Moscow School Olympiad in Physics

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Problem 1. The mass of a horizontally placed wheel of radius R mounted on a vertical axis O (see figure) is equal to m and is uniformly distributed on its boundary. Rubber threads of stiffness k and $3k$ are fixed at points A and B lying on the same diameter. The other ends of the threads are attached to the vertical wall. In the state of equilibrium the segment AB is parallel to the wall, the threads are neither sagging nor deformed, the distance between them is $2R$

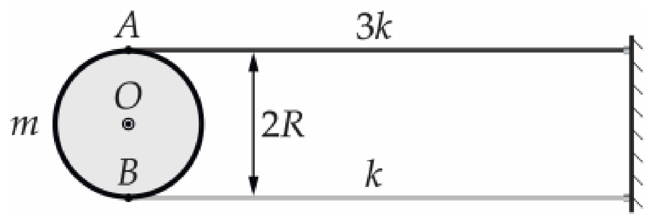


Figure 1: Problem 1

A. Let the disk be able to rotate, without friction, around the axis. Determine the period of small oscillations of the disk.

B. The axis rotates clockwise with a sufficiently large constant angular velocity. The friction between the axle and the wheel is dry. The maximum moment of frictional forces acting on the wheel is M_0 such that $M_0 \ll kR^2$. At first the wheel is held while the threads remain unstretched, then the wheel is released.

B1) How long after that will the angular velocity of the wheel become maximum? What will be this maximum velocity?

B2) How will the answer change if the axis rotates counterclockwise instead?

Problem 2. The heat machine of the room which works as a split-system operates on the inverse Carnot cycle, and it can be assumed that the room and outdoor temperatures correspond to the temperatures on the isotherms of the cycle.In summer, when the temperature outside the window is $+27^{\circ}$C. The split system, working in air conditioning mode (as a refrigeration unit), keeps the room temperature at $+17^{\circ}$C and consumes from the power grid an average power N_1. At the beginning of winter, when the temperature outside drops to -3°C, the split system switches to heat pump mode and maintains the same room temperature of $+17^{\circ}$C as in the summer, by consuming average power N_2.We can assume that the heat flow (through the windows and walls) is proportional to the temperature difference between the room and outside, with same coefficient of proportionality in summer and winter. Find the ratio of powers $n = N_2/N_1$

Problem 3. The Schlieren method is often used to photograph optical inhomogeneities in transparent media. In the picture below you can see the hot air streams generated by the flame of a gas burner and flowing around the human palm. The Schlieren method can be implemented according to the scheme

