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Short Communication

Calculation of the magnetic field of the asteroid 4 Vesta parent body (Application of SK theory)

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Abstract

The SK theory provides a deeper insight into the magnetic properties of celestial bodies. In this study, the magnetic field calculated of the parent body of asteroid 4 Vesta, could facilitate deeper insight into the formation of planets or the Universe.

Introduction

Asteroid 4 Vesta is the brightest and second most massive asteroid (R=262km, m=2.59.10^{20}kg) in MAB. It is important to note, the Down Spaceship mission (NASA's first discovery mission, which orbited the most massive of asteroids in MAB [1,2]), confirmed the hypothesis that parts of 4 Vesta asteroids (so-called HED meteorites) can be found on the Earth [3], i.e, asteroid 4 Vesta represents the parent body of the HED meteorites, which reaches the Earth. Applying the same logic that leads to understanding HED meteorites as broken fragments of asteroid 4 Vesta (reliance on the same chemical composition of the HED meteorites and the 4 Vesta asteroid), some properties of the parent body of asteroid 4 Vesta may be commented, if it is assumed that asteroid 4 Vesta represents the broken part parent's body. Recall that the HED set of meteorites usually served as analogs for 4 Vesta's chemical/mineralogical composition [1,2].

A review of the literature revealed that, based on Dawn's data, deeper a view of the petrological evolution of 4 Vesta and its internal geometry has been achieved in the last decade [4-7]. To ensure the said achievement, it was necessary to assume the chemical composition of the asteroid Vesta. Two reliable sources of data are presented in the literature discussing the chemical composition of asteroid 4 Vesta [4,8]. Knowing this data (i.e. assumed chemical composition of the asteroid Vesta), was possible again to construct some properties of the parent body of asteroid Vesta (if so assumed that it is spherical in shape, of the same chemical composition and idea that 4 Vesta represents its own fragment), by applying the SK theory [9-12]. Since the SK theory shows sufficiently good predictability in the case of calculations of the magnetic field of celestial bodies (relying on only one parameter - the chemical composition of the body) [12,13], this paper will be calculated the value of the magnetic dipole (which value is in literature accepted as a good approximation for the strength of the celestial body's magnetic field) of the asteroid 4 Vesta parent body. The magnetic field was calculated taking into account the magnetic moment of each element represented on the asteroid 4 Vesta, relying on a mathematical expression based on the calculations postulated in the SK theory. It should be noted here that the calculations are rough since the only input parameter is the chemical composition.

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Materials and methods

To calculate the magnetic field of the parent body of asteroid 4 Vesta, one needs to know the mass fraction of each element, as well as the basic data about the elements, such as the electronic configuration of the element, relative atomic mass, molar volume, and ionization energies, which could be found in Ref. [14]. A simple algebraic procedure is carried out to solve the equations postulated in the SK theory, which allows the calculation of the parent's body magnetic field.

Results and Discussion

According to the SK theory, asteroid 4 Vesta does not have a magnetic field [12] and this theory does not allow the estimation of the moment in the time in which the body is characterized by the calculated value of the magnetic field. Several assumptions are introduced: 4 Vesta and the body of the parents both consisted of the same chemical composition, the body of the parent is spherically shaped, and has its own gravity and magnetic field. Based on Down's data, one could assume that the 4 Vesta chemical composition consists of significantly more abundant elements: *Si, O, Ti, Al, Cr, Fe, Mn, Mg, Ca, Na* [4,8]. In the form of oxides, they are represented as 20% CV chondrite and 80% H chondrite [4]. Mass fractions of oxides, represented in the form of CV chondrite, are: 37:7% SiO_2, 0.2% TiO_2, 3.6% Al_2O_3, 0.6% Cr_2O_3, 27,7% FeO, 0.2% MnO, 26.9% MgO, 2.8% CaO, 0.4% Na_2O. In the case of the mentioned oxides represented in the form of H chondrite, corresponding mass fractions are: 48.3% SiO_2, 0.2% TiO_2, 2.9% Al_2O_3, 0.7% Cr_2O_3, 13.6% FeO, 0.4% MnO, 30.5% MgO, 2.3% CaO, 1.1% Na_2O [4]. Considering the magnitudes necessary for calculation (electronic configuration of the elements, their relative atomic masses, molar volumes, and ionization energies [14]) and by applying SK theory [9-12], it was possible to derive phases of the atom (element), in which the entire element will be ionized. Having on mind mass fractions of the presented elements, it could calculate the corresponding magnetic moments of the elements, contributing to the entire magnetic moment of the body.

