KamaChallenge 2021

THEORETICAL TOUR

In all tasks of the theoretical round, provide a detailed detailed solution of the problem. No points will be awarded for the answers provided without explanation.

Basic level problems

Problem 1

The projectile explodes into two fragments in flight. The first moves at a speed $\upsilon_1 = 26$ m/s at an angle of 90° to the initial direction of movement of the projectile, and the second moves at a speed $\upsilon_2 = 10$ m/s at an angle of 60°. What is the ratio of the masses of the fragments? What is the velocity of the projectile before bursting? Disregard the mass of the explosive. (5 points)

Problem 2

The horizontal cylinder contains ν = 0.24 mol of molecular nitrogen (Fig. 1). On the right, the cylinder is closed by a piston with a mass of $M = 90$ g, which is held by small stops. At some point, a bullet with a mass of $m = 10$ g, flying at a speed of $\upsilon = 100$ m/s, hits the piston and gets stuck in it. How much will the gas temperature change by the time the piston stops in the extreme left position? There is no friction. Ideal-gas constant R = 8.31 J/(mol·K). Consider that the gas does not have time to exchange heat with the piston and cylinder walls. (5 points)

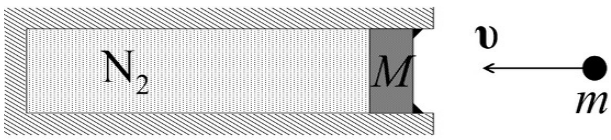

Fig. 1

Problem 3

In the electric circuit (Fig. 2), the key K is initially closed. The EMF source ε = 24 V has an internal resistance r = 5 Ohm. The resistance of the resistor R = 25 Ohm, the capacitance of the capacitor C = 1 μF. How much heat Q will be released on the resistor after opening the key? (5 points)

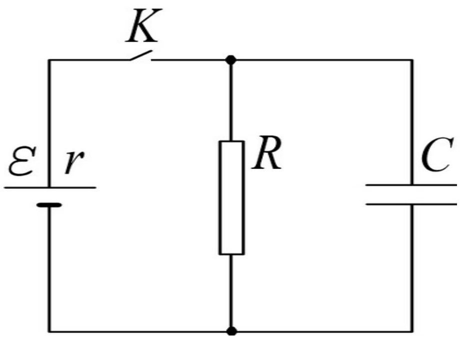

Fig. 2

Problem 4

The horse pulls the sled with a force F = 220 N directed at an angle α = 30° to the horizon (Fig. 3). With what acceleration does the sled move if its mass is m = 100 kg, and the coefficient of friction of the runners on the snow is μ = 0.1? Free fall acceleration g = 10 m/s^2. (5 points)

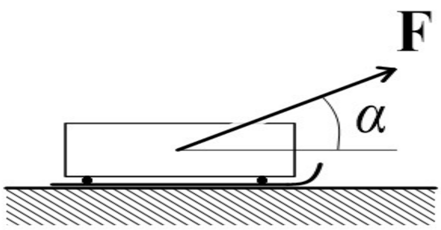

Fig. 3

Problem 5

A vertical luminous object with a height of h = 1 cm is located near the main optical axis of a thin converging lens with a focal length of F = 50 cm. The distance from the object to the lens is d = 75 cm. At what distance from the lens and what size will the object's image be? What is the characteristics of this image? (5 points)

Difficult level problems

Problem 6

Four metal plates with an area of $S = 1\ \text{m}^2$ are located parallel to each other at a distance of $d = 1$ mm. The plates are connected with wires as shown in Fig. 4. Between the two middle plates there is a dielectric layer with a permittivity $\varepsilon = 4$. The outer plates are connected to a DC voltage network $U = 10$ V through terminals *A*, *B*. What is the electrical capacity of the system? What are the charges of the plates and the field strengths between them? Neglect edge effects. Electric constant $\varepsilon_0 = 8.85\cdot10^{-12}$ F/m. (10 points)

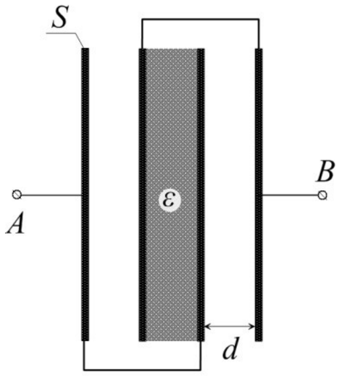

Fig. 4

Problem 7

A thin plano-convex lens (Fig. 5) made of glass with a refractive index $n_0 = 1.60$ is inserted into a hole in an opaque vessel with water. A small light source OO′ located at a great distance from the lens near its main optical axis. At what distance from the lens and where will the image of this light source be located. The radius of curvature of the lens is R = 45 cm, and the refractive index of water is n = 1.33. (10 points)

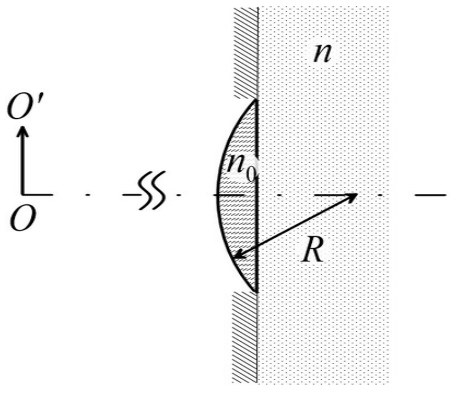

Fig. 5

Problem 8

The heat engine operates on a double cycle *OABC* – *ODEF* – *OA*… (Fig. 6). Which of the small cycles *OABC* or *ODEF* has greater efficiency? Find the efficiency of the double cycle. The working fluid is a monoatomic ideal gas. (15 points)

