A hypothetical dusty plasma mechanism of Hessdalen lights

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ABSTRACT

Hessdalen lights (HL) are unexplained light balls usually seen in the valley of Hessdalen, Norway. In this work, it is suggested that HL are formed by a cluster of macroscopic Coulomb crystals in a plasma produced by the ionization of air and dust by alpha particles during radon decay in the dusty atmosphere. Several physical properties (oscillation, geometric structure, and light spectrum) observed in HL phenomenon can be explained through the dust plasma model.

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1. Introduction

HL are unexplained lights usually seen in the valley of Hessdalen, Norway (Teodorani and Long-Term, 2004). It has the appearance of a glowing light ball with dimensions ranging from decimeters up to 30 m. In a few cases (at low level of luminosity) it explicitly shows visually some kind of geometric structure. The reason for these shapes is totally unknown. HL are characterized mostly by white color and sometimes by red color. It occurs mostly at night, more often in the winter season and with a peak around midnight. Night vision systems (spectral range 700–1000 nm) revealed that the light phenomenon produces a very strong infrared signature even when it is very faint or invisible in the optical range. HL often shows strong radar tracks also when it is not visible or faint. It is often accompanied by small and very short-duration pulsating "spikes" in the HF and VLF radio ranges, sometimes by showing Doppler features.

No existing theory or model can account for all (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). Other theories involve piezoelectricity generated under a rock strain (Takaki and Ikeya, 1998), misperceptions of astronomical bodies, aircraft, car headlights, and mirages (Leone, 2003).

A dusty plasma is a plasma containing nanometer or micrometer-sized particles suspended in it, which also behave like a plasma. Several experiments (Takahashi et al., 1998, Konopka and Morfill, 2000) have been conduced to study short-range repulsive and long-range attractive interactions between charged dust grains. Examples of dusty plasmas include comets, planetary rings, zodiacal dust cloud, and interstellar clouds (Horanyi and Mitchell, 2006). The essentially simultaneous discovery by several experimental groups in 1994 (Thomas, et al., 1994; Chu and I, 1994) of the formation of a crystal of dust particles (so-called "plasma crystals" or "Coulomb crystal") in a gas discharge showed that microparticles in a plasma are also a new, unique object that makes it possible to study phenomena lying at the junction of the physics of a nonideal plasma, solid-state theory, and the physics of phase transitions.

In this work, it is suggested that HL are formed by a cluster of macroscopic Coulomb crystals in a dusty plasma produced by the ionization of air and dust by alpha particles during radon decay. Several physical properties observed in HL phenomenon can be explained through a dust plasma model.

2. The model

A dusty plasma is an ionized gas containing micron-sized charged condensed grains (Thomas et al., 1994). The combined action of interaction between dust grains and dissipative processes in a dusty plasma can lead to the formation of both steady state dusty structures (similar to fluids or solids) and complex dynamic configurations associated with large-scale transport processes. In nature, dusty plasmas exist in interstellar clouds, planetary rings (notably Saturn), comets, atmospheric aerosols, noctilucent clouds, etc (Goretz, 1989). Here we consider HL phenomenon like a dusty plasma. HL are produced when high concentration of radon gas migrates through faults and

