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Research Article

INTER-SUBJECT RELATIONS OF THE COURSE OF GENERAL PHYSICS WITH THE COURSE OF HIGHER MATHEMATICS

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ABSTRACT

This is an article on the methodology of teaching physics at the university. The material is devoted to the enumeration and analysis of physical processes based on mathematics.

KEYWORDS

Physics, mathematics, mathematical model, induction current, Planck's coefficient, frequency, period of light oscillation.

INTRODUCTION

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There is an opinion that since physics is the science of ideas and experiments, it can be taught without a strict mathematical apparatus, that a very modest mathematical background is sufficient to introduce the basic ideas and explain experiments. We adhere to a different point of view: in order to master the general course of physics, the student must not only know the modern mathematical apparatus, but must also be able to apply it.

What are the functions of mathematics in the teaching of physics? Obviously, first of all, the same as in the science of physics. Mathematics is the language of physics. As in any activity, a person needs a special language in order to think and explain something to others. Mathematics is such a language for physics, which makes it possible to think in a special, exceptionally clear and flexible international language. As R. Feynman pointed out very figuratively, "Mathematics is not just another language. Mathematics is a language plus reasoning, it's like a language and logic together. Mathematics is a tool for thinking. It concentrates the results of the precise thinking of many people. With the help of mathematics, one statement can be related to another" (18).

The most common method for studying physical phenomena by mathematical methods is the modeling of these phenomena in the form of differential equations. This is explained by the fact that in order to compile them, it is sufficient to know only local connections and information about the entire phenomenon as a whole is not needed. For example, when compiling the equations of pendulum oscillations, we do not start from the seemingly obvious that the pendulum, taken out of equilibrium, oscillates, but only use the fact that the restoring force is proportional to the displacement.

$$\vec{F} = -k \cdot \Delta\vec{X}$$

The result is an equation whose solution has an oscillatory character. This solution allows you to conduct a qualitative and quantitative analysis of the oscillatory system as a whole. Thus, this mathematical model makes it possible to study the phenomenon in general terms, predict its development, and make quantitative estimates of the changes that occur in it over time. This is how the undulating propagation of electromagnetic disturbances was discovered: from the local properties of the phenomenon to equations, and from equations to the description of the phenomenon as a whole.

When studying the section "Physical Foundations of Mechanics", it is necessary to have an understanding of the basics of vector algebra, the derivative, the simplest rules of differentiation, the indefinite and definite integral, and the ability to integrate the simplest differential equations. When considering the rotational motion of a rigid body and gravity, knowledge of the partial derivative, gradient, scalar, vector and double vector product of vectors, vector flux, vector circulation is necessary.

The section "Molecular physics and thermodynamics" uses the same mathematical apparatus. In addition, information is needed about the curvilinear integral, the condition for its independence from the path of integration, as well as knowledge of the basic concepts and definitions of probability theory and mathematical statistics.

When studying electrodynamics, the concepts of divergence, circulation, and rotor are necessary, and it is desirable that they be written using the Hamilton operator, which is widely used in optics, atomic and molecular physics, and solid state physics. The

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Oscillations and Waves section uses second-order differential equations as well as functions of a complex variable.

The final stage of studying the basics of electrodynamics in the course of general physics is the study of Maxwell's equations. This means that the study of electrodynamics in the course of general physics goes mainly along the inductive path - based on the analysis of a number of the simplest experimental facts (electrification of bodies, the interaction of charged bodies and conductors with current, the phenomenon of electromagnetic induction, etc.), certain specific laws are formed, which are then generalized to Maxwell's equations. Consequently, here the main path is from the particular to the general, which, however, does not exclude some elements of deduction. This path is recommended by the program and accepted by the vast majority of textbooks for higher education. Of course, another way is fundamentally possible - postulating Maxwell's equations and deriving from them all the provisions of electromagnetism.

However, this approach seems to be more suitable for studying physics at a higher level, in particular, in a theoretical physics course or a special course.

In the inductive approach, Maxwell's equations act as generalizations of the Ostrogradsky-Gauss theorem for electric and magnetic field vectors, the law of total current, and Faraday's law of electromagnetic induction. In integral form in the International System of Units, they have the form:

$$\oint_S E_S \quad ds = -\frac{d\Phi}{dt} \tag{1}$$

This relation expresses the quantitative relationship between the changing magnetic field $\vec{B}$ and the vortex electric field $\vec{E}$ and is one of the basic equations in Maxwell's theory.

When an electric field changes, a magnetic field appears around that field. So the changing electric field is the displacement current.

