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RESEARCH

Hessdalen Lights and Piezoelectricity from Rock Strain

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Abstract—Hessdalen lights (HL) are unexplained light balls usually seen in the valley of Hessdalen, Norway. Some theories, such as that of Takaki and Ikeya, explain HL as a product of piezoelectricity generated under a rock strain because many crystal rocks include quartz grains which produce an intense charge density. In this work, based on the dusty plasma theory of HL (Paiva and Taft), we suggest that piezoelectricity of quartz cannot explain a peculiar property assumed by the HL phenomenon—the presence of geometrical structures in its center.

Keywords: Hessdalen lights—piezoelectricity—dusty plasma

Introduction

Hessdalen lights (HL) are unexplained earthquake lights (EQL) usually seen in the valley of Hessdalen, Norway (Teodorani, 2004). They have the appearance of a glowing light ball with dimensions ranging from decimeters up to 30 m. In a few cases (at low levels of luminosity), they explicitly show visually some kind of geometric structure. The reason for these shapes is totally unknown. HL often shows strong pulsating magnetic perturbation of about 5 Hz (Teodorani, 2004). They are often accompanied by small, short-duration pulsating "spikes" in the HF and VLF radio ranges, sometimes showing Doppler features.

No existing theory or model can account for all the (and sometimes contradictory) observations of HL. One explanation attributes the phenomenon to an incompletely understood combustion process in air involving clouds of dust from the valley floor containing scandium (Bjorn, 2007). Some sightings, though, have been identified as misperceptions of astronomical bodies, aircraft, car headlights, and mirages (Leone, 2003). A theory that has attracted great attention was proposed by Takaki and Ikeya (1998) and Teodorani (2004). It involves piezoelectricity generated under a rock strain. Change in seismic stress releases piezo-compensating, bound charges due to changes in the piezoelectric polarization of quartz grains in granitic rocks, which produces an intense electric field at the fault zone. In the specific Hessdalen area, where light phenomena are seen very often some meters over the ground, an electric triggering mechanism above might be produced by the existing high abundance of quartz, copper, and iron underground. When quartz is subjected to tectonic stress, it generates piezoelectricity (Lockner, Johnston, & Byerlee, 1983, Zou, 1995), while copper is an ideal electricity conductor and consequently might be an electrical amplifier of the HL phenomenon.

A dusty plasma is a plasma containing micrometer- or nanometer-sized particles suspended in it which also behaves like a plasma (Ivlev et al., 2000). Dust and dusty plasmas are quite natural in space. They are present in comets, planetary rings, zodiacal dust clouds, and interstellar clouds (Northrop, 1992). Dusty plasmas are found in the vicinity of artificial satellites and space stations (Robinson & Coakley, 1992) and in thermonuclear facilities with magnetic confinement (Winter & Gebauer, 1999). Dust grains immersed in plasma become charged. Electrostatic coupling between the grains can vary over a wide range so that the states of the dusty plasma can change from weakly coupled (gaseous) to crystalline, so-called "plasma crystal" or "Coulomb crystal" (Thomas et al., 1994).

In this work, based on the dusty plasma theory, we suggest that piezoelectricity (which produces an intense electric field at the ground during soil dislocation) does not explain topological structures assumed by the HL phenomenon at its low level of luminosity. The electric field created by this physical process is insufficient to produce geometric structures in the center of HL-like dusty plasma. Here we use a recent dusty plasma model of HL that explains several properties of the natural phenomenon (Paiva & Taft, 2010).

Calculations

The HL phenomenon is always preceded by short-lasting (on the order of a fraction of a second) flashes of light that appear everywhere in the valley. The Hessdalen area is likely to be one of these geophysically peculiar locations owing to the richness of quartz underground. Everywhere, both in the sky and close to the ground, flashes of light appear with durations of fractions of a second. Flashes are mostly orb-shaped, but sometimes very elongated shapes have been recorded as well. The presence in the valley of quartz mines suggests that the lights are powered electrically by piezoelectricity or the impact of cosmic rays. Some of the lights seem to be associated with radio emissions

(Teodorani, 2004, Zou, 1995) from low-energy plasmas which are possibly produced as aftereffects of tectonic strain.