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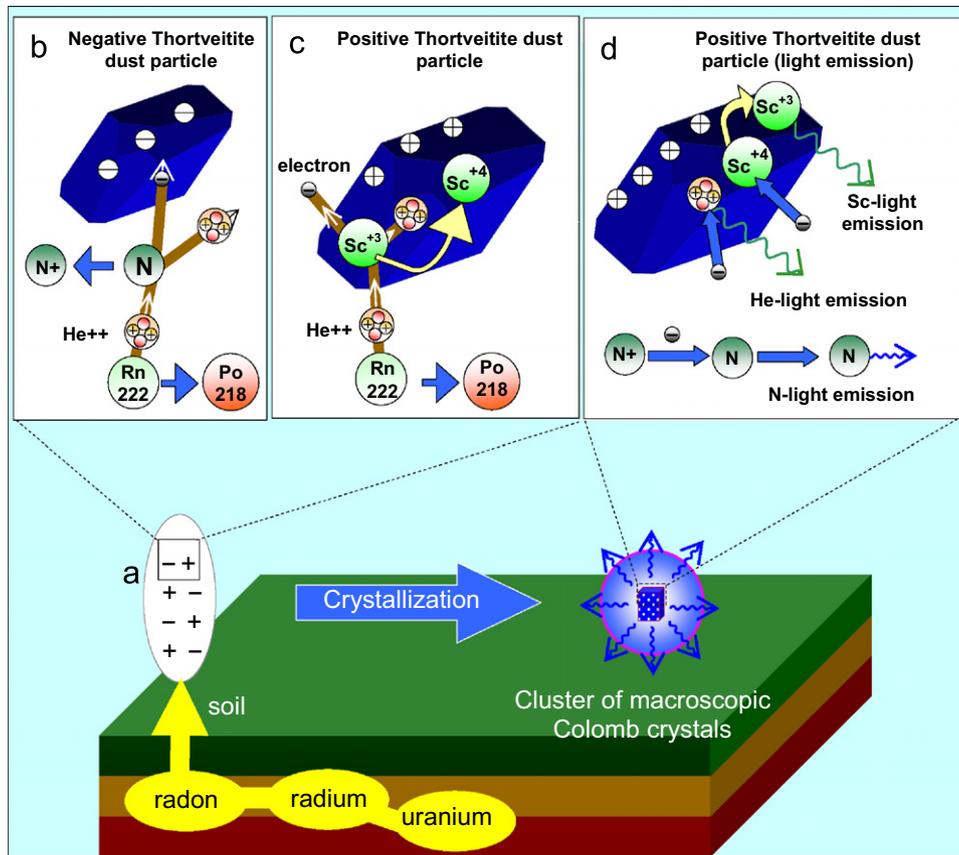 *E-mail address:* gerson_trabalho@yahoo.com.br (G.S. Paiva).

Fig. 1. *Dust plasma formation during* radon decay *(a); D*ust particle of thortveitite is charged by collecting electrons (b) and positive ions (c). Crystallization of dust plasma will form a cluster of geometric structures observed in the center of HL phenomenon (d) that emits light by electron capture (e).

fragmented soils to the atmosphere (Fig. 1). In the atmosphere, high energy ($\sim$5.48 MeV) alpha particles from radon decay ionize the atoms (air and dust) in its path (Fig. 1a and b). Electrons are collected on the dust grains, making them negatively charged (Fig. 1b). The other charge mechanism is electron emission due to impact of alpha particles from radon decaying (Fig. 1c) *and secondary electron emission*. Overall charge on the dust grain then depends on the relative strength of these competing charging processes. The dust grain will emit *light by electron capture (Fig. 1d), producing the HL spectrum.*

Norway is considered to be one of the most radon-affected areas in Europe (Strand et al., 2005). This is partly explained by the geology due to the large occurrences of radium rich soil and bedrock (e.g., alum shale and uranium-rich granites) and large occurrences of highly permeable unconsolidated sediments (e.g., moraines and eskers) (Sundal et al., 2004). Being a rare gas, it usually migrates freely through faults and fragmented soils, and may accumulate in caves or water (Sperrin et al., 2001).

In HL phenomenon, the dominant chemical element is oxygen and nitrogen. Nitrogen, at ionization on level 1, N1, is present in the HL spectra at 5281.7 Å emission line (Kristiansen, 2003). Other elements detected in HL (silicon, iron, and scandium) suggest dust from the valley, probably thortveitite—$(Sc,Y)_2Si_2O_7$—a common mineral from Norway. However, no luminescence in thortveitite is observed (under long-wave UV, short-wave UV, or visible light) to explain the HL spectrum. Since the alpha particle is basically a helium nucleus, it is the largest and most massive type of radiation. In addition, interaction of alpha particles with matter is very strong due to the alpha particle's electrical charge of two units. Thus, luminescence in thortveitite is due to ionization

produced by alpha particles in the crystal. In this way, atoms from thortveitite can produce emission lines of scandium, silicon, and iron as they go to a lower energy state or capture electrons in the dusty plasma (see Fig. 1d).

