0}C

Answer: 2.

Task 13
Entry level (1 point)

The pressure of the rarefied gas in the container rose by a factor of 8, while the average energy of the translational thermal motion of its molecules increased by a factor of 4. How did the concentration of gas molecules in the container change?

1. Has not changed
2. Has decreased by 2 times
3. Has increased by 2 times
4. Has increased by 4 times

Answer: 3.

Task 14
Entry level (1 point)

The thermodynamic system performed 300 J of work, while its internal energy decreased by 100 J. What amount of heat did the system transfer to or from the environment?

1. -200 J
2. -100 J
3. 0 J
4. 100 J
5. 200 J

Answer: 5.

Task 15
Entry level (1 point)

A heat engine operating at an efficiency of 20% receives 100 J of heat from the heater in each cycle. How much work does the engine produce in one cycle?

1. 20 J
2. 50 J
3. 80 J
4. 100 J

Answer: 1.

Task 16
Intermediate level (2 points)

The container is split into two equal sections by a stationary porous partition. Initially, the left section holds 4 moles of helium, while the right section contains 40 grams of argon. The partition allows helium molecules to pass through but is impermeable to argon molecules. The temperature of both gases is identical and remains constant. Helium has a molar mass of 4 g/mol, whereas argon has a molar mass of 40 g/mol. Identify all the accurate statements that characterize the state of the gases once the system reaches equilibrium.

1. The concentration of helium in the right section of the vessel is half that of argon.
2. **The pressure ratio of the gas in the right section to that in the left section is 1.5.**
3. The total number of gas molecules in the right section is lower than in the left section.
4. The internal energy of helium and argon is identical.
5. **Upon reaching equilibrium, the pressure in the right section of the vessel increased threefold.**

Answer: 2, 5.

You earn 1 point for each correct statement and lose 1 point for each incorrect one.

Task 17
Intermediate level (3 points)

An ideal gas is compressed at a constant pressure. Choose all the accurate statements. ΔU represents the change in the gas's internal energy, A denotes the work done by the gas, and Q indicates the amount of heat exchanged between the gas and its surroundings.

1. $\Delta U=0$
2. $\Delta U>0$
3. **$\Delta U<0$**
4. $A=0$
5. $A>0$
6. **$A<0$**
7. $Q=0$
8. $Q>0$
9. **$Q<0$**

Answer: 3, 6, 9.

For each correct answer you get 1 point, for each incorrect answer you lose 1 point.

Task 18
Advanced level (6 points)

One mole of helium undergoes isobaric expansion, performing 4.2 J of work. Following this, its temperature is decreased isochorically, and then it is compressed adiabatically, returning to its original state. Determine the efficiency of the cycle, given that 2.1 J of work is done on the gas during the adiabatic process. Please note: your solution's progression will be evaluated; simply providing the answer is insufficient.

Answer: 20%

Evaluation criteria:
Criterion 1 – 3 points: All essential relationships must be documented, including thermal and caloric equations of state, the first law of thermodynamics, and the formula for calculating efficiency. It should be clear whether the system absorbs or releases heat at each stage of the cycle.
Criterion 2 – 2 points: The total work done during the cycle and the amount of heat exchanged must be calculated accurately.
Criterion 3 – 1 point: The efficiency must be computed correctly.

Electrical Engineering and Electronics

Task 19
Entry level (1 point)

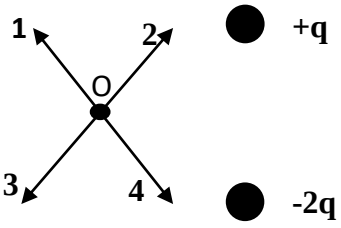
Consider three charges q_1, q_2 and q_3 positioned at the vertices of an equilateral triangle with a side length of a. A test charge Q is placed at the center of the triangle. What amount of work is required to gradually move the charge Q to infinity?

1. $\mathbf{k\frac{3Q}{\sqrt{3}a}(q_1+q_2+q_3)}$
2. $k\frac{Q}{\sqrt{3}a}(q_1+q_2+q_3)$
3. $k\frac{4Q}{a\sqrt{3}}(q_1+q_2+q_3)$
4. $k\frac{2Q}{\sqrt{3}a}(q_1+q_2+q_3)$

Answer: 1.

