JOURNAL OF
EMERGING INVESTIGATORS

Article

Generation of a magnetic field on Mars

Zhansaya Galymova[1], **Serik Anibayev**[1*], **Raya Smagulova**[1*]
[1]Nazarbayev Intellectual School of Physics and Mathematics, Semey, Kazakhstan
*These authors contributed equally to this work

SUMMARY

The depletion of Mars' magnetic field has led to drastic changes in its atmosphere, causing decreased temperatures and the disappearance of surface water. This depletion poses a threat to the health of astronauts and potential inhabitants due to increased solar radiation. Restoring Mars' atmosphere is crucial for human colonization. Our study focuses on optimizing a magnetic field for Mars using a theoretical model. We hypothesized that our model could generate a magnetic field of 2 T, which is the quantity needed to protect Mars, according to James Green. The model incorporates superconducting magnets, 5804 m^2 of solar panels, and a superconducting magnet with a current of 1.6 x 10^4 A. Here, we explore the relationship between current and magnetic field strength. Lithium-ion batteries play a pivotal role in advancing the feasibility of this proposed method for generating a magnetic field on Mars. Their high energy density, coupled with the ability to provide sustained power over extended periods, ensures a reliable and long-lasting energy source for the spacecraft tasked with implementing this technique. The method of generating a magnetic field on Mars has broad implications, offering protection against solar wind and radiation on various celestial bodies. Implementing this method could raise Mars's temperature and melt polar ice caps. In summary, our study proposes a theoretical model for a magnetic field of 2 T on Mars, with specific parameters. This has the potential to revolutionize planetary colonization and space life sustainability.

INTRODUCTION

Colonizing Mars has emerged as a captivating endeavor in the modern world, driven by the need to accommodate the growing human population. However, sustaining life on the red planet faces significant challenges due to its inhospitable conditions. One crucial requirement for human habitation is the presence of a protective magnetic field (1). Without a magnetic field, astronauts and future colonizers would be susceptible to harmful solar radiation, jeopardizing their health, since the Martian atmosphere remains vulnerable to solar wind and cosmic rays (1). Solar wind, consisting of charged particles emitted by the sun, poses a significant threat to Mars. Earth is protected from solar wind due to its magnetic field, but Mars lacks this safeguard (2). Although Mars was believed to have had its own magnetic field in the past, its small size led to the loss of energy in its core, resulting in core cooling and the inability to generate a magnetic field (3).

James Lauer Green, an American physicist and retired chief scientist for NASA, proposed generating a magnetic field on Lagrange 1 Point (L1) (4). Lagrange Points are stationary locations in space where the gravitational forces acting on a small body are balanced by the centrifugal force within a rotating frame associated with more massive bodies. In his academic paper, Green proposes placing an artificial magnetosphere shield at the L1 to obstruct solar wind, which consistently erodes the Martian atmosphere (4). He suggests that doing so could enable the accumulation of trace gases, gradually forming a tenuous atmosphere on Mars. Over time, the presence of greenhouse gases would contribute to warming the atmosphere, leading to the thawing of trapped water, which would then transform into water vapor. This process has the potential to replenish approximately one-seventh of Mars's oceans (4). Our research focuses on further developing this idea by using solar sails, solar panels, and superconducting magnets to protect Mars from solar wind and make Mars habitable **(Figure 1)**.

To generate an artificial magnetic field, superconducting magnets offer a promising solution. They are often used in hospitals for Magnetic Resonance Imaging and in scientific instruments such as Nuclear Magnetic Resonance spectrometers, fusion reactors, and particle accelerators (5). These magnets exhibit reduced resistance and increased efficiency, allowing for the production of a larger magnetic field with lower energy consumption. Superconducting magnets exhibit zero resistance and generate no heat, allowing them to maintain high current strength (6). The main requirement for maintaining zero resistance is reducing the temperature to extremely low values, which is achieved by submerging the electromagnet in liquid helium (6). To minimize gas evaporation, the container is additionally dipped into another Dewar vessel filled with liquid nitrogen. Under these conditions, the winding of a superconducting magnet has zero resistance. Even if the circuit is tightly closed, the electric current supplied to the circuit will persist for as long as desired. Superconducting magnets are well suited for use in space because they consume very little power, and superconductors can operate at current densities which are much higher than conventional conductors (7).

