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The effect of gravitational acceleration in the streaming potential on the surface of a planetary body and in orbit around it

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Abstract

A corrected gravitational acceleration has been used for the study of the electric streaming potential. The acceleration has been corrected for the oblateness of a spherical body, as well as the rotational velocity of the spherical body. For higher viscosity values we find that on the surface of a spherical body the electric streaming field is slightly higher at the poles when compared to that of the equator. Aboard an orbiting spacecraft, we find that equatorial circular orbits that they carry experiments which use high viscosity fluids result to a higher streaming field values when compared to circular polar orbits. In a similar way, we find that the electric streaming field as well as the electrophoretic velocity of the particle in the fluid considered increases significantly in elliptical orbits as the orbital eccentricity increases, being higher in equatorial orbits and smaller in polar orbits.

Keywords: Gravitational potential; Spherical harmonics; Streaming potential; Electrophoretic velocity

1. Introduction

Today's progress in the domain of gravitational cell biology research lies on the continuous research of a variety of physical phenomena, and in particular phenomena that are affected by the force of gravity, in extracellular, intercellular and intracellular processes. It is possible to consider inertial accelerations as a continuous variable ranging from 10^{-6} to 10^{-4} g, something that is peculiar to space flights and often described as "weightlessness", "zero gravity", or "microgravity". These terms usually refer to scenarios where the inertial acceleration is drastically reduced or the conditions are such that gravity is very low. Offset situations make one to express various experimental results in terms of the effects that microgravity simply describes. In simple terms the term microgravity simply describes an environment that the living systems encounter during a spaceflight.

Gravitational biology experiments are usually performed on centrifuges, devices which produce a gravitational loading greater than 1 g, (Brown and Chapman, 1977) or in scenarios that result in hypogravity conditions, aboard orbiting centrifuges (Brown and Chapman, 1984). Microgravity also occurs during free fall scenarios, something that is produced for very short periods (seconds) during parabolic aircraft flights, sounding rockets, or drop towers.

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All cells on the Earth have evolved in 1 g gravity field. Thus, some type of cells have also developed essential mechanisms with the help of which, they exploit the gravity field by orientating themselves to the $\vec{g}$ vector. Microgravity research has started at approximately fifty-five years ago in an effort to determine if exposure to microgravity has serious effects on various biological systems that participate in experiments that take place in spacecraft under microgravity conditions (Marbarger and Vasiliev, 1975). Early biological experiments had focused in the study of the combined effects of microgravity and radiation (Taylor, 1977) at cellular level. Initial experiments have demonstrated that limited exposure to microgravity was not catastrophic. On the other hand long time exposure to microgravity during spaceflights resulted in profound physiological changes therefore counter measures were used during spacecrafts (Lenorowitz, 1989). Since the beginning of the orbital spaceflight era in 1957 various microgravity experiments have been performed e.g. Krikorian et al. (1986), Krikorian and Stweard (1978) and Todd et al. (1988). Furthermore, in Haranas et al. (2012) the authors study the effect of gravity in intracellular molecular distributions in spacecraft experiments on the surface as well as in orbit around Earth. This is achieved by using a corrected gravitational acceleration in which the J_2 harmonic for the asphericity of the Earth and also the Earth's rotation is taken into account. Moreover, in Haranas et al. (2013) the authors investigate the effects of torque on cells in experiments that take place on the surface of a planet, as well as in experiments that take place in a spacecraft in orbit above the surface of a planetary body. Finally, in Haranas et al. (2014) the authors have examined the effects of corrected gravity in experiments involving fractal formations on the surface of a planetary body and in orbit around Earth.

Similarly Corey and Zanello (2014) have studied long duration exposure to microgravity which leads to ocular changes in astronauts manifested by a variety of signs and symptoms during spaceflight which they persist after their return to Earth. These are morphological and functional changes that are only partially understood.

In this contribution, we examine the effect of a corrected gravitational acceleration, the space an acceleration corrected for spherical oblateness and rotation in the calculation of the electric streaming potential as well as the electrophoretic velocity of particles moving in this field. The streaming potential effect takes place when a charged particle moves, and as a result impacts the motion of other charges in its environment, including dissolved ions. In our opinion, this correction is important and must be taken into account, if more precise experiments are required. We remind the reader, that the electric streaming potential as well as the electrophoretic velocity exhibited by the particles in this type of field depends on the acceleration of gravity g. We also propose that this kind of experiments can be used in the determination of geophysical parameters, once values the electric streaming field and electrophoretic particle velocities can be measured.

2. Theory of particle electrokinetics and the streaming potential

In a distribution of charged suspended particles the surface charge density prevents their coagulation and as a result leads to the stability of lyophobic colloids. This stability can determine various material processes such that pulp and paper processing, fermentation and much more. If surface charges are present they can result to motion of the particle, if the particle is suspended in the electric field lines. In this case the particle surface exhibits an electrokinetic potential, the so called zeta potential ζ, (Todd, 1989) (Delgado et al., 2005) a potential proportional to the surface charge density of the particle σ_e. Zeta potential can be of the order of few mV in the case of non-conducting particles, including cells, where these are suspended in aqueous suspension. Furthermore, if the solution has a dielectric constant ε we can write the electrophoretic velocity (Todd, 1989) to be:

$$v_{el} = \frac{\zeta\varepsilon}{6\pi\eta}E, \quad (1)$$

where η is the viscosity of the solution. Eq. (1) can be applied in small particles whose radius of curvature is almost the same as to that of the dissolved ion commonly known as Debye–Hückel particles for which Eq. (1) takes the form (ibid, 1989):

$$v_{el} = \frac{\zeta\varepsilon}{4\pi\eta}E. \quad (2)$$

Equation (2) can be applied for larger particles for example cells, organelles and other. Next we proceed with some basic theory regarding the streaming potential. The main idea is that when a charged particle moves a potential is created as a result of this motion. This resulting potential will affect the motion of other charges in the particle's nearest environment, also including any dissolved ions. When comparing this potential with the potential of a stationary particle or the ζ potential can be felt from particles at a distance up to 7 Å. Next, if a particle moves under the acceleration of gravity $\boldsymbol{g}$ the intensity of the electric field generated is given by:

$$E = \frac{\zeta\varepsilon}{3\pi\eta k}(\rho - \rho_0)g, \quad (3)$$

Where k is the so called Debye–Hückel constant which at room temperature (25 °C), in water for 1:1 for electrolytes we can consider the relation $k^{-1} = 0.304/\sqrt{I(M)}$, where k^{-1} is expressed in nanometers (nm) and I is the ionic strength expressed in molar (M or mol/L) (Israelachvili, 1985). The force of the corresponding field is opposite to the direction of the particle's motion and therefore it takes the name "counter streaming potential". Potential values