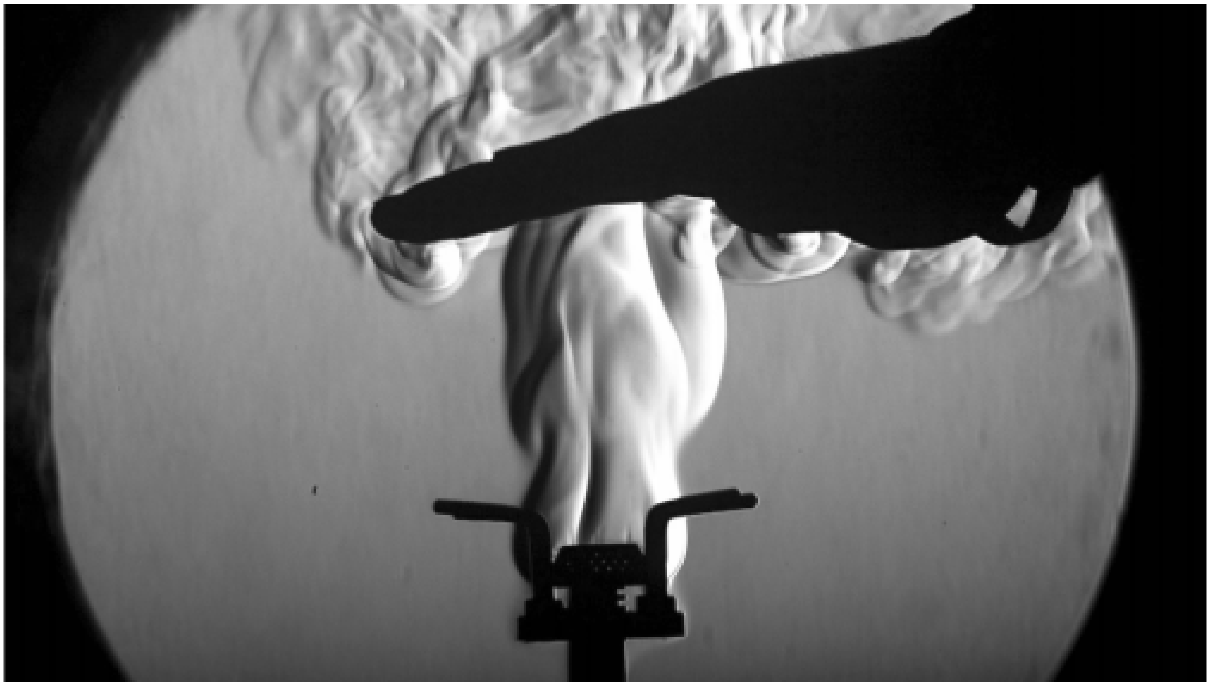


Figure 2: Problem 2

shown in the figure below. Two thin lenses L_1 and L_2 are placed such that their optical axes coincide with each other. At the focus of one lens, F_1 is a point light source, and in the focal plane of the other lens, point F_2 is a Foucault knife- a large opaque screen K with a sharp edge protruding above the level of the optical axis at a short distance h. The focal plane of the camera lens coincides with the focal plane of the lens L_2.

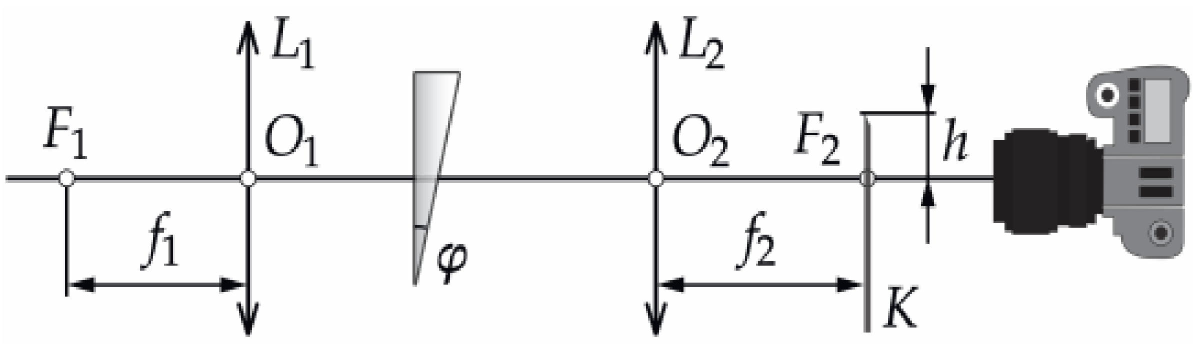


Figure 3: Problem 2

A. Let a prism with a small refractive angle φ and refractive index n. At what values of h, would the only gray background be visible in the picture?

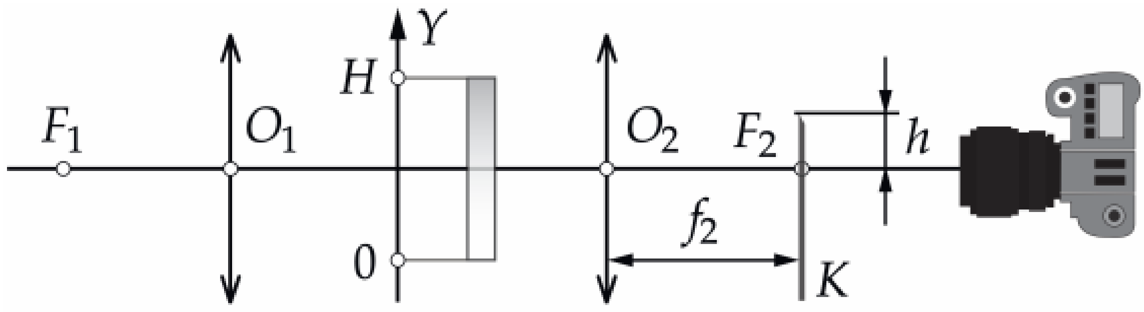


Figure 4: Problem 2

B. A prism is replaced by a plane-parallel plate (see fig. above) of thickness d and and length H such that d $\ll H$ whose refractive index linearly depends on the coordinate y: $n(y) = n_0(1 + \alpha y/H)$, the values $\alpha \ll 1$ and n_0 are considered to be known.
At what values of h in this case will only the gray background be visible in the photo?

C. Explain briefly (in two or three sentences) why in the picture at the beginning of the problem, palm and burner are dark and the air currents are light, and also why all the images are visible on the background of a gray circle

Problem 4. A battery with an EMF ε, whose internal resistance can be assumed to be zero, is charged in the circuit shown in the figure. A diode bridge consists of perfect diodes that open at zero voltage. A