To transport and deploy these magnets, solar sails could be an ideal solution. Solar sails utilize the pressure of light emitted by the sun to propel spacecraft. Solar sails eliminate the need for fuel as they rely on photons for movement (8). To supply energy to the magnets, solar panels can be used. When the sun shines onto a solar panel, energy from the sun-

https://doi.org/10.59720/23-181

Figure 1: A physical model that illustrates the idea of generating a magnetic field on Mars. The yellow sphere is the Sun. Colorful garlands are solar wind. The little green point is L1. The little red point is Mars. If a magnetic field is placed on L1, a solar wind that heads toward Mars will collide with the magnetic fields on L1 and leave Mars under protection.

light can be absorbed by the photovoltaic cells in the solar panels to convert sunlight directly into electricity (9,10). Lithium-ion batteries, known for their high energy storage capacity, efficiency, and relatively low mass, can store the energy harnessed by the solar panels. Energy of lithium-ion batteries can reach 130 W/kg or more, with an efficiency of 95% (11). However, one of the main advantages of lithium-ion batteries is their small mass compared to other batteries; minimizing mass is critical for achieving efficient fuel consumption and overall system performance

To ensure the stability of the magnet system, it has been proposed by James Lauer Green to launch the solar sail and magnets to L1. By establishing a magnetic system at L1, Mars can be shielded from solar wind for an extended period of time (4). The purpose of this work is to investigate the feasibility of protecting Mars from solar wind and radiation by generating an artificial magnetic field. In our study, we aimed to determine if our model could generate a magnetic field of 2 T, as hypothesized by James Lauer Green to be necessary for effectively protecting Mars from solar wind**.** The experiment demonstrates the feasibility of generating a magnetic field using superconducting magnets and solar sails and highlights the significance of L1 as a stable location for the magnet system. We identified L1 as a suitable location for the magnet system, determined the required current strength and parameters for the superconducting magnets, and evaluated conductive materials for their superconducting properties. Our findings that creating a 2 T magnetic field with our design hold promise for advancing our understanding of Mars colonization and motivate further research in the field.

RESULTS

Overall, our experiments were designed to test the hypothesis that there is a dependence between magnetic flux density and current. This investigation stems from our interest in exploring the feasibility of generating magnetic fields using superconducting magnets. Specifically, we sought to understand how variations in current affect magnetic flux density, which is crucial for optimizing the performance of such magnets. In this experiment, a circuit was activated by turning on the direct current source. Then, we measured magnetic flux density with a conditional teslameter and current with an ammeter while adjusting resistance using a rheostat **(Figure 2)**. Our results demonstrate a clear and expected dependence between current strength and magnetic flux density **(Figure 3)**. This experimental work serves as a foundational step for further calculations and practical applications involving superconducting magnets.

The experimental results (B/T) exhibit a consistent trend, decreasing from 1.50 T to 0.50 T in response with current strength **(Table 1)**. Notably, the values generally align with the corresponding theoretical predictions, but deviations are observed in certain instances, such as in experiments 2 and 3, where theoretical and practical results of magnetic flux do not align (**Figure 3**). Deviations indicate instrumental errors, environmental factors, and human errors. The comparison between experimental results and theoretical calculations served as a critical validation step, ensuring the accuracy of the experimental model. This verification process is essential for establishing the reliability of the experimental setup and the applicability of the coil magnetic induction formula in predicting magnetic field strength under varying current conditions.

The magnetic induction is required to calculate magnetic stress, which was found to be 1.6x10^{6} A/m. We calculated the coil size, current strength of the magnet to be 1.6x10^{4} A, and magnet power to be 512x10^{3} W. Subsequently, these values were employed to calculate the necessary area of solar panels, which are used for powering the proposed super magnets.

