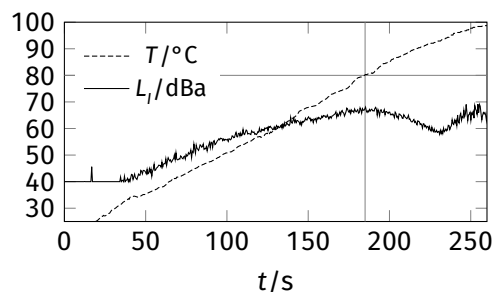
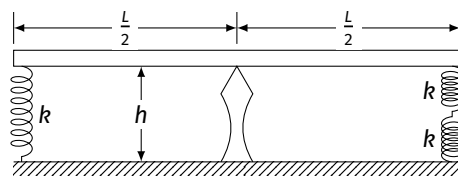


9-1° Kettle (3 p) While water is being heated up, one can notice that the noise level L_i produced by the kettle increases until the temperature reaches ca. 80°C and then decreases again (see the plot). Explain why it happens.



9-2° Stone (3 p) If a piece of a meteorite attached to a dynamometer, is submerged in water, the dynamometer reads 14 N, but if it is submerged in oil – 16 N. Find the mass and the density of the meteorite piece. Water density $1 \frac{\text{g}}{\text{cm}^3}$, oil density $0,8 \frac{\text{g}}{\text{cm}^3}$.

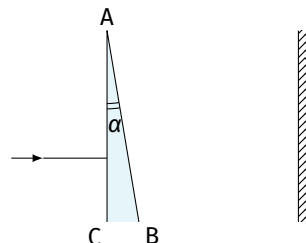
9-3° Strange scales (3 p) A uniform plank of length $L = 1 \text{ m}$ is supported at its midpoint at the height $h = 5 \text{ cm}$ above the table. Between the table and one end of the plank, a spring of stiffness $k = 50 \frac{\text{N}}{\text{m}}$ is attached. The relaxed length of the spring is h . Between the table and the other end of the plank, two similar identical springs, connected in series, are attached. How far from the centre of the plank and on which side of the scales does one need to put a mass $m = 1 \text{ kg}$, so that the plank remains horizontal?



9-4° Global warming (3 p) Two identical cylindrical glasses of cross-section area $S = 30 \text{ cm}^2$ contain identical cubes of ice of mass $m = 10 \text{ g}$ each. Both glasses are filled to half-height: the first one with distilled water (density $\rho_0 = 1,00 \frac{\text{g}}{\text{cm}^3}$), the second one with salt water (density $\rho_1 = 1,02 \frac{\text{g}}{\text{cm}^3}$) so that ice cubes do not touch the bottom of the glass. After some time ice melted in both glasses. Explain how the water level will change and determine the water level difference between the glasses when ice will have melted.

9-5° Goldfish (3 p) A pot of volume $V_t = 2 \ell$ is filled up to brim with water at temperature $T_0 = 10^\circ\text{C}$. A gold rod with temperature $T_1 = 70^\circ\text{C}$ is then placed in the pot, and some water has flown out of the pot. After some time, temperatures of the rod and water equalised at $T = 20^\circ\text{C}$. Determine the equilibrium temperature of water, if not one but two such gold rods were placed in the pot. Specific heat capacity of water $c_0 = 4,2 \frac{\text{J}}{\text{g}^\circ\text{C}}$ and density $\rho_0 = 1 \frac{\text{g}}{\text{cm}^3}$. Specific heat capacity of gold $c_1 = 0,13 \frac{\text{J}}{\text{g}^\circ\text{C}}$ and density $\rho_1 = 19,3 \frac{\text{g}}{\text{cm}^3}$. Neglect heat exchange with the environment.

9-6° Maximal refraction (4 p) A narrow laser beam is normally incident onto the side face AC of a straight prism, the base of which is a right-angled triangle (see fig.). How many bright points will be seen on a screen, which is located behind the prism and is parallel to the face AC? Refraction index of glass $n = 1,41$, angle $\alpha = 10^\circ$. Assume that the length of the face AC and the screen are very large.