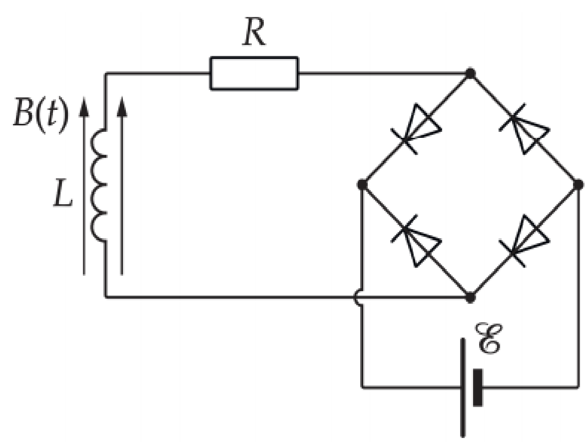
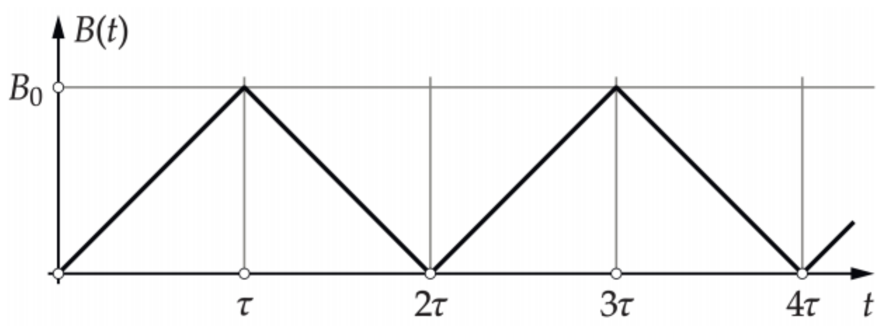


Figure 5: Problem 3

coil with inductance L is placed in the region of a periodically varying magnetic *B(t)*. We can assume that the resistance of the coil and connecting wires is concentrated in a resistor of resistance R. The coil is wound on a core in the form of a hollow cylinder with cross section S and contains N turns. The outer radius of the coil is slightly different from the inner radius.The induction of the magnetic field *B(t)* created by external sources is directed along the axis of the coil. We can assume that the field inside the core is homogeneous. A fragment of the dependence of field induction on time is shown in the graph below. The constants B_0 and τ are assumed to be known, and their values are such that the circuit can charge the battery in a finite time.



A. It is known that the circuit parameters satisfy the relation $L/R \ll \tau$. Determine the charge flowing through the battery in time t_0.

B.Let the resistance R be so small that the condition: $L/R \gg \tau$ is satisfied. Find the average current flowing through the battery after a long time when charging begins.

Problem 5. The mechanism by means of which the tilt garage door works is shown in the figure below with the door ABC in the vertical position (closed). Applying the handle at the bottom edge of the door at point A, it is possible to move the door to the horizontal position (open). As the door is lifted, the roller C fixed to the upper edge of the door moves on the horizontal support. In point B (AB = BC = L) the gate is pivotally connected to a rocker which can rotate around a fixed axis O. At the other end of the yoke is a weight of $m = 25\ kg$. The gate can be thought of as a thin homogeneous plate of mass $M = 30$ kg. The mass of the beam and the roller, any kind of friction, and the linear dimensions of the roller and can be neglected. The acceleration of free fall and the values of are: g = 10 m/s^2,$L = 92\ cm$, $h = 65\ cm$. In the upper position, the gate is fixed with a latch.

A.
A1) How much force F_1, perpendicular to the gate, must be applied to the handle to hold the gate stationary with the rocker horizontal?

A2) What is the minimum force F_2 that must be applied to the handle to keep the gate stationary when the rocker is horizontal?

B. Suppose that during a very slow lifting of the gate from the initial vertical position to the final horizontal position, the minimum force required to lift the gate at any given time is applied to the handle. What is the maximum value of F_{max} of this minimum force?

C. If you open the latch in the upper position, the gate will start to move downward and the rocker will rotate. Determine the velocity of the bottom point of the gate when it touches the ground.

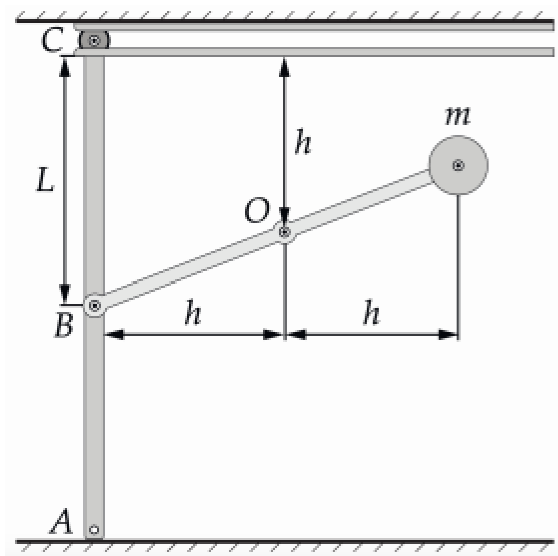


Figure 6: Problem 5