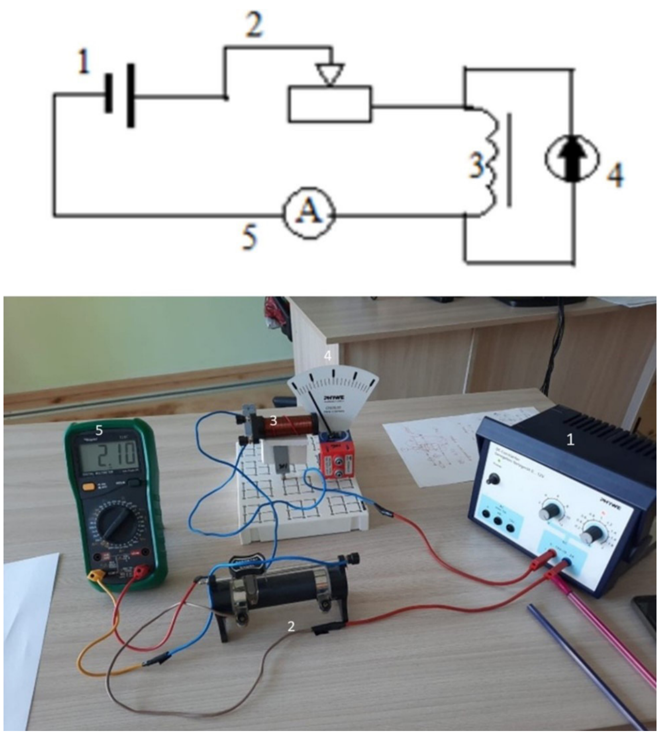

Figure 2: Experimental setup. This picture shows tools used in experiment. The experimental setup consisted of a circuit comprising a (1) current source, (2) resistor, (3) coil, (4) conditional teslometer, and (5) ammeter.

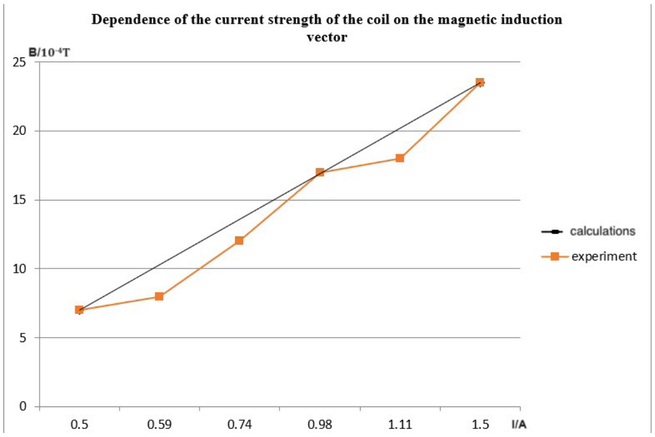

Figure 3: Dependence of the current strength of the coil on the magnetic induction vector. Despite minor fluctuations in the experimental data compared to the values predicted by calculations demonstrating the relationship between magnetic flux density and current remains important. The graph illustrates the relationship between current, I, and magnetic flux density, B, with likely calculated values represented by a curve.

The area of the solar panels is estimated at approximately 5804 m^2. By calculating the required strength density, we were able to identify a suitable material for a superconducting magnet. Based on our findings, a vanadium-gallium mixture exhibits the characteristics of a superconducting magnet (6).

DISCUSSION

Our findings corroborate the fundamental principles of electromagnetic theory. Specifically, we observed that an increase in current strength leads to a corresponding increase in magnetic induction. This relationship underscores the predictable nature of electromagnetic phenomena and validates the theoretical framework on which our experiment was based.

However, further investigation is needed to understand the slight disparities observed, particularly in experiments 2 and 3, where theoretical and experimental values of magnetic flux density diverge by 0.2x10^{-4} T and 1.3x10^{-4} T, respectively (**Table 1, Figure 3**). Deviations between experimental and theoretical values provide insights into model accuracy. Analysis of results may reveal factors like experimental error or calibration issues contributing to these deviations. These deviations may guide further refinement of the theoretical model.