Task 20
Entry level (1 point)

Indicate the direction of the resultant electric field at point O created by two stationary point charges (see the figure).



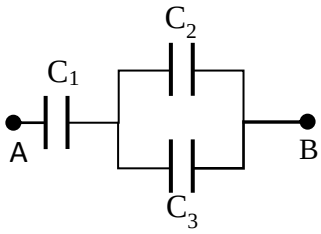
1. 1

2. 2
3. 3
4. 4

Answer: 4

Task 21
Entry level (1 point)

Find the capacitance of the circuit section AB consisting of the three capacitors $C_1 = C_2 = C$, and $C_3 = 3C$ shown in the figure.



1. $\frac{7}{4}C$
2. $\frac{9}{5}c$
3. $\frac{4}{5}C$
4. $\frac{3}{4}C$

Answer: 3.

Task 22
Entry level (1 point)

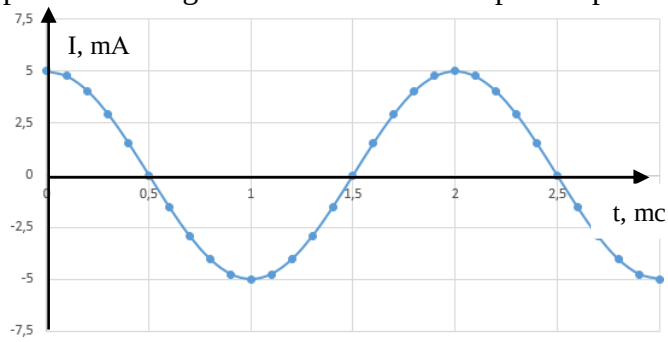
How does the resistance of two parallel wires, which are identical in shape and size, change if the length of one wire is tripled?

1. The resistance increases by 1.5 times.
2. The resistance decreases by 1.5 times.
3. The resistance increases by 2 times.
4. The resistance decreases by 2 times.
5. The resistance does not change.

Answer: 1.

Task 23
Entry level (1 point)

The figure shows a graph of the time dependence of the current in a LC circuit. What is the period of charge fluctuations on the capacitor plates?



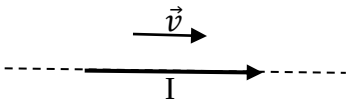
1. 1 ms

2. **2 ms**
3. 2 s
4. 1 s

Answer: 2.

Task 24
Entry level (1 point)

A positively charged particle is moving horizontally with velocity $\vec{V}$ along a straight long wire with current I (see the figure). Find the direction of the magnetic force exerted on the particle.



1. Up
2. **Down**
3. Left
4. Right
5. From the observer
6. To the observer
7. The force does not exert

Answer: 2.

Task 25
Intermediate level (3 points)

A charged particle with mass $5 \cdot 10^{-27}$ kg and charge $6.4 \cdot 10^{-19}$ C enters a uniform electric field of 100 V/m. If the initial velocity is zero, how long does it take a particle to pass 2 m along the electric field lines? Round the answer (in μs) the nearest whole number.

Answer: 18 μs

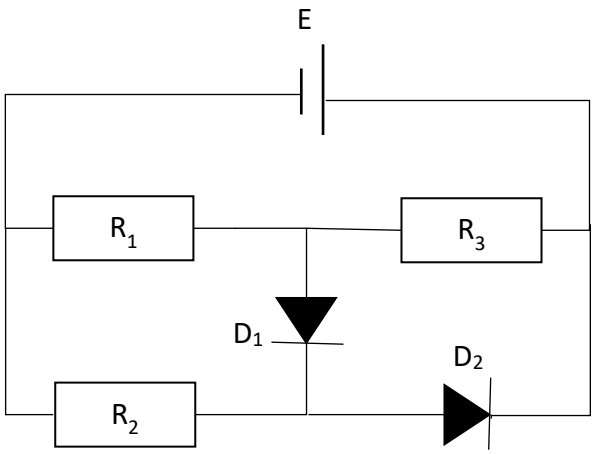
Task 26
Intermediate level (4 points)

A capacitor in an ideal oscillating circuit has capacitance $C = 20$ μF. The charge on the capacitor plates changes according to the law $q(t) = 4 \cdot 10^{-4}\sin(2500t)$ (all values are expressed in SI). Determine the value of the magnetic field energy of the coil at the time $t = \frac{T}{2}$.

