The European Journal of Education and Applied Psychology 2023, No 4
ISSN 2310-5704

PREMIER Publishing
ppublishing.org

DOI:10.29013/EJEAP-23-4-32-35

DEVELOPING STUDENTS' SCIENTIFIC RESEARCH SKILLS BY SOLVING PHYSICAL PROBLEMS NUMERICALLY

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Cite: *Jalolova P.M. (2023). Developing Students' Scientific Research Skills by Solving Physical Problems Numerically. European Journal of Education and Applied Psychology 2023, No 4.* https://doi.org/10.29013/EJEAP-23-4-32-35

Abstract

This article deals with the problem of numerically finding electric and magnetic field strengths of charged particles or charged systems. In addition, the dependence of area sizes on various parameters was considered.

Keywords: *Physical process, computer simulation, plasma, electron, electrically neutral, gas, ion, physical model, elementary volume, oscillations, equation, amplitude, electric field strength, potential distribution, impulse field*

Introduction

In order to increase the efficiency of scientific research in the future, it reduces the period of creating an optimal physical model of a device or material that needs to be created using IT technologies and accelerates the expected result. In addition, the creation of an optimal physical model must be created with the help of numerical modeling, an animation of a physical process that can take place based on theoretical knowledge, or a graph depicting the interdependence of various physical parameters.

These requirements lead undergraduate physics students to increasingly focus on solving physics problems numerically. For this purpose, the subject "Computer modeling of physical processes" (Kotkin, G. L., Popov, L. K., Cherkassky, V. S. 2016) is included in the curriculum. With the granting of academic and financial independence to higher educational institutions, higher educational institutions had the opportunity to change the curriculum and program based on the requirements of the times. With this in mind, it is possible to increase the number of hours to work on physical problems with the help of numerical modeling.

This requires attention to the number and quality of problems offered for use in practical training.

In addition, solving physical problems numerically allows to simultaneously study the dependence of the numerical value of one physical parameter on several parameters in a large range. We found it appropriate to consider some of these issues below.

Materials and methods

In recent years, Poisson's equation has been widely used to study the distribution of electric field strength and potential in semiconductor structures with the help of numerical modeling. However, there are hardly any analytical problems related to the above topic in the practical exercises of the II-year "Electricity and magnetism" (Kalashnikov, S. G., 2003) and III-year "Electrodynamics" (Landau, L. D., Lifshits, Ye. M., 2006) sections of the bachelor's degree. In addition, it is more complicated to create a graph of the dependence of the parameter determined on the obtained analytical expression on the remaining parameters. Taking this into account, in this article, the electric field strength and potential of the system of charges is determined using Poisson's equation, and the time and coordinate change graph is obtained using numerical modeling.

For this we will see the following issue.

Problem: Determine the conditions for the appearance of an electric field in a low-temperature plasma and learn the distribution of E and φ

In the problems used in practical exercises in the course of general physics or in the course of theoretical physics, based on the given physical parameters characterizing the physical process, the quantitative value or analytical expression of the unknown parameters is found, but almost never analyzed. Using such problems does not develop creativity in students. When the problem is presented as above, students should imagine the physical quantities characterizing the process and create a physical model close to reality.

The purpose of this approach to the issue is to further develop their creativity and scientific research skills.

In working on this issue, we first seek answers to the following questions.

1. What is a low-temperature plasma and does it have an electric field?

2. How to create if it does not exist, explain the process in detail.

Answers:

1. As a well-known low-temperature plasma, an example can be given of helium gas ionized by external impact. If the system is closed, the ionized gas can be considered as a neutral system, because in a closed system electroneutrality is achieved, i.e.

$$Q_+ + Q_- = 0$$

An electric field does not form around and inside electroneutral systems.

2. An electric field can be created only due to the redistribution of charges inside electroneutral systems, and no electric field can be created outside.

Charges can be redistributed in two different ways.