These results, therefore, lay a robust foundation for future investigations and calculations. The demonstrated relationship between current strength and magnetic flux density opens avenues for more nuanced studies, contributing to the broader understanding of magnetic fields and their applications. Additionally, the successful validation of the theoretical model enhances the credibility of the methodology, underscoring its potential significance in practical applications and furthering advancements in related research endeavors.

Our study was conducted using a coil as a simplified simulation, and further research is essential to validate these results in a more realistic environment, for example outer space. Future work should consider disruptions such as the impact of solar wind and cosmic radiation. Our experiment could also benefit from an increased number of replicates to enhance the statistical robustness of the outcomes.

There are also practical limitations to consider regarding the feasibility of our research. Our calculations reveal that a considerable amount of wire will be needed to create the desired magnetic field. Subsequent experiments may delve into alternative coil configurations, varying the number of windings, launching methodologies, or different materials to optimize magnetic field generation at the Lagrange point (6). Even with sufficient financial resources, the challenges of launching such a colossal mass and size into space must be addressed. The feasibility of deploying necessary equipment and associated energy requirements should be explored for a more accurate understanding of the proposed magnetic field construction in the Martian environment. Finally, investigating the influence of temperature and external factors on magnetic field generation holds potential for practical applications.

In conclusion, our work effectively supports the positive correlation connection between magnetic field strength and coil current. Our findings have significant implications for the endeavor to generate a robust magnetic field at Mars's Lagrange point. Following Jim Green's proposed requirement for a magnetic induction of 2 T at L1, our method of calculating magnetic induction in the coil can serve as a basis for determining the construction specifications necessary to establish the magnetic field at this pivotal location (4). These applications extend to future space missions and the prospective colonization of the red planet.

MATERIALS AND METHODS

Experimental Setup

We used an electrical circuit consisting of a current source (JA-SI-8050), resistor (I# RM5000), coil (ElectraCoil X-200, Cat# ECX200), conditional teslameter, and ammeter (Tech-Probe Inc., Model# TP5000) (**Figure 2**). The experiment involved measuring the current strength of the coil and the magnetic induction vector while varying the resistance of the resistor.

According to the technical characteristics of the solenoid used in the experiment, the inductance, L=0.014 H; the number of windings, N=80, and the length, l = 63x10^{-3} m. Using these data, the magnetic induction, B, in the coil was calculated as

$$B = \frac{\mu 0 \cdot I \cdot N}{l} \qquad \text{(Eq. 1)}$$

№	**I (A)**	**Experimental B (T)**	**Calculated B (T)**	**Δx/10^{-4} (T)**	**(Δx/x)*100%**
1	1.50	23.5*10^{-4}	24.0*10^{-4}	0.50	2.08
2	1.11	18*10^{-4}	17.8*10^{-4}	0.20	1.12
3	0.98	17*10^{-4}	15.7*10^{-4}	1.30	8.28
4	0.74	12*10^{-4}	11.9*10^{-4}	0.10	0.84
5	0.59	8*10^{-4}	9.44*10^{-4}	1.44	15.3
6	0.50	7*10^{-4}	8.00*10^{-4}	1.00	12.5

Table 1: Theoretical and experimental values of magnetic induction as resistance changes. Comparison of the experimental and calculated values of magnetic flux density, B, for various values of current strength, I. The absolute error, Δx, and relative error, Δx/x, between the calculated data and data obtained through the experiment are also reported. I varied between 1.50 and 0.50 A, while B varied between 23.5x10^{-4} and 7x10^{-4} T.

where μ_0 is the magnetic constant, I is the current strength, N is the number of rolls, and l is the length of the coil.

$$B = \frac{\mu 0 \cdot I \cdot N}{l} = \frac{12.56 \cdot 10^{-7} \cdot 1.2 \cdot 80}{63 \cdot 10^{-3}} = 19.14 \cdot 10^{-4} T \qquad \text{(Eq. 2)}$$

Current strength of the coil and the magnetic induction vector were measured while changing the resistance of the resistor.