3. Calculations

In most cases, HL (at high level of luminosity), if seen from far away, has the appearance of a glowing light ball with no structure, in other cases (at low level of luminosity) it explicitly shows visually some kind of geometric structure (Teodorani and Long-Term, 2004). Rectangular shapes have been recorded as well. 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 photographs. In a specific case, the rectangular shape is much smoothed owing to fast motions of satellite spheres around the rectangular core during a long-time exposure. Interestingly, 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. This is known as a Coulomb fluid or a coulomb 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 crystal formation 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*):

$$\Gamma \equiv \frac{\langle PE \rangle}{\langle KE \rangle} \qquad (1)$$

The coupling parameter Γ depends on the ratio of the square of particle charge to particle temperature:

$$\Gamma \equiv \frac{(Q_p)^2}{4\pi\varepsilon_0 a_p k_B T_p} e^{(-a_P/\lambda_D)} \qquad (2)$$

where Q_p is the charge on the grain, a_p the interparticle distance, k_B the Boltzmann constant, ε_0 the permittivity of vacuum, T_p the particle temperature, and λ_D the Debye length. The charge on an isolated grain particle in the dusty plasma is

$$Q_p = C\Phi_s \qquad (3)$$

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 the energy E_i of the primary ions (i.e., energy of alpha particles from radon decay) as (Cermák et al., 1995)

$$\Phi_s = \frac{E_i}{e} \qquad (4)$$

where e is the elementary charge. Let us calculate the surface potential on the dust grains in HL. According to Bjorn (2007), based on the arbitrarily assumption that HL spectrum is due to some kind of gas of ions and electrons in thermodynamic equilibrium (blackbody radiator), its mean temperature is $T = 5100$ K. The average kinetic energy of electron in this plasma will be:

$$E_e = \frac{3}{2} k_B T \qquad (5)$$

Inserting the value $T = 5100$ K, we found $E_e \sim 1$ eV. This energy is *much lower than* those for alpha particles from radon decay, $E_i \sim 6$ MeV (Espinosa et al., 2008). In this case, polarization of dust grain in the plasma will be predominantly due to alpha particles collisions. Thus the surface potential of dust grains will be $\Phi_s = E_i/e \sim 10^6$ V.

The Debye length of electrons is given by

$$\lambda_D = 69\sqrt{\frac{T}{n_e}} \qquad (6)$$

where T is the mean temperature inferred to HL phenomenon (Bjorn, 2007) and n is its electron density (electrons per m³). Considering HL like a blackbody radiator with the mean temperature of $T = 5100$ K, its electron density can be estimated based on the solar photosphere. The Sun's photosphere has a temperature between 4500 and 6000 K (with an effective temperature of 5000 K) and mean electron density of 10^{18} m^{-3} (Vranjes and Poedts, 2009). 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 $r = 10$ μm (soil dust grain), typical interparticle distance of the order of 10^2 μm (Chu et al., 1994), and $\lambda_D = 5$ μm Eq. (6), we found through Eq. (2) a *coupling plasma parameter* $\Gamma \sim 4 \times 10^7$. 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 $\Gamma_c \sim 178$) is the critical coupling parameter for the liquid–solid transition (Gilbert et al., 1988). Since this value is very much larger than Γ_c, dust particles in HL should crystallize. Depending on particle density, different geometric structures of Coulomb crystals should arise in a dust plasma (cubic, rectangular, hexagonal, etc.; Schweigert and Schweigert, 1998). Thus, geometric structures observed in HL phenomenon can be explained through crystallization of a dust plasma.
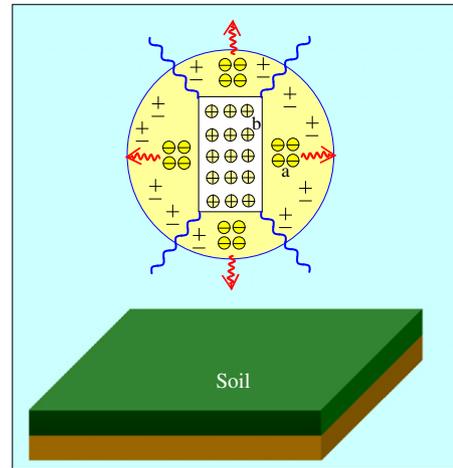

