LPR Cup

10.s05.e05

Hint 2

IMPORTANT! The next task is both a hint and an alternative to the main task. Three important points:

1. You can continue to send the solution to the main problem.
2. At any moment before the final deadline you can start to solve the Alternative problem. If you do so, at the beginning of the solution write: *I am doing the Alternative problem!* In this case a penalty coefficient for the Alternative problem is

$$0{,}7 \cdot \sum_i \frac{k_i \cdot p_i}{10},$$

where p_i is a point for the problem item, and k_i is a penalty coefficient for the corresponding problem's item at the moment of moving to the Alternative problem. In other words, maximal points for the alternative problem equals to the maximal points you can gain at the moment of moving to the alternative one multiplied by 0,7. Also, we remind you that a penalty coefficient can't be less than 0,1. Solutions of the main problems from that moment will not be checked. Be careful!

3. The task consists of several items. The penalty multiplier earned **before** is applied to all points. In the future, each item is evaluated as a separate task. If you send a solution without any item, this item's solution is considered as Incorrect. For more information about scoring points for composite tasks, see the rules of the Cup. **Since switching to an alternative selection, there is no opportunity to return to solving the main task.** Also, after switching to an alternative task **the points for the main task are reset**.

Introduction

There were drafts next to the folder, from which an attentive Observer could find out how Hans came to certain results of his main work.

Alternative task

Part 1. Why do nuclei reactions matter?

The correct dice was rolled 3 times and the sum of the results turned out to be 6.

1. *(0 points)* What are the possible sequences of dice roll results?
2. *(0 points)* What is the most likely sequence?
3. *(2 point)* Which result set is the most likely?

Part 2. Déjà vu

This section challenges you to derive a criterion that, when satisfied, ensures the operation of a fusion power plant at zero net power output. Consider a finite volume containing a plasma composed of deuterium and tritium nuclei, along with electrons resulting from their ionization. All plasma components behave as an ideal gas. The number of deuterium-tritium fusion reactions

$$d + t \longrightarrow {}^{4}_{2}\mathrm{He} + n + 17.6\mathrm{MeV}$$

per unit volume per unit time is given by:

$$A \cdot n^2 \cdot T^{1/2},$$

where n is the known concentration of each type of nuclei within the reactor, T is the known temperature of all plasma components, and A is a known constant.

Assume that all reaction products reach the reactor walls without interacting with the plasma, transferring all their kinetic energy as heat. The walls, in turn, convert this heat into electricity, which is then used to heat/maintain the plasma temperature. This feedback system operates with efficiency η. It is known that if the feedback mechanism and nuclear reactions are "stopped the plasma will cool down with a characteristic cooling time τ, which is determined by the reactor's design features and is one of its key parameters. Here, the characteristic cooling time is the time it would take for the plasma to reach zero temperature if it were to cool at a constant rate equal to the initial rate.

1. *(3 points)* Under what condition on the value of $n\tau$ is it possible for the reactor to operate in such a way that the described system can operate indefinitely and "self-sustain"due to the feedback mechanism?

Part 3. Plasma

1. *(0 points)* The space is filled with an ideal gas with a particle radius of R and a concentration of n. Estimate the average particle path length. Find the numerical value for $R = 10^{-10}$ m and $n = 10^{25}$ m^{-3}. Consider that molecules do not interact with each other at a distance, but when approaching at a distance less than the sum of the radii, a collision occurs.
2. *(0.25 points)* A fast electron flies into the region where neutral atoms with a concentration of n are located. Each time it hits an atom, it loses $\alpha = 0.1\%$ of its energy. Consider the effective area for calculating impacts to be equal to S. Estimate the distance at which the electron will lose half of its energy. Find the numerical value for $n = 10^{25}$ m^{-3} and $S = 4 \cdot 10^{-20}$ m^2.

3. *(0.25 points)* Find the electric field strength for a uniformly charged infinite layer with a thickness of h. The bulk charge density is ρ. Plot the dependence of the electric field strength on the distance to the central section of the layer.

4. *(0.25 points)* A narrow through channel is made across a uniformly charged infinite layer with a thickness of $2d$ and with a charge density of ρ. An electron flies into the channel at a speed of v_0. Find the velocity of the electron in the middle and at the exit of the channel.

5. *(0.25 points)* An electric dipole of mass m and with a dipole moment p flies into the channel at a speed of v_0. The speed of the dipole increases. Find the velocity of the dipole in the middle of the channel. Find the velocity of the dipole at the outlet of the channel.

Part 4. Déjà Déjà vu

Let's consider qualitatively the process of the emergence of an independent gas discharge. The space between two flat conductive electrodes (cathode and anode) located at a distance of d from each other is filled with gas, and the electrodes themselves are connected to a DC voltage source.

The process of forming a gas discharge consists of two parts. The first is the formation by electrons in the process of ionization of a current of electrons and ions in a medium filling the space between the electrodes. The second part is the knocking out of new secondary electrons by ions from the cathode. To simplify the task, we will replace the process of knocking out electrons from the cathode with a similar one: we will assume that every electron that reaches the anode is captured by some element that provokes the birth of electrons in the cathode region and at the same time all the ions in our system will not affect anything.

Let's look at each of these processes in more detail. Suppose an electron was formed between the electrodes for some reason. Under the influence of an electric field, it begins to accelerate and move from the cathode to the anode and in the process collide with gas molecules, ionizing them. The new electrons formed will also move towards the anode. At the same time, they will form more and more electron-ion pairs, and ions will not do this (because their speed, which is one of the determining parameters in this process, will be significantly less than the speed of electrons). And then, when reaching the anode, a special element will provoke the birth of new electrons in the cathode region in proportion (with a coefficient of η) to the electrons that have come to the anode.

We will call the total ionization coefficient α the number of electrons at the end (in the anode region) of the avalanche generated from one electron that began its path in the cathode region. We will call external ionization a certain process that creates primary electrons. These can be a variety of processes: ultraviolet or gamma radiation passing through a gas, an additional conductor creating a small current of electrons, and so on. In our consideration, we will assume that this process is localized in the cathode region.

1. *(1 point)* It is known that the electron current in the cathode region is equal to I_{ek}, which includes the current of an external ionizer and the current of secondary electrons generated by a special element. The total ionization coefficient α is known. Find the electronic current in the anode area.

2. *(1 point)* Determine what is the current generated by a special element in the cathode area I_{xk}.

3. *(1 point)* Express the electron currents of the cathode and anode I_{ek} and I_{ea} through the ionization current I_i.

A breakdown is a situation when the electronic current I_{ea} increases infinitely at an arbitrarily small ionization current. If, after the breakdown occurs , the external ionizer is removed and the current does not stop, then the discharge is called independent: ionization is supported by processes in the discharge itself. (In our simplified case, processes in a discharge and a special element)

4. *(1 point)* Determine under what condition a breakdown will occur on α, η and d and the discharge will become independent?