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About One Impact-Electric Effect And Possibilities of Creation of Impact Acceleration Sensor

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Abstract - **The theoretical explanation of experimentally found phenomenon of emergence of macroscopic area of local violation of electro neutrality is given. The area arises at blow to a metal core and extends with an impact impulse. We will explain observed macroscopic effect from a position of physics of a solid body.**

Index Terms – **Metal core, impact-electric effect, physics of a solid body, sensor of shock acceleration.**

I. Introduction

As KNOWN, an impact of metal bodies goes with number physical effects phenomena: thermal, acoustic, electric [1]. They can affect and affect under certain conditions an impact momentum. At the same time they can be used as an impact process indicator. One of these events will be discussed in this report.

In report [2] the discovery of the electrical effects occurring on impact on the conductive stems was described. Further, the experiments conducted in conjunction with the author of article [2] showed that when hitting the stem macroscopic area of local violation of electrical neutrality (charge density ρ_e is not equal to zero) arises which extends from the impact momentum. This area was indicated by concomitant electric field fixed by the capacitive sensor connected to an oscilloscope. The signal on the oscilloscope in shape repeated an accelerating impulse in this section of the rod. This can be seen on Fig.1.

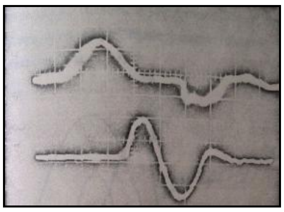

Fig.1. Oscillograms of signals taken from a) the strain gauges, б) capacitive sensor.

According to classical ideas, any violation of electrical neutrality in the conductor would have to be neutralized for the time of the order ε_0/σ, где ε_0 - he dielectric constant of vacuum, σ - conductivity. In case of alleged in [2] inertial separation of charges as in experiments Nichols, Tolman, Stuart, Mandelstam and Papaleksi [3,4], field intensity by calculation although it was proportional to acceleration impulse a, no more than 6-orders less than experimentally found one.

II. Problem Definition

The observed macroscopic effect succeeded in explaining from the position of physics of solid body.

As known metallic connection binding metallic atoms in a solid body is done by collectivized valent electrons which are also conduction electrons. These conduction electrons determine mainly elastic properties of metals. Exactly conduction electron binding function ignored under classical consideration. Assume that in the experiment wave of compression deformation (density wave of substance of lattice) reached some section. According to classical considerations of electrons in the surrounding area should be increased. This would lead to a change in the electrochemical potential. However it should remain in the given volume of metal constant [5]. That`s why part of the conduction electrons will leave the field of increased concentration leveling electrochemical potential. In consequence of this violation of electrical neutrality in area of shock pulse the macroscopically observable electric field. The area with violated electro neutrality such as "minus-plus-minus" will be spread together with an impact impulse (Fig.2.)

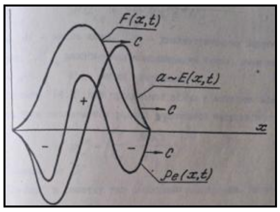

Fig.2. The motion of area with the broken electro neutrality like "minus - plus or minus" together with an impact Impulse.

III. Theory

Quantitative assessments of observed variables could be done by three independent methods. The results turned out to be identical. Here we consider the dynamics of lattice and electron gas in accordance with the principle of adiabatic principle [6].

Consider the first method. According to [5], waves of the elastic deformation in a solid can be described as the spread of long-wavelength acoustic phonons with wave vector $\vec{k}$. The latter are quantum fluctuations in the ionic lattice [5, 6]. In accordance with the principle of adiabatic we can consider first the oscillation spectrum of bare ions, and then consider the effect of the introduced work of the free electron gas. Imagine longitudinal displacement the i-th ion as a set of partial displacements with wave vectors $\vec{k}$.

$$U_i = \sum_i U_{ik} \, . \quad (1)$$

Then, according to (6.80) from [5, p.233], the equation of motion of the bare ion in the *k*-th mode will look like

$$M\ddot{U}_{ik} = \frac{1}{\varepsilon_0} N z^2 e^2 U_{ik} \, . \quad (2)$$

Where M - mass of the ion, ε_0 - the dielectric constant of vacuum, N - equilibrium concentration of ions, having a charge: $q = -ze$, e - the electron charge.