1. By heating one side of the container in which the gas is trapped. Since the mass of the positive helium ion $m_{He} \approx 2000 m_e$ is related to the mass of the electron, the relation is valid $v_{He} \approx 140 m_e$. So electrons move faster to the cold side and charge separation occurs

The speed of electrons and neitrons $v_{He} \ll v_e$ satisfies the relationship. Therefore, helium ions can be considered as immobile. In this case, an uneven distribution of electrons occurs on one side of the container.

2. Charges are stimulated by placing the ionized gas container in an electric field for a short period of time. If we consider the positive helium ions to be immobile due to the above mass ratio, the electron container will be compressed to one side. Due to the interaction forces and the generated electric field, the distribution of electrons becomes uneven as above.

So, in both cases, almost the same physical process occurs, plasma, that is, an electric field is formed in a container containing ionized gas. The main problem is to study the distribution of electric field magnitudes in time and coordinates.

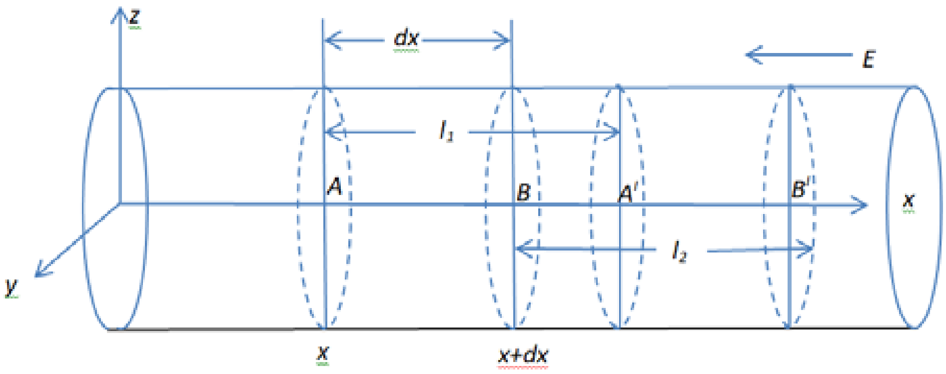
It is known that a physical model is created to work out any physical problem.

Physical model: Let a low-temperature plasma with equal concentrations of positive ions and free electrons be confined in a cylindrical vessel of finite length with cross section S. As a result of the external influence, we assume that the charged particles move along only one axis.

Results and discussions

In solving the problem, we extract an elementary volume $dV = Sdx$ from a cylindrical container (Fig. 1). The separated volume has a total charge $Q = 0$, because the system is electroneutral. We define this volume in the drawing as follows. We see an electric field pulse as an external impulse. Free electrons are uniformly accelerated along the *X-axis* by the instantaneous electric field

Figure 1. *An elementary volume isolated from a cylindrical container*



Due to the difference in their motion and interaction with electrons in the elementary volume, the electrons in the A level move a distance *h*, while the electrons in the *B* level move a distance $l_2 = l_1 + dh$. But the total number of free electrons in the resulting elementary volumeremains unchanged

$$N_0 = N_1 \qquad (1)$$

$$N_0 = n_0 dV_0 = n_0 S(x + dx - x) - n_0 S dx$$

$$N_1 = n_1 dV_1 = n_1 S(l_2 - l_1) -$$
$$-n_0 S(x + dx + l_1 + dl - x - l_1) dx$$
$$N_1 = n_1 S(dx + dl) \qquad (2)$$

(1) and (2) $n_0 S dx = n_1 S(dx + dl)$

$$n_1 = \frac{n_0 dx}{dx + dl} = \frac{n_0}{1 + \frac{dl}{dx}}$$

$\frac{dl}{dx} \ll 1$ considering them done $\left(1 + \frac{dl}{dx}\right)^{-1} = 1 - \frac{dl}{dx}$ is proper. So we will get $n_1 = n_0\left(1 - \frac{dl}{dx}\right)$ (3)

Due to the decrease in the concentration of electrons in the elementary volume dV1 between the levels A and B, it becomes positively charged. Because we consider that positive ions are almost immobile, their concentration throughout the volume does not change, that is, it is equal to *n*0.