Answer: 0.004 J

Task 27
Advanced level (6 points)

Determine the current flowing through a battery in the circuit depicted in the figure. The diodes are considered ideal, the internal resistance of the battery is r = 2R, the battery EMF E = 21 V, The values for the other circuit components are also provided in the figure, where $R_1 = R_2 = R_3 = R = 5$ Ω.



Note that the evaluation will consider how you solve the task; providing only the final answer is not sufficient.
Answer: 1.2 A

Evaluation criteria:

Criterion 1 – 3 points: The potential directions of current in the circuit are accurately identified, and the equivalent circuit is properly illustrated.

Criterion 2 – 3 points: The total resistance of the circuit is calculated correctly.

Criterion 3 – 1 point: The current is computed accurately

Task 28
Advanced level (5 points)

A circular wire loop with a diameter of 0.3m is situated in a modulo varying homogeneous magnetic field, with the plane of the loop oriented perpendicular to the magnetic field lines. What is the modulus of the rate at which the magnetic field is changing? The current flowing through the wire is 5 A, and the resistance of the wire is 0.03 Ω.

Note that the evaluation will consider how you solve the task; providing only the final answer is not sufficient.

Answer: 2.1 T/c

Evaluation criteria:
Criterion 1 – 2 points: The formula for calculating the induced EMF and current is accurately stated.
Criterion 2 – 2 points: The formula for the rate of change of the magnetic field is accurately stated.
Criterion 3 – 1 point: The calculations are performed correctly.

Optics

Task 29
Entry level (1 point)

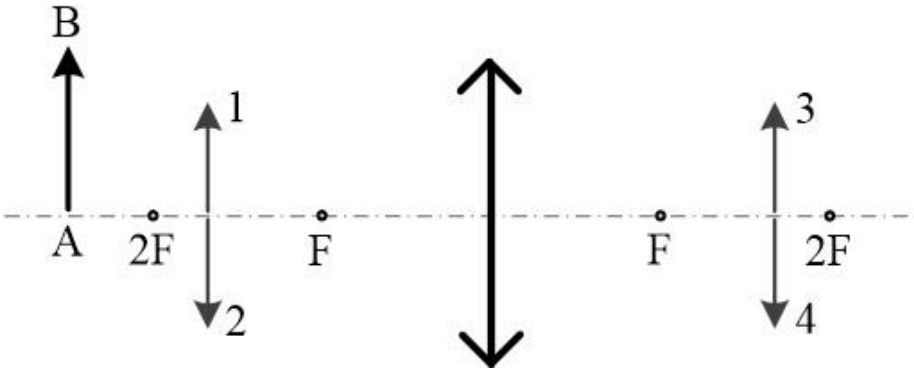
Light passes from water into a flat sheet of glass. The angle between the incident ray and the interface is 50°. Find the angle between the reflected ray and the refracted ray. The refractive indices of glass and water relative to air are 1.5 and 1.33, respectively.

1. 74.7°
2. 86.5°
3. 87.2°
4. 93.5°
5. **105.3°**

Answer: 5.

Task 30
Entry level (1 point)

Which of the objects labeled 1-4 represents the image of arrow AB when viewed through a thin lens with a focal length of F?



1. Arrow 1.
2. Arrow 2.
3. Arrow 3.
4. **Arrow 4.**

Answer: 4.

Task 31
Entry level (1 point)

A monochromatic plane wave from the green part of the visible spectrum (with a wavelength of 550 nm) falls on a slit that is 2 μm wide. A converging lens is placed behind the slit so that its focal plane is parallel to the plane of the screen containing the slit. How does the distance between the second-order and third-order dark fringes in the focal plane of the lens change when the width of the slit is increased by a factor of 1.5?

1. The distance increases by 3 times.
2. The distance increases by 1.5 times.
3. The distance decreases by 1.5 times.
4. **The distance decreases by 3 times.**

Answer: 4.