According to (1, 2) for longitudinal wave with wave vectors $\vec{k}$ the frequency turns out to be equal to the plasma frequency of the ions [5]

$$\omega_k^0 = (\frac{1}{\varepsilon_0} \frac{Nz^2 e^2}{M})^{0.5} \quad (3)$$

and does not depend on $\vec{k}$.

Let we “bring” free electron gas to the lattice. Their interaction with the lattice, providing stability of the whole system, changes (3). Now $\omega_k = \frac{\omega_k^0}{\sqrt{э}}$, where $э$ - inductivity and a long wavelength limit according to (6.84) from [5, c.233] looks like

$$\omega_k = k(\frac{Nz^2}{MP(\varepsilon_F)})^{0.5} , \quad (4)$$

$$p(\varepsilon_F) = 1.5 \frac{n}{\varepsilon_F} \, . \quad (5)$$

Here $\vec{k}$ - wave vectors of a phonon, k - the wave number of a photon, $p(\varepsilon_F)$ - the density of the electron gas states at the Fermi surface, n - concentration of electrons.

Now equation (2) k longitudinal ion oscillations taking into account (3-5) will be

$$M\ddot{U}_{ik} = -k^2 \frac{Nz^2}{p(\varepsilon_F)} U_{ik} \, . \quad (6)$$

On the other hand,

$$M\ddot{U}_{ik} = zeE_{ik} \, , \quad (7)$$

where E_{ik} - electric field intensity arising due to k-th displacement of ions. According to the condition of electrical neutrality [5, 6],

$$Nz = n \, . \quad (8)$$

From (6) and (7), taking into account (5) and (8) it follows that

$$E_{ik} = -k^2 \frac{2\varepsilon_F}{3e} U_{ik} \, . \quad (9)$$

Now we pay attention to the fact that the spread impact impulse through the waveguide is described by the wave equation. For *k*- mode, taking into account the replacement of discrete index *"i"* to a continuous "*x*," it will look like

$$\frac{\partial^2 U_k}{\partial x^2} - \frac{1}{c_0^2} \frac{\partial^2 U_k}{\partial t^2} = 0 \, . \quad (10)$$

As $U_k(x) \sim e^{ikx}$, $a_k = \frac{\partial^2 U_k}{\partial t^2}$

$$a_k = -c_0^2 k^2 U_k(x,t) \, . \quad (11)$$

With (10-11) in mind, the expression (9) can be rewritten as

$$E_k = \frac{2}{3e} \frac{\varepsilon_F}{c_0^2} a_k(x,t) \, . \quad (12)$$

As $E(x,t) = \sum_k E_k(x,t)$ $a(x,t) = \sum_k a_k(x,t)$, (13)

that, according to (11, 12) expression (13) will take a form:

$$E(x,t) = \frac{2}{3e} \frac{\varepsilon_F}{c_0^2} a(x,t) \, . \quad (14)$$

Thus, the formula for assessment of the tension of macroscopic electric field arising in the area of electro neutrality disturbances is obtained.

We will consider the second way of an explanation of effect. The same result (14) can be obtained, if we use phenomenological theory deformation potential [5]. The change of ion concentration N leads to the change in electron concentration n . This would result in a shift of electrochemical potential μ by amount, equal, accordingly the formula (6.97) from [5, c.240],

$$\Delta\mu = -\frac{n_0 \Delta}{p(\varepsilon_F)} = -\frac{2}{3} \varepsilon_F \Delta \, , \quad (15)$$

where $\Delta = \Delta(\vec{r}, t)$ - relative change of volume.

We will notice that at thermal equilibrium in the absence of diffusion electrochemical potential remains to constants ($\Delta\mu = 0$) and agrees accordingly [6, p.291]. Namely electrons’ leaving the field of increased concentration keeps μ constant. As a result, an electric field appears, the potential φ of which compensates the shift (15)

$$\varphi = \frac{\Delta\mu}{e} = -\frac{2}{3e} \varepsilon_F \Delta \, . \quad (16)$$

For uniaxial deformation and in a mode odd travelling wave

$$\Delta = \frac{\partial U}{\partial x} = \frac{v}{c_0} \quad (17)$$

Here v - the speed of particles of the section of a waveguide. Accordingly (16, 17) will receive the same result (14):

$$E = -\frac{\partial \varphi}{\partial x} = \frac{2}{3e} \frac{\varepsilon_F}{c_0^2} a \, .$$

Thus, the equivalence of these approaches is proved. The described effect is defined as the lattice dynamics, as the dynamics of electronic gas.