9-7° Weak heater (3 p) A vessel is filled with water at temperature $T_0 = 20^\circ\text{C}$. The water is to be heated up with an immersive heater (metal spiral), the resistance R of which changes with temperature T in such a way that $R = R_0[1 + \alpha(T - T_0)]$, where $\alpha = 0,1 \frac{1}{^\circ\text{C}}$ and $R_0 = 100 \Omega$. Assume that temperatures of the heater and water are equal at any time. The vessel is not insulated, and each second energy $Q = \beta(T - T_0)$ is lost to the environment, where $\beta = 2 \frac{\text{J}}{^\circ\text{C}}$. The heater is connected to a current source, which ensures constant current $I = 0,2 \text{ A}$ in the heater. Determine the maximal temperature T_{max} of water that can be achieved.

9-8° Strings and units (3 p) Oscillation frequency of a string depends only on its diameter D , density ρ and tension force F . One of the nylon guitar strings was replaced with a nickel string of 1,5 times smaller diameter. By what factor should the tension force be increased for the frequency to remain the same? Nylon density $\rho_1 = 1240 \frac{\text{kg}}{\text{m}^3}$, nickel density $\rho_2 = 8900 \frac{\text{kg}}{\text{m}^3}$.

9-9° Winter delights (2 p) A boy on a sled slid with constant velocity down the shallow ice slope, which makes an angle $\varphi = 1^\circ$ with the horizontal. At the end of the slope it turned out that the rails of the sled were $\Delta T = 0,5^\circ\text{C}$ warmer than at the beginning of the descent. The total mass of the boy and the sled is $M = 70\text{ kg}$, the rails are made of steel of specific heat capacity $c = 420 \frac{\text{J}}{\text{kg}^\circ\text{C}}$ and their net mass $m = 0,75\text{ kg}$. Assume that the rails absorb $\eta = 40\%$ of the total released heat. Free fall acceleration $g = 10 \frac{\text{m}}{\text{s}^2}$.

- (a) Determine the friction force that acts on the sled during the ride.
- (b) Determine the length of the slope.

9-10° Multiple choice questions (3 p) For each question there is one correct answer. Justify your choice. Answers without justification will receive zero marks.

(1) Gravity on Mercury is K times smaller than on Earth. A ball dropped on Earth from height h takes time t to reach the ground. From what height should it be dropped on Mercury so that it takes the same time t to reach the surface? Neglect air resistance.

- (a) h/K^2
- (b) h/K
- (c) h
- (d) hK
- (e) hK^2

(2) A block of brass (an alloy of density $8730 \frac{\text{kg}}{\text{m}^3}$) has sides of length 3 cm, 4 cm and 5 cm. What is the maximum pressure that can be exerted by this block when it is placed on a table on one of its faces?

- (a) 4,28 kPa
- (b) 428 kPa
- (c) 3,43 kPa
- (d) 257 kPa

(3) An astronaut in the International Space Station experiences weightlessness because...

- (a) she is outside the Earth's gravitational field;
- (b) the attraction force of the Moon cancels out that of the Earth;
- (c) the attraction force of the Sun cancels out that of the Earth;
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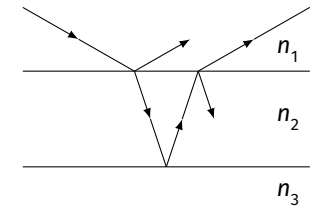
(4) A lift is moving upwards at a constant speed. Ignoring any friction, which statement is correct?

- (a) The kinetic energy of the lift is constant.
- (b) The gravitational potential energy of the lift with respect to the ground is constant.
- (c) The mechanical energy of the lift with respect to the ground is constant.
- (d) Statements (a) and (c) are both correct, but (b) is not correct.
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(5) A drop slide in a fairground has a steep initial slope which gradually curves into a more gentle slope. If a child drops down the slide, what happens to his speed v and the magnitude of his acceleration a , ignoring any friction forces?