In that case, taking into account the charge density in the field (3), we get the following:

$$\rho = e\Delta n = e(n_0 - n_1) = e n_0 \frac{dl}{dx} \qquad (4)$$

(4) using the expression, we find the distribution of the electric field strength and potential inside the container using Poisson's equation as follows

$$divE = 4\pi\rho = 4\pi e n_0 \frac{dl}{dx} \text{ (SGSE)}$$

$$divE = \frac{1}{\varepsilon_0} e n_0 \frac{dl}{dx} \text{ (SI)}$$

Since the field is directed only along the X-axis, we have

$$\frac{dE}{dx} = \frac{e}{\varepsilon_0} n_0 \frac{dl}{dx} \text{ or } E = \frac{e}{\varepsilon_0} n_0 l \qquad (6)$$

Under the influence of this generated electric field, free electrons move in the direction opposite to their previous movement. Using Newton's second law, we find the law of motion of electrons.

$$F = ma \text{ and } F = -eE$$

(6) considering it

$$ma = -eE = -\frac{e^2}{E_0} n_0 l$$

since it travels a distance l along the x-axis during its motion we get $a = \ddot{l} = 1$. Then we have the following equation

$$\ddot{l} + \frac{e^2 n_0}{\varepsilon_0 m} l = 0 \qquad (7)$$

In this equation if we put $\omega_0 = \sqrt{\frac{e^2 n_0}{\varepsilon_0 m}}$ we get the equation of free oscillations in the form

$$\ddot{l} + \omega^2 l = 0 \qquad (8)$$

The solution of the equation can be found by numerical modeling of the coupling of the amplitude, electric field strength and potential distribution to the electron motion.

Discussion and conclusion

As we mentioned above, the main goal is to develop scientific research skills in students. Therefore, analyzing the obtained results, obtaining various graphs is considered one of the most important. In addition, it is necessary to analyze the reliability of the physical parameters obtained as a result of the research and how well they match with the experimental results.

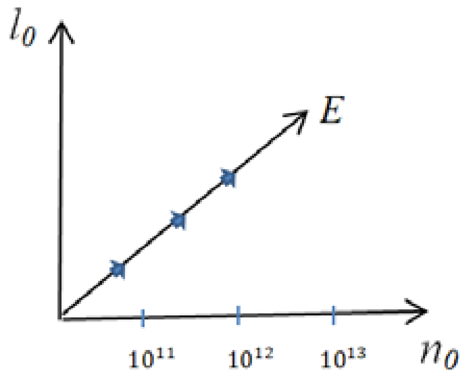
For this, it is necessary to determine the type of physical process occurring in the considered physical object, i.e., the type of vibration, and to select the physical quantity whose graph is to be drawn. It is known that the dependence of the studied parameter on one or two parameters is obtained only by modeling the graph in two and three dimensions with the help of a computer.

Since the field is placed along the x-axis, the electrons move along this axis. The area we are looking at, that is, the length of the cylindrical container should not be less than 2*l*0. Here is the amplitude of the solution of equation l0–(8) (6) is determined using an expression.

$$l = \frac{\varepsilon_0 E}{e n_0} \quad (9)$$

If the external pulsed field is taken in the range $E \approx 10^3 \div 10^5 B/m$ l_0 varies in the range $10^{-1} \div 10^{-3}$ *см*. This expression can be graphed in three dimensions. (Figure 2)

Figure 2. *A three-dimensional graph of the momentum field*



In the same way, the frequency of oscillation *w*0 can be plotted as a function of xam *n*0 and m. The above problem is solved without giving any parameters and the necessary graphs are obtained with the help of a computer. It is clear that solving such problems requires the student to have deep knowledge and to visualize the physical process. In addition, taking a graph from the expression of interdependence between quantities and analyzing it with the help of a computer will develop scientific research skills in students. Taking this into account, it is appropriate to give such issues as a course work or a graduation thesis to students who are talented and intend to do scientific research in the future.

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submitted 22.08.2023;
accepted for publication 20.09.2023;
published 28.12.2023

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