So there are three types of currents.

1. The ordered movement of charges is a current. (In metals, free electrons create a current) $J = \frac{q}{t}$
2. Induction current appears when crossing an alternating magnetic field closed circuit.

$$\mathcal{E}_i = -\frac{\Delta\Phi}{\Delta t}$$

3. The displacement current is an alternating electric field. An alternating magnetic field creates an alternating electric field. The bias current density will be:

$$j_C = \frac{dD}{dt}$$

$\vec{D}$ - vector of electrostatic induction. Let's write the law of total current:

$$\oint_S H_S dS = J_{полн}$$

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ℓ - is the length of a closed circuit located inside the conductor, through which alternating current flows. S is the area of the closed circuit.

$$J_{полный} = \int_S j_{полный} ds = \int_S jds + \int_S \frac{dD}{dt} ds$$

$$\int_S \frac{dD}{dt} ds = \frac{d}{dt} \int_S D \cdot ds = \frac{dN}{dt}$$

N is the flux of the electrostatic displacement vector.

To mean:

$$J_{полный} = J + \frac{dN}{dt}$$

$$\oint H_S dS = J + \frac{dN}{dt} \tag{2}$$

To these equations, two more equations must be added that express the Ostrogradsky-Gauss theorem for electric and magnetic fields:

$$\oint_S D \quad dS = q \tag{3}$$

$$\oint_S \vec{B} d\vec{S} = 0 \tag{4}$$

To this are added the relations between the field vectors:

$$\vec{D} = \varepsilon \varepsilon_0 \vec{E} \tag{5}$$

$$\vec{B} = \mu \mu_0 \vec{H} \tag{6}$$

$$\vec{j} = \chi \vec{E} \tag{7}$$

Equations (1-7) constitute the system of Maxwell's equations.

They are the most general equations for electric fields.

Note that the quantities $\varepsilon, \mu \quad u \quad \chi$ enter Maxwell's equations as material constants, i.e. as given quantities characterizing the properties of the medium.

When considering the connection between a conservative force, for example, the force of gravity, and potential energy, the Hamiltonian differential operator (nabla - operator) can be introduced into the course of general physics. The elementary work of a conservative force is, by definition, equal to the total potential energy differential with the opposite sign:

$$\partial A = F \cdot d\ell = -dU$$

Given that

$$F \cdot d\ell = F_x dx + F_y dy + F_z \cdot dz$$

and according to the property of the total differential of a function of several variables known to students

$$dU = \frac{\partial U}{\partial x} \cdot dx + \frac{\partial U}{\partial y} \cdot dy + \frac{\partial U}{\partial z} \cdot dz$$

we have:

$$F_x = -\frac{\partial U}{\partial x}; \qquad F_y = -\frac{\partial U}{\partial y}; \qquad F_z = -\frac{\partial U}{\partial z}$$

Or in vector form:

$$\vec{F} = F_x \cdot \vec{e}_x + F_y \cdot \vec{e}_y + F_z \cdot \vec{e}_z = -\left(\frac{\partial U}{\partial x} \vec{e}_x + \frac{\partial U}{\partial y} \vec{e}_y + \frac{\partial U}{\partial z} \vec{e}_z \right)$$

Note that writing a vector using the notation of orts is $\vec{e}_x, \ \vec{e}_y, \ \vec{e}_z$ more convenient than using orts, $\vec{i}, \ \vec{j}, \ \vec{k}$ since *i* is the notation for both the current strength and the imaginary unit, it $\vec{j}$ is the notation for the current density vector in the course of general physics.

The expressions for the current strength can be symbolically written as:

$$J = -\nabla U = gradU$$

where

$$\nabla = \frac{\partial}{\partial x} \vec{e}_x + \frac{\partial}{\partial y} \vec{e}_y + \frac{\partial}{\partial z} \vec{e}_z$$

Similarly, in electrostatics, the relationship between the strength and potential of the electrostatic field is derived:

$$E = -grad\varphi = -\Delta\varphi$$

The correctness of the physical interpretation of a mathematical model can only be established by direct experience. For example, it became possible to consider Maxwell's equation as a mathematical model of a real physical process only after Hertz's experimental confirmation of the actual existence of electromagnetic waves.

The volume and depth of interpretation of this issue in different textbooks for universities differ significantly. So in the book (3) Maxwell's equation is absent at all; in books (2,5,6) they are given only in integral form; in book (14) they are expressed in differential form.