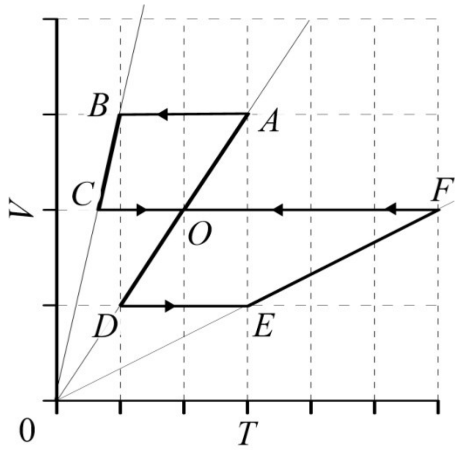

Fig. 6

Problem 9

The air condenser plates have a square shape with a side a = 10 cm, and the gap between them is d = 0.1 mm. The lower plate is stationary, and the upper plate is able to move parallel to the lower one without friction. The capacitor using flexible conductors is connected through an ideal diode* D to an ideal source of constant EMF ε = 100 V. At the initial moment (Fig. 7), the upper plate begins to shift at a constant speed υ = 1 m/s. How long after the start of movement between the plates will an electrical breakdown of air occur if the field strength sufficient for breakdown is E_0 = 30 kV/cm? What work will be done by the forces acting on the plate? Neglect edge effects. The work spent on changing the kinetic energy of the plate should not be taken into account. Electric constant $\varepsilon_0 = 8.85\cdot10^{-12}$ F/m (15 points)

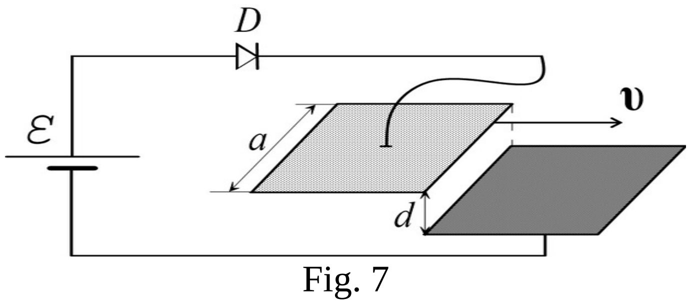

Fig. 7

** An ideal diode is a one-sided conduction element that has zero resistance when current flows in the direction indicated by the arrow and infinite resistance in the opposite direction.*

Problem 10

The cruisers of the enemy fleet are heading at an angle $\gamma = 60°$ with the same speed $\upsilon_0 = 15$ m/s. The crew of cruiser "*A*" detects the enemy directly along the course at a distance of $L_0 = 2.25$ km (Fig. 8). Quickly assessing the situation, the captain orders to fire a shot at the cruiser "*B*" at the moment of the closest approach to it.
1. After what time *t*, at what angle to the horizon α and lead angle β ** is it necessary to fire cruiser *A* for the projectile to hit point *B*? The initial velocity of the projectile is $u_0 = 150$ m/s. (15 points)
2. Suggest a way to find α and β for an arbitrary time instant *t* by construction. Conduct construction in $t = 1$ min. (10 points)
Ignore air resistance and earth curvature. Free fall acceleration $g = 10$ m/s^2.

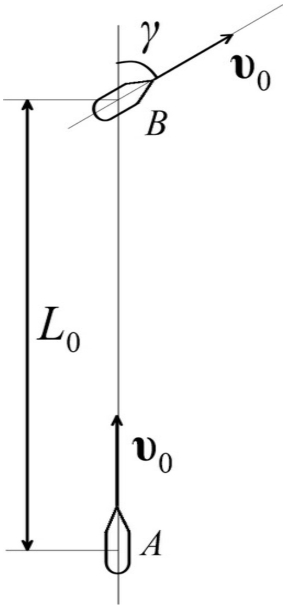

Fig. 8

** *Lead angle - the angle measured* ***horizontally*** *from the direction to the target to the direction in which the shot is fired.*

EXPERIMENTAL TOUR

Qualitative problems

In all the tasks of the section it is necessary to give a full detailed explanations of the video recordings of the experiments. Explanations that are not based on physical laws or have an ambiguous interpretation will not be counted.

Video 1: https://youtu.be/Bmlgmja6U-0

From the video of the experiment, explain the difference in the distance traveled by the carts to the stop. Follow the explanatory drawing, if necessary. (5 points)

Video 2: https://youtu.be/F4uWncdfvJo

Explain the difference in the damping rate of the oscillations of the pendulums based on the video recording of the experiment. (5 points)

Video 3: https://youtu.be/dDdqH5JfoAI

Using the video recording of the experiment, explain why the paper petals on the inner side of the cylinder formed by the metal mesh go down, and on the outside they deflect more. (5 points)

Quantitative problems

In all tasks of the section, it is necessary to submit for verification a complete detailed description of the processing of experimental data. The description should contain explanatory figures, calculation formulas, tables of measurement and calculation results. Reports that do not contain experimental data will not be counted.

Video 4 Simple Pendulum: https://youtu.be/tjgrH0IFq9s

Determine the acceleration of gravity from the video recording of the experiment. Estimate the error of the result. Explain the reason for the observed difference with the tabular value $g = 9.8$ m/s^2. (15 points)

Video 5 Angle Throw: https://youtu.be/W86xWHQq92E

According to the video recording of the experiment *, estimate the initial speed of the body thrown at different angles to the horizon **. Perform statistical processing of the result and estimate the measurement error. Explain the reasons for the discrepancy in the results. What are the limitations of the chosen physical model? (15 points)

* *Video recorded in slow motion.*

** *For throwing the body, a small spring cannon was used, located near the zero mark of the measuring scale.*