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Charged Particles Close to the Mars Surface

M. Ramírez-Nicolás (1,2), L. Vázquez (1), D. Usero (3) and M. Herraiz (2,4)
(1) Departamento de Matemática Aplicada, Facultad de Informática, Universidad Complutense de Madrid, Spain. (2) Departamento de Física de la Tierra, Astronomía y Astrofísica I, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, Spain. (3) Departamento de Matemática Aplicada, Facultad de Químicas, Universidad Complutense de Madrid, Spain. (4) Instituto de Geociencias, UCM-CSIC, Spain (marramir@fis.ucm.es)

Abstract

One way to address the Martian crustal magnetization is to use the classical source models, where the field created by a volume of a magnetized material is compared with the observed one. These source models allow introducing additional constraints related to the available information of the magnetic field. In this context, our goal is to find the relevant features of the charged particle dynamics at low altitudes in the Martian atmosphere. To this purpose, the motion of different charged particles (e^-, p^+ and ^4He) moving in different uniformly magnetized sources has been analyzed. To complete this study, the gravitational field has been included in all the equations. To a first approximation, we have assumed a constant gravitational field and finally, a non-uniform gravitational field dependent on altitude has been modeled. The dynamics of the charged particles has been studied numerically in to coordinates representations, (x,y,z) and (ρ,z) where $\rho=(x^2+y^2)^{1/2}$.

1. Introduction

It is well known that currently Mars does not have a principal magnetic field therefore its remanent magnetism must be a relict of an earlier planetary field. This remanent magnetic field was detected by the observations made by the Mars Global Surveyor during the aerobreaking phase which has been evidenced the existence of materials with intense remanent magnetization on the Mars surface. There are different theories about these anomalies detected on Mars. One of them suggests the existence of an ancient tectonic activity similar to the observed in the Earth (not definitive evidence) which can be fairly explained as the result of a process of collision in a zone of crustal destruction, causing continental accretion [2]. The other one addresses a crustal magnetization through the use of source models [1], comparing the field produced by a volume of a magnetized material with the data observed [3].

The aim of this work is to show the magnetic fields generated by different sources that could explain the Mars crustal magnetic field. In this context, the trajectories of different charged particles under different magnetic fields are also presented.

2. Methodology

We have assumed that Mars crustal magnetization anomalies can be obtained by different kinds of magnetized sources. We have calculated the equations of the magnetic field generated by a sphere (1) and a cylinder (2).

$$\vec{B}=\frac{C_m\cdot\left[3\left(\vec{m}\cdot\vec{r}\right)\cdot\vec{r}-r^2\vec{m}\right]}{r^5} \quad (1)$$

$$\vec{B}=\frac{2\cdot C_m\cdot\left[2\left(\vec{m}\cdot\vec{r}\right)\cdot\vec{r}-r^2\vec{m}\right]}{r^4} \quad (2)$$

where C_m is a constant, $\vec{m}$ the dipolar moment and $\vec{r}$ the position vector.

To study the motion of different particles in the magnetic field generated by a magnetized sphere we have worked with the components of the magnetic field in cylindrical coordinates, in order to reduce the three-dimensional problem to the two-dimensional motion of a particle in the ρ-z plane [5]. We have obtained the potential field U(ρ,z) for a magnetized sphere by using the basic principles of the Störmer's Theory [4].

3. Results

Magnetic field components B_x and B_z are represented in figure 1 for the different sources. Taking the same values for the terms C_m and m_z we can conclude that intensity of the component B_z is greater for the sphere than the ones obtained for the cylinder and the complex source. A similar behavior can be observed for the component B_x.

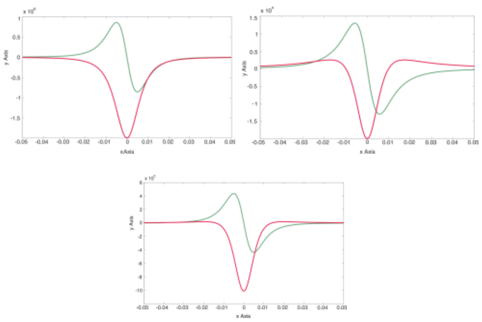

Figure 1: Magnetic field components B_x (pink) and B_z (green) in the XY plane due to, an sphere (up-left), a cylinder (up-right) and a composition of both (bottom).

We represent the potential field for three different particles (figure 2). We have approximate the U(ρ,z) as the behavior of an electron moving in the magnetic field generated by a magnetized sphere. We have obtained that the energy needed by a particle to escape from this magnetic field decreases with increasing either the mass or the charged.

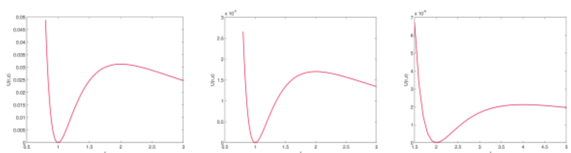

Figure 2: Potential field for an e^- (left), p^+ (middle) and ^4He (right), moving in a magnetic field generated by a spherical source.

The motion equations are (4), and they are studied by using the numerical scheme (5).

$$\frac{d^2\rho}{dt^2} = -\frac{\partial U}{\partial \rho} \qquad \frac{d^2 z}{dt^2} = -\frac{\partial U}{\partial z} \tag{4}$$

$$\begin{aligned} \frac{\rho^{n+2} - 2\rho^{n+1} + \rho^n}{(\Delta t)^2} &= -\frac{U(\rho^{n+2}, z^n) - U(\rho^n, z^n)}{r^{n+2} - r^n} \\ \frac{z^{n+2} - 2z^{n+1} - z^n}{(\Delta t)^2} &= -\frac{U(\rho^{n+2}, z^{n+2}) - U(\rho^{n+2}, z^n)}{z^{n+2} - z^n} \end{aligned} \tag{5}$$

This scheme is conservative, reversible and reflects very well the dynamics of the underlying continuous system. Figure 3 represents the confined paths for an electron and a proton in a magnetic field generated by a magnetized sphere. Comparing with the results of figure 2, we can confirm that the behavior of both particles is very similar. The only difference is the energy needed by each particle to escape from the magnetic field confined.

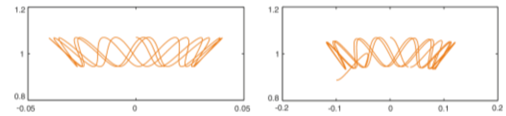

Figure 3: Trapped orbits in the ρ-z plane for an electron (left) and a proton (right) moving in the same magnetic field.

5. Summary and Conclusions

Using the magnetic field and the potential field proposed by Störmer, we have obtained the trajectories for three different particles moving in a magnetic field generated by a sphere. In absence of a gravitational field the energy needed by a particle to escape from the magnetic field decreases with increasing either the mass or the charge.

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