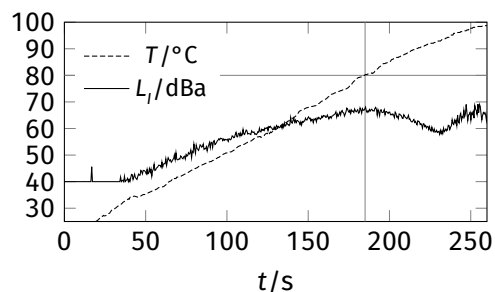
- (a) v and a both increase.
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- (c) v increases, a decreases.
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(6) Light rays propagate through three media of refractive indices n_1 , n_2 and n_3 , respectively, as shown in the diagram. Which of the following statements is correct?



- (a) $n_1 < n_2 < n_3$
- (b) $n_2 < n_1 < n_3$
- (c) $n_1 < n_3 < n_2$
- (d) $n_3 < n_1 < n_2$
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10-1° Kettle (3 p) While water is being heated up, one can notice that the noise level L_I produced by the kettle increases until the temperature reaches ca. 80°C and then decreases again (see the plot). Explain why it happens.



10-2° Weak heater (3 p) A pot is filled with water at temperature $T_0 = 20^\circ\text{C}$, which is to be heated up with an immersive heater (metal spiral), the resistance R of which changes with temperature T so that $R = R_0[1 + \alpha(T - T_0)]$, where $\alpha = 0,1 \frac{1}{^\circ\text{C}}$ and $R_0 = 100 \Omega$. Assume that the heater and water are in thermal equilibrium at all times. The pot is not insulated and loses energy $Q = \beta(T - T_0)$, where $\beta = 2 \frac{1}{^\circ\text{C}}$ every second. The heater is connected to a current source, which outputs constant current $I = 0,2 \text{ A}$. Determine the maximum temperature T_{max} of water that can be achieved.

10-3° Falling target (3 p) Jānis is shooting arrows at target located at height H above the ground and at horizontal distance L from Jānis. The arrow is to be shot with initial velocity v from height h the moment when the target starts to fall. Free fall acceleration is g .

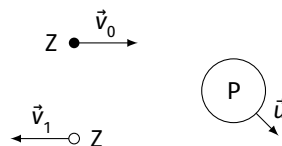
- At what angle should an arrow be shot in order to hit the target?
- In reality, reaction time τ has to be taken into account. At what angle should Jānis shoot in this case?

10-4° Motorboat (5 p) A motorboat of mass $m = 100 \text{ kg}$ is moving on a lake with velocity $v_0 = 2 \frac{\text{m}}{\text{s}}$. A drag force on the boat is proportional to the velocity: $\vec{F} = -k\vec{v}$, where $k = 5 \frac{\text{kg}}{\text{s}}$. The engine of the boat is stopped at $t = 0$, and the boat continues to move on a straight line.

- Determine the acceleration (both magnitude and direction) of the boat at $t = 0$.
- Determine the distance travelled by the boat from $t = 0$ to the moment when the velocity of the boat was $\frac{1}{2}v_0$.
- Determine the velocity of the boat when it has travelled one third of its maximum displacement since $t = 0$.

10-5° Global warming (3 p) Two identical cylindrical glasses of cross-section area $S = 30 \text{ cm}^2$ contain identical cubes of ice of mass $m = 10 \text{ g}$ each. Both glasses are filled to half-height: the first one with distilled water (density $\rho_0 = 1,00 \frac{\text{g}}{\text{cm}^3}$), the second one with salt water (density $\rho_1 = 1,02 \frac{\text{g}}{\text{cm}^3}$) so that ice cubes do not touch the bottom of the glass. After some time ice melted in both glasses. Explain how the water level will change and determine the water level difference between the glasses when ice will have melted.

10-6° Gravitational manoeuvre (4 p) A probe Z is approaching the planet P from far away with velocity $v_0 = 7 \frac{\text{km}}{\text{s}}$. The probe passed near the planet, and when it was once again far away, the probe was moving in the opposite direction (see fig.). Assume the orbital velocity of the planet is $u = 10 \frac{\text{km}}{\text{s}}$ and does not change either in magnitude or direction during the manoeuvre. Determine the maximal and minimal possible magnitude of the velocity v_1 of the probe after the manoeuvre. All velocities and directions are relative to the star around which the planet is orbiting.



