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GeV plasmons and spalling neutrons from crushing of iron-rich natural rocks

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ABSTRACT

Many experimental evidences highlight the emission of neutrons when a solid body is subjected to rapid fluctuations or it breaks. In this Letter a possible unified approach is suggested by introducing the plasmon-lattice interactions. The theoretical results, here obtained, agree with the experimental results.

1. Introduction

Any solid body is subjected to rapid fluctuations for a few moments when it breaks in a brittle way, even if only partially, or when the formation and propagation of micro-cracks occurs. This phenomenon appears under the form of longitudinal waves of expansion–contraction (tension–compression), in addition to transverse (shear) waves [1–4].

From a particle (and quantum) point of view, these pressure waves are phonons or plasmons in relation to the frequency (physical effect) we consider [5–8]. Indeed in solids, the cracks that are formed or propagate are of different lengths, sometimes belonging to different orders of magnitude [9,10].

In particular, at the nanoscale, the frequency measured is that at the order of THz [1–4,9,10]. Higher frequency scales would imply defects at the atomic or subatomic scales within the atomic lattice [5–8]. On the other hand, during the experimental activities significant neutron emissions have been repeatedly measured [1–4,9,10]. These neutrons were named piezo-neutrons [1].

The piezo-properties are a very interesting topic of research in condensed state physics and material engineering [11,12]; consequently, any related piezo-lattice effect results to be an actual fundamental topic of research. In particular, piezo-neutrons have been experimentally [1] and theoretically [13,14] analyzed; indeed, there has been considerable interest in recent experiments on iron nuclear disintegrations observed when rocks containing such nuclei are crushed and fractured. Moreover, the resulting nuclear transmutations are particularly strong for loadstones with the conclusion that the fission of the iron nucleus is a consequence of the photo-disintegration [15–17]. The electro-strong coupling between electromagnetic fields and nuclear giant dipole resonances has been considered the theoretical core for the explanation of the observed nuclear reactions. The electro-weak interactions can produce neutrons from energetic protons and electrons thus inducing nuclear transmutations. The electro-strong condensed matter coupling can represent new many body collective nuclear photo-disintegration effects [13–17].

Just the collective effect in the solid lattice can be used to obtain a new approach useful to explain the piezo-neutrons. So, here, we intend to introduce the concept of spalled neutrons generated by a plasmon-lattice interaction.

2. Materials and methods

A plasmon [1–4] can be interpreted as a collective oscillation of the electronic plasma inside the solid lattice, i.e. an oscillation of the electronic density [5,6] (Figure 1). At the equilibrium state, the electric charge of the electronic gas is balanced by the electric charge of the nuclei of the lattice knots [5–7].

On the other hand, when the electron gas moves through a lattice dislocation, a charge asymmetry occurs on the opposite sides of the dislocation. As a consequence of the generated opposite sign, a reactive force appears generating a simple harmonic motion at the plasmonic frequency [8]:

$$\omega_p^2 = \frac{ne^2}{\varepsilon_0 m_{eff}} \tag{1}$$

where n is the electron density, e is the electric charge of the electron, ε_0 is the electric permittivity in vacuum, and m_{eff} is the

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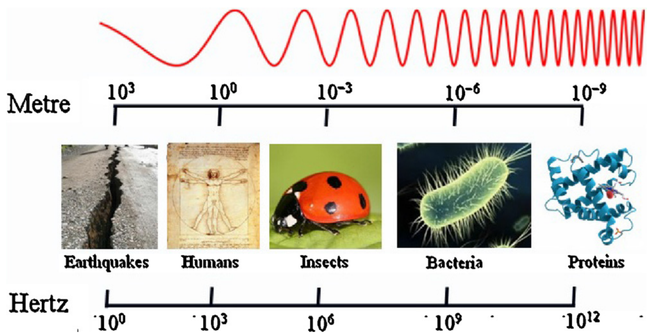

Figure 1. Correlation between wavelength scale and frequency scale by assuming a constant pressure wave speed.

effective electron mass. Plasmons produce important effects on the physical properties of matter interacting with electromagnetic fields, because they generate a relative electric permittivity:

$$\varepsilon(\omega) = 1 - \frac{\omega_p^2}{\omega(\omega + i\gamma)} \quad (2)$$

where γ is the damping factor and ω is the electromagnetic frequency. The value of relation (2) is negative for frequencies lower than the plasmonic ones. The physical meaning of this negative electric permittivity consists in the generation of electromagnetic structures at the border of dislocations. For the frequencies of the incident electromagnetic waves in the infrared range, the relative dielectric constant becomes imaginary and the dissipation becomes predominant [8].