Fig. 2. HL phenomenon like a dusty plasma. It is formed by a cluster of "satellite" Coulomb crystals (a) containing negatively charged dust particles and a large central Coulomb crystal (b), containing positively charged dust particles. The color of the light balls might be produced by natural aerosols in the atmosphere, whose nature varies with locality.

HL phenomenon is visually formed by "satellite spheres" around a central luminous core (Teodorani and Long-Term, 2004). According to the dust plasma model, HL phenomenon is formed by a cluster of "satellite" Coulomb crystals presenting dust grains negatively charged around a central luminous Coulomb crystal, with positively charged dust grains (Fig. 2).

Similar to the HL phenomenon, laboratory dust plasmas also oscillate. These oscillations are the result, in part, of mutual repulsion of the particles in the presence of a restoring force, in this case both gravity and electrostatic plasma forces. Such oscillations could easily be induced by a rapid change of the plasma and/or confining potential. The rate of oscillations of the particles cloud depend on a variety of parameters, ranging from particle mass and charge to strength of the confining field and/or Debye length. In such cases the dust distribution will oscillate with a frequency (in Hertz)

$$f = Q^{0.52} m^{-0.50} \qquad (7)$$

where Q and m are, respectively, the charge and mass of dust particle (Vasut et al., 2004). Assuming the steady state (initial) surface charge of a particle to be $Q = 10^{-9}$ C (see Eq. (3)) and mass of a thortveitite particle ($r = 10$ μm, thortveitite density $d = 3.5$ kg m^{-3}) as $m = 1.4 \times 10^{-11}$ kg, the oscillation frequency will be $f \sim 5$ Hz, in a good agreement with the frequency of pulsating magnetic perturbation observed in a HL phenomenon, which is 7 Hz (Teodorani and Long-Term, 2004). This is produced by oscillation of charged particles (in the same frequency) in the Coulomb crystal.

Night vision systems (spectral range 700–1000 nm) revealed that the light phenomenon produces a very strong infrared signature even when it is very faint or invisible in the optical range (Teodorani and Long-Term, 2004). In the dust plasma model for HL, this can be explained by the electron capture from three times ionized scandium (Sc-IV) in the thortveitite dust particles. Emission lines from Sc-IV have been identified up to 1000 nm (infrared frequencies; Holmstrom, 1972).

4. Conclusions

Thus, HL is a cluster of Coulomb crystals in a dusty plasma produced by radon decay in the atmosphere. Radon decay produces alpha particles (responsible by helium emissions in HL

spectrum (Teodorani and Long-Term, 2004)) and radioactive elements such as polonium (Espinosa et al., 2008). Teodorani and Long-Term (2004) showed a HL occurrence where a higher level of radioactivity on rocks was detected near the area where a large light ball was reported. In fact, when radon is released into air, its solid decay products readily attach to airborne dust (IARC, 1988). Spectrum of the Hessdalen light phenomenon appears continuum with no resolved lines (Bjorn, 2007). Air turbulence or even fog is able to smooth greatly the spectrum at its base and induce the growth of exponential wings in the spectrum of an illuminated solid body. This happens normally with the light of the stars (the most typical plasma objects) when they are observed through the atmospheric layers—in such a case the "seeing disk" is larger with increasing atmospheric turbulence, which results in the exponential wings of Gaussian shape of their spectrum much more broadened. Probably the emission bands from HL are due to a blend of many very close emission lines, due to the excitation of several chemical elements together.

Acknowledgments

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