The postulated expressions are obtained by relying on the expressions that describe the magnetic moment of an electron moving at a certain velocity around a given central point (which represents a geometric representation of an ellipse, in which the electron orbits around the nucleus), which basically represents an elementary circle of current [12]. Taking into account the movement of electrons on an ellipse, the transition of the material through different phases (which occurs during the ionization of atoms), including the calculated potential and kinetic energy of electrons, is mathematically described. Taking into account the coincidence of the ellipse in different positions, the transition of the material through different phases and the change of the total energy were considered. Also, taking into account the kinetic moment, it was established that, instead of the coincidence of the ellipses during the phase, we can talk about the constancy of the total energy and the kinetic moment. Consequently, a dimensionless parameter k_i (appeared due to the numerical eccentricity of the ellipse) is introduced, which is important because it participates in Eq. (1). As a result of calculations and corresponding substitutions, eq. (1) is obtained [12]:

$$L_{element} = 14.184 \cdot 10^{-24} \frac{(V_{mol})^{\frac{1}{6}}}{A} k_i \quad (1)$$

In this expression, L_{element} – a magnetic moment of the element; V_{mol} – molar volume; A – relative atomic mass; k_i – dimensionless parameters, are introduced due to the geometrical postulation of the model.

Ex. (2) represents the contribution of the magnetic moment of each element, which is found by taking into account the mass fraction of the mentioned element (X), the calculated magnetic moment (L_{element}), the relative atomic mass (A) and the electron-deficient mass of the considered celestial body (i.e. the mass at which the ionization of the given element ends) ($M_k^{'}$) [12]:

$$L_{element,contr} = X \frac{M_k^{'}}{A} L_{element} \quad (2)$$

And finally, it was possible to determine the entire magnetic dipole moment by using eq. (3), which represents the entire magnetic moment of the celestial body (L), obtained by summing the contribution of the magnetic moments of all considered elements ($L_{\mathrm{element},\, contr}$) and multiplying that sum by Avogadro's number (N):

$$L = (\sum L_{element,contr}) \cdot N \quad (3)$$

Accordingly, the calculated value for the dipole moment is: $L = 1.8523 \cdot 10^{9} \frac{J}{T}$, which could be understood as the lower-limit value of the magnetic field of asteroid 4 Vesta's parent's body.

If we compare the chemical compositions of the two largest and most massive asteroids in the MAB, 1 Ceres (r=473km, m=9.10^{20} kg, most abundant elements: (33% O, 20% C, 17% Fe, 11% Si, 7% Mg [15]) and 4 Vesta, some remarks could be made. Asteroid 4 Vesta is characterized by a higher percentage of the Fe (in the form of FeO) compared to asteroid 1 Ceres. Since it is known that iron is a magnetic element, so one might expect that the parent body of asteroid 4 Vesta is characterized by a slightly higher value of the magnetic field, compared to the magnetic field of asteroid 1 Ceres parent's body.

It is important to note that the consideration of the four most represented elements, in the case of the asteroids 4 Vesta, 1 Ceres, and the planet Earth, discovered relatively similar chemical compositions in all cases. In the case of asteroid 4 Vesta, elements are: *Si*, *O*, *Mg*, *Fe*; in the case of 1 Ceres: *O*, *C*, *Fe*, *Si*; and in the case of Earth, are: *O*, *Si*, *Al*, *Fe* [16]. Considering the role of SiO_2 and its participation in the Earth's crust, as well as knowing the importance of elements *Fe* for planet Earth, the role of the element *Mg* in asteroid 4 Vesta formation (as well as element C in the formation of asteroid 1 Ceres) is not clear.

Conclusion

In this paper, the value of the magnetic field of the parent body of asteroid 4 Vesta was calculated. It was found that

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its value of dipole magnetic moment cannot be smaller than $L = 1.8523 \cdot 10^9 \frac{J}{T}$. The derived result can be of importance for better insight into celestial bodies and the formation of the solar system.

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