The electrons move in a direction perpendicular to the dislocation surface of area A, and the number of electrons which concur to the plasmonic frequency is not the total but only that of the ones really in motion inside the dislocation. Therefore, it follows:

$$n_{eff} = \frac{A}{a} n \quad (3)$$

where a is the lattice constant. The electronic motion generates a magnetic field which produces a self-induction effect with a consequent superposition of different forces acting on the electrons: the global (cooperative) effect is represented by the apparent effective mass of the electrons [8]:

$$m_{eff} = \frac{\mu_0}{2\pi} n e^2 A \; \ln\left(\frac{a}{r}\right) \quad (4)$$

where μ_0 is the magnetic permeability in vacuum and r is the radius of the virtual cylinder generated by the electron trajectories.

Introducing now relation (4) into relation (1), it follows that the plasmonic frequency is:

$$\omega_p^2 = \frac{n_{eff} e^2}{\varepsilon_0 m_{eff}} = \frac{\frac{A}{a} n e^2}{\frac{\varepsilon_0 \mu_0}{2\pi} n e^2 A \ln\left(\frac{a}{r}\right)} = \frac{2\pi}{\varepsilon_0 \mu_0 a \ln\left(\frac{a}{r}\right)} = \frac{2\pi \quad c^2}{a \ln\left(\frac{a}{r}\right)} \quad (5)$$

In order to assess the previous theoretical relations and to compare them to the experimental evidences, phengite, biotite, olivine, and magnetite minerals are considered. The results are represented in Table 1. It is possible to highlight how the scattering of the electronic motion inside the dislocation presents the same inertial effect as that of a nucleus of the same velocity and a consequent scattering energy ~1 GeV.

3. Results and discussions

The result obtained represents a completely new explanation of the neutron emissions from stone breaking. It can explain the piezoneutrons experimentally revealed by considering the spalling effect generated by the plasmon-lattice interaction. Different types of detectors have demonstrated the presence of significant neutron emissions, in some cases by several orders of magnitude higher than the usual environmental background [1–4,9]. The neutron flux was found to depend, besides on the iron content, on the size of the specimen through the well-known brittleness size effect [10]. Larger sizes imply a higher brittleness, i.e. a more relevant strain energy release, and therefore more neutrons.

On the other hand, this theoretical approach is interesting because it allows us to explain the experimental results obtained in relation to the neutron emissions from stone breaking, but also for the links to the energy–mass conversion inside solid lattice. Indeed, it recalls some new discussion on mass [18] in the Universe, founded on the fundamental laws of physics, with particular regards to the principle of least action. In fact, the principle of least action in its original form [19,20] explains various phenomena using the general concept of momentum on a path or equivalently energy over time. In this context, Annila proved that the discrete character of nature is reflected in multiplicity at all levels of its hierarchical organization [18–21] and that the basic geometry implies also how baryons could pack together in an atomic nucleus. In this way, he highlighted how a coordinate of space embodies a closed circulation of energy, and a moment of time will elapse when the circulation opens up either to acquire or discard quantized flux of energy [21]. So, the mass of a body depends on how much its energy density on the least-action path perturbs, i.e. the elastic energy against the solid lattice. Consequently, when the mass of a particle is measured, the corresponding geodesic's curvature of the lattice in the fatigue points must be considered because the mass manifests itself as a curved spacetime. Therefore the curvature and chirality of particular paths invariably relate gravitational and electromagnetic interactions, as well as weak and strong interactions with one another [18].

These last considerations could open new frontiers in the research on the links among solid lattice, its geometry curvature, and the fundamental interactions inside the solids.

Table 1
Applications of relations (4) and (5) to different minerals. It is possible to highlight how the scattering of the electrons moving inside the dislocation presents the same inertial effect as that of an equivalent nucleus with the same velocity and a consequent scattering energy ~1 GeV.

Mineral	a 10^{-10} m	n m^{-3}	a/r	A m^{-2}	ω THz	m_{eff} m_p [a]
Phengite	9.64	10^{29}	9.635	10^{-11}	16.1	6.9
Biotite	10.23		10.225		15.4	7.1
Olivine	5.48		5.477		24.6	5.2
Magnetite	8.40		8.396		17.8	6.5

[a] m_p = proton mass = 1.673×10^{-27} kg.

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