We will consider the third way of an explanation of effect. This result can be obtained strictly from model considerations. Consider the metal with a spherical Fermi surface. In this case, the electron density is given by the formula

$$n_e = \chi(\varepsilon_F - e\varphi)^q \, , \quad (18)$$

where $\chi = \frac{(2m)^{1.5}}{3\pi^2 \hbar^3}$, $q = 1.5$ in accordance with (8.20) and (8.21) from [6, p.291].

Here φ - the potential which appears because of violation of electro neutrality. It is defined within the framework of the quasi-classical approximation the Thomas-Fermi by the Poisson's equation [6, 7]

$$\nabla^2 \varphi = \frac{e}{\varepsilon_0} (n_e - zN_i) \, . \quad (19)$$

Here n_e and N_i - non-equilibrium concentration of electrons and ions, at that

$$N_i = N(1+\Delta).$$

We decompose (18) in powers $e\varphi$ and confine ourselves to first order of smallness due to the fact that $e\varphi << \varepsilon_F$.

$$n_e \approx \chi\varepsilon_F^q - q\chi\varepsilon_F^{q-1}e\varphi = n - q\chi\varepsilon_F^{q-1}e\varphi. \quad (20)$$

We rewrite (19) in view of (18), (20) и conditions of electro neutrality (8). We will receive

$$\nabla^2\varphi + \frac{q\chi e^2\varepsilon_F^{q-1}}{\varepsilon_0}\varphi = -\frac{e\chi\varepsilon_F^q}{\varepsilon_0}\Delta. \quad (21)$$

In this equation we can neglect the contribution $\nabla^2\varphi$. For this imagine again

$$\varphi = \sum_k \varphi_k = \sum_k \varphi_{0k}e^{ikx}; \Delta = \sum_k \Delta_k = \sum_k \Delta_{k0}e^{ikx}. \quad (22)$$

Inserting (22) in (21), we will receive

$$\varphi_{0k} = \frac{e\chi\varepsilon_F^2}{\varepsilon_0}\frac{\Delta_{0k}}{k^2 - k_0^2}, \quad (23)$$

where

$$k_0^2 = \frac{q\chi e^2\varepsilon_F^{q-1}}{\varepsilon_0}, \quad (24)$$

The assessment (24) provides in the case of a spherical Fermi surface of metals $\sim 10^{20}m^{-2}$, at the same time even for ultrasonic waves in the metal $\sim 10^{2-6}m^{-2}$. In view of (21-24) we always can conclude

$$\varphi = -\frac{e\chi\varepsilon_F^q}{\varepsilon_0}\frac{\Delta}{k_0^2} = -\frac{\varepsilon_F}{qe}\Delta = -\frac{2}{3}\frac{\varepsilon_F}{e}\Delta,$$

that is equal to meaning (16).

Thus, the presence of electric effect in metals is theoretically justified and its explanation is given.

We make a quantitative assessment of, for example, aluminum and copper at $a \sim 10^5 ms^{-2}$ which occurs upon an impact of metal bodies in the range of average speeds of collisions $(10 \div 100 ms^{-1})$. In accordance with [6] for aluminum we have $\varepsilon_F \approx 11.6eV$, $c_0 \approx 5.1\cdot 10^3 ms^{-1}$ and $E \approx 3\cdot 10^{-2}Vm^{-1}$. For copper we have $\varepsilon_F \approx 7.0eV$, $c_0 \approx 3.57\cdot 10^3 ms^{-1}$ and $E \approx 3.72\cdot 10^{-2}Vm^{-1}$.

VI. CONCLUSION

The given theoretical results show that this effect is observable in the range of "average speeds of impacts" [1]. And on this basis the sensor of accelerations can be created.

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