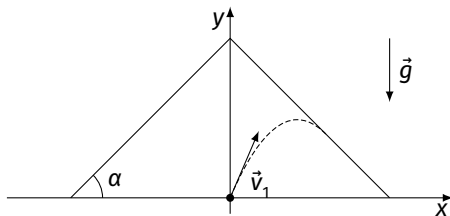
10-7° Heavy pigeon (4 p) A pigeon is perching at the middle of a stretchable string, the ends of which are fixed at the same height. Before the pigeon has perched on it, the string was not deformed, its length was $l_0 = 5 \text{ m}$ and cross-section area $S_0 = 2 \text{ mm}^2$. The string snaps when the stress and the strain in it exceed $\sigma = 2,5 \text{ MPa}$ and $\epsilon = 0,5$, respectively. The volume of the string does not change. Determine the maximum mass of a pigeon that can still perch on the string without making it snap. Free fall acceleration $g = 9,8 \frac{\text{m}}{\text{s}^2}$.

10-8° Ball in a tank (3 p) Consider a cylindrical tank with water, which can rotate around its axis. At the distance R from the axis, a light thread of length l is attached to the bottom of the tank. At the other end of the thread, a small ball of density that is less than the density of water is attached. The ball is always completely submerged in water.

- In which direction is the ball deflected in the rotating tank?
- Determine the angular velocity of the tank that is required for the thread to make angle α with the vertical.

10-9° Lazy throw (5p) An object is thrown from a level surface with a fixed speed. The locus of points of the vertical plane that this object can reach is bounded by a parabola. Free fall acceleration is g .

- (a) Derive the equation of this parabola, if the object is thrown from the origin with the speed v_0 . Consider the case when the initial velocity is vertical, and the case which maximizes the range.
- (b) An object is thrown from the centre of the base of the cone. The side surface of the cone makes an angle $\alpha = 30^\circ$ with the floor. The minimum initial velocity that is required for the object to reach the vertex of the cone is v . Determine the minimum initial velocity v_1 that is required for the object to reach the side of the cone.



10-10° Multiple choice questions (3p) For each question there is one correct answer. Justify your choice. Answers without justification will receive zero marks.

(1) Gravity on Mercury is K times smaller than on Earth. A ball dropped on Earth from height h takes time t to reach the ground. From what height should it be dropped on Mercury so that it takes the same time t to reach the surface? Neglect air resistance.

- (a) h/K^2
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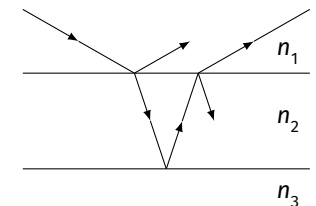
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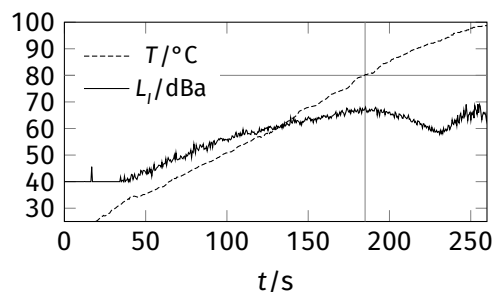
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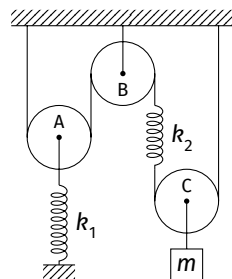


11-2° Falling target (3 p) Jānis is shooting arrows at target located at height H above the ground and at horizontal distance L from Jānis. The arrow is to be shot with initial velocity v from height h the moment when the target starts to fall. Free fall acceleration is g .