Task 32
Intermediate level (4 points)

An object is positioned 12.5 cm away from a converging thin lens, resulting in a real image. The magnification produced by the lens is 2.5. Calculate the power of the lens and round your answer to the nearest whole number.
Answer: 11 D

Task 33
Intermediate level (4 points)

In the experiment involving a Fresnel double mirror and the interference of light waves, the distance from the intersection line of the mirrors to the actual narrow light source is 8 cm, while the distance to the screen is 120 cm. The wavelength of the monochromatic light used is 0.48 μm. Calculate the angle of inclination between the mirrors, given that the distance between adjacent bright interference fringes on the screen is 1.3 mm. Provide your answer in angular minutes, rounded to the nearest whole number.
Answer: 10

Condensed Matter Physics

Task 34
Entry level (1 point)

The vessel under the piston contained air with a relative humidity of 50%. The air was compressed isothermally, reducing its volume by 3 times. What was the relative humidity of the air in the vessel after compression?
1. 17%
2. 25%
3. 50%
4. 75%
5. 100%
6. 150%

Answer: 5.

Task 35
Entry level (1 point)

How do amorphous solids behave when heated?
1. amorphous substances remain in a solid state up to a certain temperature, then begin to melt and change to a liquid state.
2. amorphous substances remain in a solid state up to a certain temperature, then begin to sublimate, changing to a gaseous state.
3. amorphous substances soften when heated, smoothly changing from a solid to a liquid state.
4. amorphous substances remain in a solid state up to a certain temperature, then undergo chemical reactions.
5. amorphous substances remain solid at any temperature.

Answer: 3.

Task 36
Intermediate level (3 points)

Select all the accurate statements that define boiling:

1. Boiling is the vaporization that occurs solely from the surface of a liquid at temperatures above its melting point**.**
2. **Boiling happens when the saturated vapor pressure matches atmospheric pressure.**
3. **As one ascends a high mountain, the boiling point of water decreases; conversely, as one descends into a deep mine, the boiling point of water increases.**
4. During the boiling process, the internal energy of the substance remains unchanged.
5. **Throughout boiling, the temperature stays constant, and the heat absorbed is utilized to increase the potential energy of the molecules.**
   Answer: 2, 3, 5.

You earn 1 point for each correct statement and lose 1 point for each incorrect one.

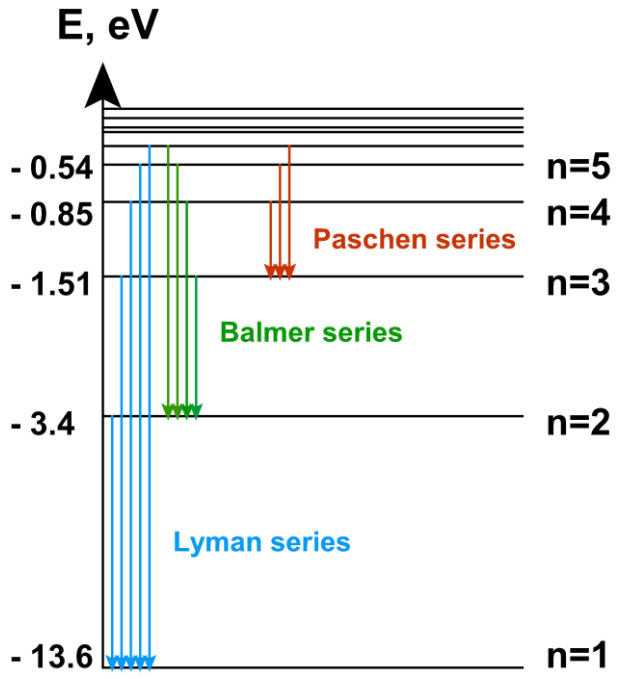
Task 37
Intermediate level (4 points)

In a sauna with a volume of 10 m^3, the thermometer shows 100^0C, the hygrometer shows 30%. Find the mass of water vapor in the sauna. The density of saturated steam at 100^0C is 0.59 kg/m^3. Give the answer in kilograms, rounded to the nearest tenth.
Answer: 1.7 kg.

Atomic, Molecular and Chemical Physics

Task 38
Entry level (1 point)

The diagram illustrates the energy levels of a hydrogen atom. What frequency of photon must the atom absorb to transition from the ground state to the fourth excited state?
The value of Planck's constant: $h = 4.135\,668 \cdot 10^{-15}$ eV · s, $\hbar = 6.582\,120 \cdot 10^{-16}$ eV · s.