The electric field in the air can be estimated considering the appearance of transient charges caused by the charge of seismic stress, σ, and the decay of the change in a conductive earth with the dielectric constant, ε, and the resistivity, δ. The charges, q, may be expressed as:

$$\frac{dq}{dt} = -\alpha\left(\frac{dq}{dt}\right) - \frac{q}{\varepsilon\rho\delta} \qquad (1)$$

where α is the piezoelectric coefficient (Takaki & Ikeya, 1998). These charges cause the electric field in the air. Considering the stress drop $\Delta\sigma$, the stress change is $\sigma(t) = \Delta\sigma\exp(-t/\tau)$. The charge density is obtained from Equation 1 and is expressed as

$$q(t) = \alpha\sigma\frac{\varepsilon\sigma}{\tau - \varepsilon\delta} \times \left\{\exp\left(-\frac{t}{\tau}\right) - \exp\left(-\frac{t}{\varepsilon\delta}\right)\right\} \quad . \qquad (2)$$

The charge relaxation time for electrostatic processes is $\varepsilon\delta = 0.7$ µs for a typical value of $\varepsilon = 8\varepsilon_0$ and $\delta = 10^4$ Ωm in granite. The piezoelectric coefficient is $\alpha = 4.6 \times 10^{-12}$ C/N for quartz crystal in shear stress. The charge density was calculated using Equation 2 for the piezoelectric constant of quartz crystal, the dielectric constant, and the resistivity of granite. The maximum charge density, q_{max}, is given by (Takaki & Ikeya, 1998)

$$q_{max} = \alpha\Delta\sigma\left(\frac{\varepsilon\delta}{\tau}\right)^{\frac{\tau}{\tau-\varepsilon\delta}} \qquad (3)$$

where τ is the displacement time which is on the order of 1µs, and $\Delta\sigma = 10^7$ N/m^2 is the effective stress drop. Inserting the values into Equation 3, we found $q_{max} = 1.4 \times 10^{-5}$ C. The electric field given by:

$$E_{max} = \frac{q_{max}}{4\pi\varepsilon_0 R^2} \qquad (4)$$

where R (on the order of meters) is the vertical high above the vein. Thus, we found $E \sim 1.5 \times 10^5$ V/m in the air on the vein. If a new physical process

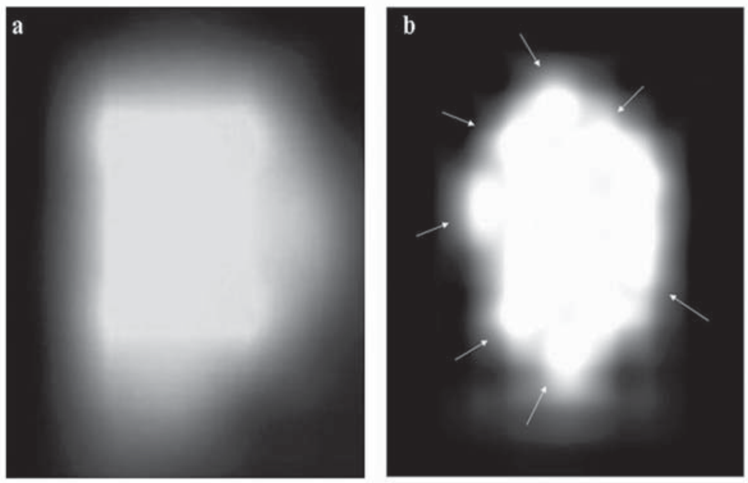

Figure 1. Hessdalen lights at low levels of luminosity show rectangular shapes. (a) Rectangular shape recorded by conventional photography. (b) Rectangular shape surrounded by spherical light balls indicated by arrows.
(Teodorani, 2004)

of ferroelectric orientation of piezo-compensating, bound charge pairs were present, an intense charge density would be produced (Brune, 1970). In our calculations, the charge was approximated for the charge density of $q = 1 \times 10^{-5}$ C/m^2 in the area of 10 × 10 m during 1×10^{-6} s in the calculation, which is sufficiently long for ionization to occur because electrons are accelerated to 94% of the final velocity within 10^{-8} s. Free electrons with the density of $4 \times 10^6 - 1 \times 10^7$ electrons m^{-3} s^{-1} are generated by cosmic rays and natural radiation due to atmospheric radioactivity. The electric field generated by the seismically induced charges on the ground accelerates these electrons which ionize or excite N_2 and O_2 in the air and atoms in the atmospheric dust grains. The excited state of $B^3\Pi_g$ for an N_2 molecule has a lifetime of 8 μs and makes the electronic transition to the excited state of $A^3\Sigma_u^+$ observable (Radzig & Smirnov, 1985).

In most cases, HL (at high levels of luminosity), if seen from far away, have the appearance of a glowing light ball with no structure; in other cases (at low levels of luminosity), they explicitly show visually some kind of geometric structure (Teodorani, 2004). Rectangular shapes have been recorded as well (Figure 1). This shape (recorded on 1/30 s video frames), in particular, is not simply a result of videocamera pixilation effects, since the same kind of shape is recorded by conventional photography.

Dust plasma theory predicts that there are plasma conditions where the particles show collective behavior and all the particles are in a cloud that behaves like a fluid or solid. Sometimes all the particles are of approximately the same size, and then it is possible that the ensemble of particles gathers into a crystal that appears with the geometric structures in HL phenomenon.