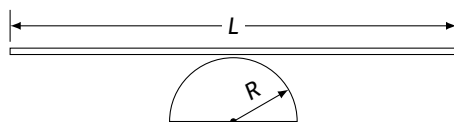
- At what angle should an arrow be shot in order to hit the target?
- In reality, reaction time τ has to be taken into account. At what angle should Jānis shoot in this case?

11-3° Pulleys and springs (3 p) Three pulleys, two springs of stiffness $k_1 = 15 \frac{\text{N}}{\text{m}}$ and $k_2 = 10 \frac{\text{N}}{\text{m}}$, respectively, and a block of mass $m = 100 \text{ g}$ are connected with strings as shown in the figure. Masses of pulleys, springs and strings are negligibly small, strings are not stretchable. The system is in equilibrium.

- Determine the absolute deformation of each spring.
- Determine the distance the pulley C would rise, if the mass m is gradually decreased to zero.



11-4° Rocking rod (4 p) A thin uniform rod of length L is placed symmetrically on a half-cylinder of radius R . Determine the period of small oscillations of the rod. The central moment of inertia of a rod is $\frac{1}{12}mL^2$. Free fall acceleration is g . Assume the rod is not slipping.



11-5° I-U source (2 p) Power supply unit automatically switches between two regimes: (a) if the current in the outer circuit does not exceed I_{max} , it ensures constant potential difference U_0 ; (b) if the potential difference across the outer circuit does not exceed U_{max} , it ensures constant current I_0 . Determine the long-time average power dissipated on the load of resistance R if the switching from regime (a) to (b) and from (b) to (a) takes equal short time.

11-6° Mercury merge (4 p) What is the maximum radius of two identical drops of mercury on a glass surface that will spontaneously merge when brought in contact? Density and surface tension of mercury are $\rho = 13,6 \frac{\text{g}}{\text{cm}^3}$ and $\sigma = 0,5 \text{ J/m}^2$, respectively; acceleration due to gravity $g = 9,8 \frac{\text{m}}{\text{s}^2}$. Assume that drops are spherical and that mercury does not wet glass.

11-7° Candle light (3 p) A thin convex lens with optical power $D = 2 \text{ m}^{-1}$ and radius $r = 15 \text{ cm}$ is located at distance $a = 75 \text{ cm}$ from a candle. A screen is located at distance $b = 200 \text{ cm}$ behind the lens. The lens is then removed. Determine the ratio of the maximum illuminance of the screen after and before the lens is removed. The principal optical axis of the lens passes through the candle flame and is perpendicular to the screen.

11-8° Across the Universe (4 p) In this problem, we assume that the Universe does not expand and is transparent for radiation. This model is rather simplistic, but is still useful for rough estimates. Assume that the average luminosity of stars in the Universe is L , and the number of stars per unit volume n is constant throughout the whole Universe. The energy density of radiation at any point of the universe is ϵ .

- Using the given quantities, determine the radius R of a visible part of the Universe.
- Explain why R must be finite within this model.

11-9° Origami (4 p) Two infinite paper sheets with uniform surface charge density $+\sigma$ are folded at an angle 2α and put together as shown in Fig. 1.

- (a) Determine the angle α that would maximise the electric field intensity E at point A.

A $2a \times a$ rectangle is cut from one of the sheets and folded at a 90° angle as shown in Fig. 2, forming two adjacent faces of a cube.

- (b) Determine the electric field intensity at the centre C of such an imaginary cube.

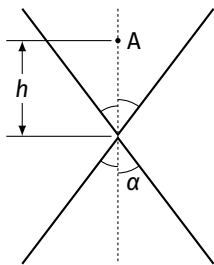


Fig. 1

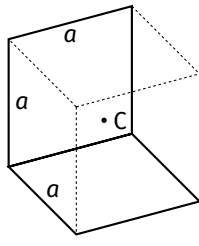


Fig. 2

11-10° Multiple choice questions (3 p)

For each question there is one correct answer. Justify your choice. Answers without justification will receive zero marks.