1. $\nu = 2.466$ Hz
2. $\nu = 2.923$ Hz
3. $\nu = 3.083$ Hz
4. $\boldsymbol{\nu = 3.158}$ **Hz**

Answer: **4.**

Task 39
Entry level (1 point)

An α particle with an energy $T_\alpha = 10$ MeV collides with a stationary silver atom nucleus ${}_{47}Ag$ positioned directly in the path of the α particle. Determine the minimum distance the α particle can reach to the nucleus, treating the nucleus as a point particle. Express the answer in femtometers (fm). The Coulomb constant $k = 8.987552 \cdot 10^9 \ \frac{N \cdot m^2}{C^2}$, the charge of the electron $|e| = 1.602177 \cdot 10^{-19}$ C. 1 eV $= 1.602177 \cdot 10^{-19}$ N · m.

1. 3.68 fm
2. 6.77 fm
3. **13.54 fm**
4. 27.07 fm

Answer: 3.

Task 40
Intermediate level (4 points)

Neutral atom, formed by the nucleus ${}^{16}_{8}O$ and electrons. Calculate the mass of this atom $M_{atom}({}^{16}_{8}O)$, knowing that the binding energy of the nucleus $\Delta W({}^{16}_{8}O) = 127.617$ MeV. Give the answer in energy equivalent $M_{atom}({}^{16}_{8}O) \cdot c^2$ in megaelectronvolts (MeV), rounded to the nearest unit.
The mass of the proton $m_p \cdot c^2 = 938.272$ MeV, the mass of the neutron $m_n \cdot c^2 = 939.565$ MeV, the mass of the electron $m_e \cdot c^2 = 0.511$ MeV.

Answer: 14899 MeV

Task 41
Intermediate level (4 points)

Calculate the energy released as a result of the reaction:

$$p + p \rightarrow d + e^+ + \nu_e$$

The mass of the proton $m_p \cdot c^2 = 938.272$ MeV, the mass of the deuteron $m_d \cdot c^2 = 1875.612$ MeV, the mass of the electron $m_e \cdot c^2 = 0.511$ MeV. Neglect the mass of the neutrino ν_e. Express the answer in MeV, rounded to the nearest hundredth.

Answer: 0.42 MeV

Quantum Technologies

Task 42
Entry level (1 point)

Monochromatic light with a wavelength of 200 nm strikes the surface of a metal. The wavelength that corresponds to the red limit of the photoelectric effect for this metal is 300 nm. What portion of the photon energy is used to give kinetic energy to the electron?

1. 2/3
2. **1/3**
3. 1/2
4. 3/4

Answer: 2.

Task 43
Entry level (1 point)

When the cathode of a vacuum photocell is exposed to a stream of monochromatic radiation, it emits photoelectrons. How will the saturation photocurrent be affected if the frequency of the incident radiation is doubled?

1. Will increase by 2 times
2. Will increase by more than 2 times
3. Will increase by less than 2 times
4. Will decrease by 2 times
5. Will decrease by more than 2 times
6. Will decrease by less than 2 times
7. **The value of the saturation photocurrent does not depend on the frequency of the incident radiation**

Answer: 7.

Task 44
Entry level (1 point)

Determine the work function of a specific metal surface if the maximum velocities of the emitted photoelectrons vary by a factor of 4 when exposed alternately to radiation with wavelengths of 400 nm and 600 nm.
Planck's constant $h = 4.136 \cdot 10^{-15}$ eV · s, the speed of light $c = 2.998 \cdot 10^{8}$ m/s.

1. **2.00 eV**
2. 2.76 eV
3. 3.51 eV
4. 4.01 eV

Answer: 1.

Task 45
Intermediate level (4 points)

The longest wavelength of light at which the photoelectric effect can still be observed in a nickel photocell is 249 nm. Find the speed of electrons ejected by light with a wavelength of 150 nm. The electron mass is $m_e \cdot c^2 = 0.511$ MeV, the Planck constant is $h = 4.136 \cdot 10^{-15}$ eV · s, the speed of light is $c = 2.998 \cdot 10^{8}$ m/s
Express your answer in Mm/s and round to the nearest hundredth.

Answer: 1.08 Mm/s