To predict the possibility of geometrical structures in HL phenomenon through dust plasma theory, one parameter of importance is the *coupling parameter* Γ (also known as the plasma parameter or strength of interaction in a plasma; Thoma et al., 2005) of a collection of charged particles defined as the ratio of potential energy (*PE*), due to Coulomb interaction, to kinetic energy (*KE*):

$$\Gamma \equiv \frac{\langle PE \rangle}{\langle KE \rangle} \tag{5}$$

Coupling parameter Γ depends on the ratio of the square of the particle charge and particle temperature:

$$\Gamma \equiv \frac{(Q_P)^2}{4\pi\varepsilon_0 a_p k_B T_P} e^{\left(-\frac{a_P}{\lambda_D}\right)} \tag{6}$$

where Q_p is the charge on the grain, a_p is the interparticle distance, $k_B = 1.38 \times 10^{-23}$ m^2 kg s^{-2} K^{-1} is the Boltzmann constant, $\varepsilon_0 \sim 8.85 \times 10^{-12}$ F/m is the vacuum permittivity, T_p is the particle temperature, and λ_D is the Debye length. The charge on an isolated grain particle in the dusty plasma is

$$Q_p = C\Phi_S \tag{7}$$

where $C = 4\pi\varepsilon_0 r$ is the capacitance, r the particle's radius, and the particle surface potential in volts Φ_S can be calculated from

$$\Phi_S = \frac{Ze}{4\pi\varepsilon_0 r} \tag{8}$$

where Z is the charge number of dust, and e is the elementary charge. Considering that HL is a free-floating light ball, the equivalence between gravitational and electrostatic forces should be observed. Thus, the charge of the dust grain can be determined from the balance of gravity and electric forces (Smirnov, 2000):

$$Z = \left(\frac{mg}{eE}\right) = \frac{4\pi r^3 \rho g}{3eE} \tag{9}$$

where g is freefall acceleration, ρ is the dust density, and E is the electric field (calculated in Equation 3). On the other hand, Debye length of the electrons is given by:

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T}{e^2 n_e}} \tag{10}$$

where T is the mean temperature inferred for HL phenomena (Bjorn, 2007), and n_e is the electron density (electrons per m^3). Considering HL as a blackbody radiator with mean temperature $T = 5{,}000$ K, electron density can be estimated based on the solar photosphere. The Sun's photosphere has a temperature between 4,500 K and 6,000 K (with an effective temperature of 5,000 K) and mean electron density of 10^{18} m^{-3} (Vranjes & Poedts, 2007). Thus, let us consider electron density for HL as being $n_e \sim 10^{18}$ m^{-3}. For the sake of convenience assuming the steady state (initial) surface temperature of a particle to be $T_p = 350$ K (Stoffels et al., 1996), dust particle radius $r = 10 \times 10^{-6}$ m [soil dust grain], typical interparticle distance of the order of $a_P = 100 \times 10^{-6}$ m (Chu & Lin, 1994), Debye length $\lambda_D = 5 \times 10^{-6}$ m (Equation 10), and dusty particle density $\rho = 3.5$ kg m^{-3} (for thortveitite, a common mineral in the Hessdalen valley; Anthony et al., 1995), we found through Equation 6 a coupling plasma parameter $\Gamma \sim 2 \times 10^{-3}$. Monte Carlo simulations showed that the charged species in a dusty plasma should form regular lattices (Coulomb Crystals) at $\Gamma \geq \Gamma_c$, where $\Gamma_c = 170$ (or $\Gamma_c \sim 178$). Since this value is very much lower than Γ_c, dust particles cannot crystallize. Thus, different geometric structures observed in HL phenomenon should not be explained by air ionization produced by an electric field during tectonic stress on quartz under the ground.

Conclusion

We conclude that theories that involve piezoelectricity generated under a quartz strain at the ground cannot explain the geometrical structures observed in HL phenomenon in its low level of luminosity. Here we use a recent dusty plasma model of HL that explains several properties of the natural phenomenon (Paiva & Taft, 2010). According to dusty plasma theory, geometrical structures in a plasma should occur when *coupling parameter* Γ (also known as the plasma parameter or strength of interaction in a plasma) is $\Gamma \geq \Gamma_c$ where $\Gamma_c = 170$ (or $\Gamma_c \sim 178$). We have found a coupling plasma parameter of $\Gamma \sim 2 \times 10^{-3}$ for dusty plasma within an electric field in the air produced by the tectonic stress, $E = 1.5 \times 10^5$ V/m, which is insufficient to originate in (dusty) plasma geometrical structures observed in the center of some HL.

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