(1) Given three resistors with resistances $R_1 = 10\ \Omega$, $R_2 = 50\ \Omega$ and $R_3 = 100\ \Omega$, how should you arrange them for the equivalent resistance to be between $40\ \Omega$ and $50\ \Omega$?

- (a) R_1 and R_3 in parallel, connected to R_2 in series
- (b) R_2 and R_3 in parallel, connected to R_1 in series
- (c) R_1 and R_3 in series, connected to R_2 in parallel
- (d) R_2 and R_3 in series, connected to R_1 in parallel

(2) An incompressible fluid flows into a pipe of diameter 2 m with the speed $5\ \frac{\text{m}}{\text{s}}$. If the other end of the pipe has a cross-section area of $0,5\ \text{m}^2$, what is the speed of the fluid as it exits the pipe?

- (a) $1,3\ \frac{\text{m}}{\text{s}}$
- (b) $12\ \frac{\text{m}}{\text{s}}$
- (c) $31\ \frac{\text{m}}{\text{s}}$
- (d) $40\ \frac{\text{m}}{\text{s}}$

(3) Healthy human eye (at a certain age) can form a sharp image of an object not closer than 25 cm away from it. Suppose a person cannot see objects clearly if they are closer than 50 cm away from the eye. A lens of what minimum optical power will allow the person to see clearly again at the distance of 25 cm?

- (a) $-4\ \text{dpt}$
- (b) $-2\ \text{dpt}$
- (c) $+2\ \text{dpt}$
- (d) $+4\ \text{dpt}$

(4) A cylinder contains gas at pressure p and volume V . The gas undergoes isothermal expansion to volume $3V$ followed by isobaric contraction back to its original volume, followed by isochoric increase in pressure until it has returned to its original pressure. Which of the following is true regarding the work A done by the gas?

- (a) $A < \frac{2}{3}pV$
- (b) $\frac{2}{3}pV < A < \frac{4}{3}pV$
- (c) $\frac{4}{3}pV < A < 2pV$
- (d) $A > 2pV$

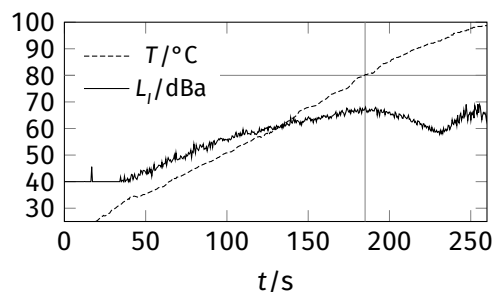
(5) Two metallic spheres X and Y are initially in contact and carry no charge. A negatively charged rod is brought near sphere X. If the two spheres are then separated, which of the following is true about the charges on each sphere?

- (a) $q_X = 0$, $q_Y = 0$
- (b) $q_X > 0$, $q_Y > 0$
- (c) $q_X < 0$, $q_Y > 0$
- (d) $q_X > 0$, $q_Y < 0$

(6) A rectangular ($a \times b$) wireframe is rotating around one of its sides in a uniform magnetic field of flux density \vec{B} . Is electromotive force (EMF) induced in the frame?

- (a) EMF is not induced
- (b) EMF is induced
- (c) Depends on the direction of \vec{B}
- (d) Depends on the $\frac{a}{b}$ ratio
- (e) Depends on the material of the wire

12-1° Kettle (3 p) While water is being heated up, one can notice that the noise level L_I produced by the kettle increases until the temperature reaches ca. 80°C and then decreases again (see the plot). Explain why it happens.

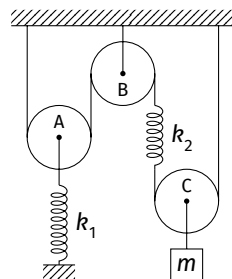


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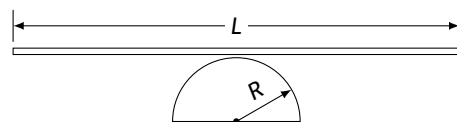
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12-8° Across the Universe (4 p) In this problem, we assume that the Universe does not expand and is transparent for radiation. This model is rather simplistic, but is still useful for rough estimates. Assume that the average luminosity of stars in the Universe is L , and the number of stars per unit volume n is constant throughout the whole Universe. The energy density of radiation at any point of the universe is ϵ .