Referring to the well-known theorems of Gauss and Stokes, we bring Maxwell's equations to differential form.

$$\nabla \cdot \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{8}$$

$$\nabla \cdot \vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t} \tag{9}$$

Now it is easy to prove that in a homogeneous and isotropic dielectric in the absence of free charges and conduction currents, electromagnetic waves are possible, and also to find the speed of these waves. For this purpose, equations (8 and 9) are reduced to a system with two field vectors:

$$\nabla \cdot \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\frac{1}{\mu\mu_0}\left(\nabla \cdot \vec{B}\right) = \varepsilon\varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

Considering that $\varepsilon_0 \mu_0 = \frac{1}{c^2}$, we get:

$$\nabla \cdot \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (10)$$

$$\nabla \cdot \vec{B} = -\frac{\varepsilon\mu}{c^2}\frac{\partial \vec{E}}{\partial t} \qquad (11)$$

Multiply the nabla operator to equation (10) vectorially, i.e., let us differentiate it vectorially with respect to the coordinates. Since the coordinates and time are independent variables, the operations of differentiation with respect to them are permutable. Then, using (11) we get:

$$\nabla(\nabla\vec{E}) = -\nabla\frac{\partial \vec{B}}{\partial t} = -\frac{\partial}{\partial t}(\nabla\vec{B}) = \frac{\varepsilon\mu}{c^2}\cdot\frac{\partial^2 \vec{E}}{\partial t^2} \qquad (12)$$

Means:

$$\nabla^2 \vec{E} = \frac{\varepsilon\mu}{c^2}\cdot\frac{\partial^2 \vec{E}}{\partial t^2} \quad (\mathrm{I})$$

Students should point out that exactly the same equation is obtained for the magnetic induction vector.

$$\nabla^2 \vec{B} = \frac{\varepsilon\mu}{c^2}\cdot\frac{\partial^2 \vec{B}}{\partial t^2} \quad (\mathrm{II})$$

and recommend deriving this equation on your own by applying the vector nabla operator to equation (11). here it should be shown that the equations obtained are wave equations. This can be done by assuming that a plane transverse wave propagates in the dielectric.

Graphic images (I) and (II) will be the following:

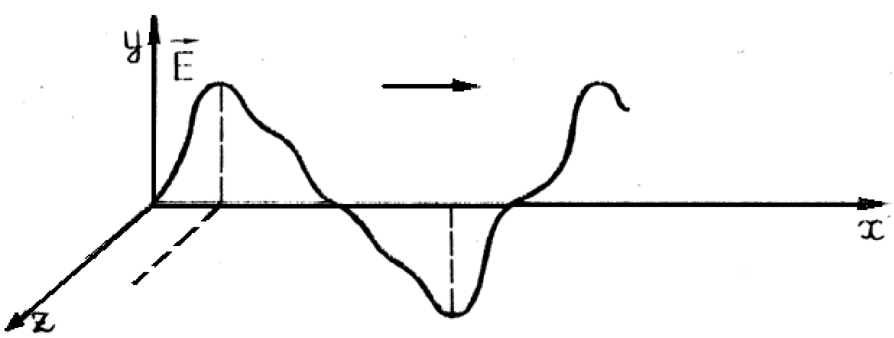

Fig. 1

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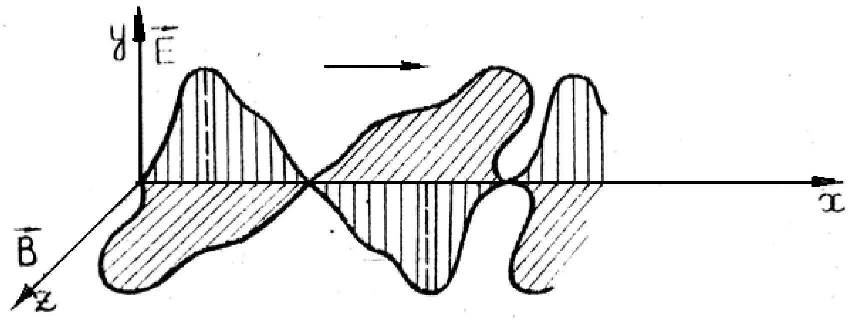


Fig. 2

Now we will consider what we understand when we say light. There are two theories in the study of light:

1. Light consists of small particles (photons) and propagates in portions first in one direction, then in the other direction. This is Newt's theory.

The energy of one portion of the light beam is:

$$E = h\nu$$

Here E is the energy of one portion

h – Planck coefficient

v - frequency

2. Light is an electromagnetic wave. Maxwell's theory.

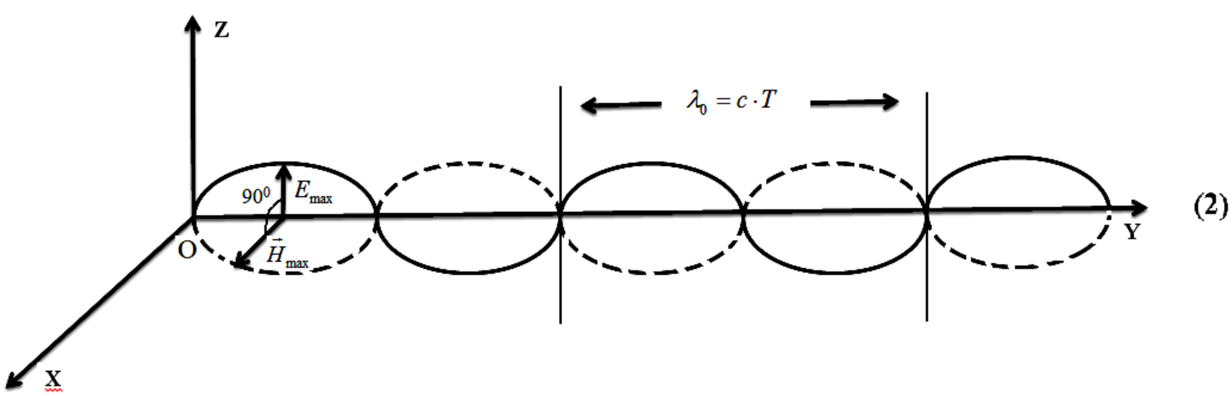
Electromagnetic wave equation (mathematical formula of light):

$$E = E_{\max} Sin(\omega t + \varphi)$$
$$H = H_{\max} Cos(\omega t + \varphi_2) \quad \text{(one)}$$

Here: E - electric field strength

H - magnetic field strength

The graphical representation of an electromagnetic wave is as follows:



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E_{max} and H_{max} are the amplitudes of the electromagnetic wave (light)

ω - cyclic frequency of electromagnetic wave (light)

t is the time of the electromagnetic wave (light)

φ_1 φ_2 - initial phases of an electromagnetic wave (light)

λ - wavelength of electromagnetic wave (light).

The speed of light in vacuum is: $c=3 \cdot 10^8$ m/s$=3 \cdot 10^5$ km/s.

Light from the sun to the Earth takes 8 seconds.

Light Wavelength:

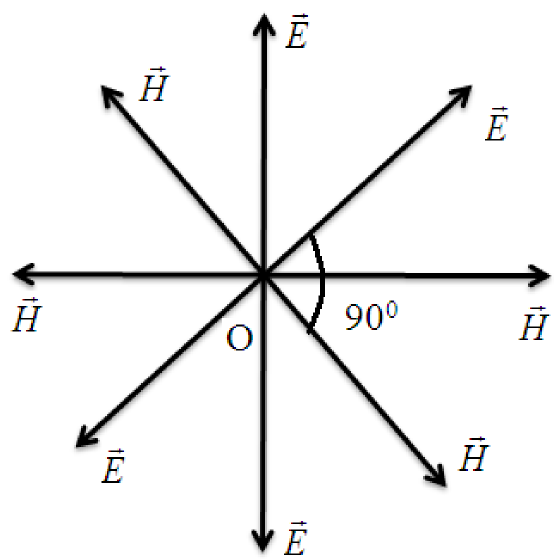
$$\lambda = c \cdot T$$

c is the speed of light $c=3 \cdot 10^5$ km/s

T is the period of light oscillation

The propagation of an electromagnetic oscillation in a vacuum or in a medium is an electromagnetic wave. The electromagnetic wave equation is (1).

The vector diagram of an electromagnetic wave has the following form:



$\vec{E}$ - electric field strength vector.

$\vec{H}$ - the vector of the magnetic field.

$$T = \frac{t}{n} \quad [T] = \frac{[t]}{[n]} = c$$

The period is the time required for one complete oscillation.

Oscillation frequency is denoted by *v*

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$$\nu = \frac{n}{t}$$

number of oscillations per unit of time
Frequency unit Hz- Hertz

$$[\nu] = \frac{[n]}{[t]} = \frac{1}{c} = \Gamma ц$$

CONCLUSION

Physics cannot be explained without mathematics. Maxwell's equations are the theorems of Ostrogradsky Gauss, displacement current, transformation of an electric field into a magnetic field, a magnetic field into an electric one, etc. Physical laws are proved by mathematical equations.

Mathematics can be used to relate one statement to another.

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