- Using the given quantities, determine the radius R of a visible part of the Universe.
- Explain why R must be finite within this model.

12-9° Origami (4 p) Two infinite paper sheets with uniform surface charge density $+\sigma$ are folded at an angle 2α and put together as shown in Fig. 1.

- (a) Determine the angle α that would maximise the electric field intensity E at point A.

A $2a \times a$ rectangle is cut from one of the sheets and folded at a 90° angle as shown in Fig. 2, forming two adjacent faces of a cube.

- (b) Determine the electric field intensity at the centre C of such an imaginary cube.

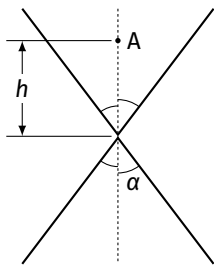


Fig. 1

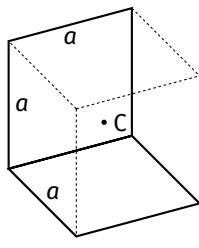


Fig. 2

12-10° Multiple choice questions (3 p)

For each question there is one correct answer. Justify your choice. Answers without justification will receive zero marks.

(1) Given three resistors with resistances $R_1 = 10 \Omega$, $R_2 = 50 \Omega$ and $R_3 = 100 \Omega$, how should you arrange them for the equivalent resistance to be between 40Ω and 50Ω ?

- (a) R_1 and R_3 in parallel, connected to R_2 in series
- (b) R_2 and R_3 in parallel, connected to R_1 in series
- (c) R_1 and R_3 in series, connected to R_2 in parallel
- (d) R_2 and R_3 in series, connected to R_1 in parallel

(2) An incompressible fluid flows into a pipe of diameter 2 m with the speed $5 \frac{\text{m}}{\text{s}}$. If the other end of the pipe has a cross-section area of $0,5 \text{ m}^2$, what is the speed of the fluid as it exits the pipe?

- (a) $1,3 \frac{\text{m}}{\text{s}}$
- (b) $12 \frac{\text{m}}{\text{s}}$
- (c) $31 \frac{\text{m}}{\text{s}}$
- (d) $40 \frac{\text{m}}{\text{s}}$

(3) Healthy human eye (at a certain age) can form a sharp image of an object not closer than 25 cm away from it. Suppose a person cannot see objects clearly if they are closer than 50 cm away from the eye. A lens of what minimum optical power will allow the person to see clearly again at the distance of 25 cm?

- (a) -4 dpt
- (b) -2 dpt
- (c) +2 dpt
- (d) +4 dpt

(4) A cylinder contains gas at pressure p and volume V . The gas undergoes isothermal expansion to volume $3V$ followed by isobaric contraction back to its original volume, followed by isochoric increase in pressure until it has returned to its original pressure. Which of the following is true regarding the work A done by the gas?

- (a) $A < \frac{2}{3}pV$
- (b) $\frac{2}{3}pV < A < \frac{4}{3}pV$
- (c) $\frac{4}{3}pV < A < 2pV$
- (d) $A > 2pV$

(5) Two metallic spheres X and Y are initially in contact and carry no charge. A negatively charged rod is brought near sphere X. If the two spheres are then separated, which of the following is true about the charges on each sphere?

- (a) $q_X = 0$, $q_Y = 0$
- (b) $q_X > 0$, $q_Y > 0$
- (c) $q_X < 0$, $q_Y > 0$
- (d) $q_X > 0$, $q_Y < 0$

(6) A rectangular ($a \times b$) wireframe is rotating around one of its sides in a uniform magnetic field of flux density \vec{B} . Is electromotive force (EMF) induced in the frame?

- (a) EMF is not induced
- (b) EMF is induced
- (c) Depends on the direction of \vec{B}
- (d) Depends on the $\frac{a}{b}$ ratio
- (e) Depends on the material of the wire