Calculations

Generating a strong magnetic field on the planet Mars requires a magnetic induction at L1 equal to 2 T (4). The magnetic stress, H, was calculated as follows from the magnetic induction vector, B, and the magnetic constant, μ0:

$$H = \frac{B}{\mu 0} = \frac{2}{12.56 \cdot 10^{-7}} = 1.6 \cdot 10^{6} A/m \qquad \text{(Eq. 3)}$$

The length of the rolls, L_{rolls} was calculated as follows from the length of the coil, L_{coil} = 5×10^5 cm, the diameter of the windings, d = 1 cm, and the diameter of the coil, D = 1×10^4 cm.

$$L_{rolls} = \pi D \frac{L_{coil}}{d} = 3.14 \cdot 10^{4} \cdot \frac{5 \cdot 10^{5}}{1} = 15.7 \cdot 10^{9} cm \qquad \text{(Eq. 4)}$$

Similarly, the number of wounds on the coil for the superconducting magnet was determined as follows:

$$N = \frac{l}{d} = \frac{5 \cdot 10^{3}}{0.01} = 5 \cdot 10^{5} \qquad \text{(Eq. 5)}$$

Previously calculated values were used to find the current strength as follows:

$$I = \frac{B \cdot l}{\mu 0 \cdot N} = \frac{2 \cdot 5000}{12.56 \cdot 10^{-7} \cdot 5 \cdot 10^{5}} = 1.6 \cdot 10^{4} A \qquad \text{(Eq. 6)}$$

The area of the superconducting magnet, S, was calculated as follows, where R is the radius of the coils:

$$S = \pi \cdot R^2 = 3.14 \cdot 0.25 cm^2 = 0.78 cm^2 \qquad \text{(Eq. 7)}$$

The resistance, R, of the superconducting magnet was calculated as follows, where ρ is the magnetic resistivity, l is the length of the rolls, and S is the cross sectional area of the superconducting magnet.

$$R = \rho \frac{l}{S} = 10^{-13} \cdot \frac{15.7 \cdot 10^{9}}{0.78} = 20 \cdot 10^{-4} \Omega \qquad \text{(Eq. 8)}$$

The voltage of the superconducting magnet, U, was calculated as follows, where I is the current strength and R is the resistance of the superconducting magnet:

$$U = I \cdot R = 1.6 \cdot 10^{4} \cdot 20 \cdot 10^{-4} = 32V \qquad \text{(Eq. 9)}$$

The power required for the magnet, W, was calculated as follows:

$$W = U \cdot I = 32 \cdot 1.6 \cdot 10^{4} = 512 \cdot 10^{3} W \qquad \text{(Eq. 10)}$$

The current strength density, j, was calculated as follows, where I is the current strength and A is the cross sectional area of the coil:

$$j = \frac{I}{A} = \frac{16 \cdot 10^{3}}{0.78 cm^2} = 2 \cdot 10^{4} A/cm^2 \qquad \text{(Eq. 11)}$$

Given a solar panel efficiency of 15%, the area of this solar panel was calculated using the formula given below, where A is the area of the solar sail, W is power, H_0 is intensity of a sun in W/m^2, and Ƞ is efficiency of the solar sail (14):

$$A = \frac{W}{H_0 \cdot \eta} = \frac{512 \cdot 10^{3}}{588 \cdot 0.15} = 5804 m^2 \qquad \text{(Eq. 12)}$$

The properties of conductive materials used for windings of superconducting magnets were evaluated. The distance from Mars to the L1 for the sun and Martian system was calculated using Kepler's law,

$$r = R^3 \frac{\sqrt{M_2}}{3M_1} \qquad \text{(Eq. 13)}$$

where r is the distance of L1 from Mars, R is the distance between the sun and Mars (R_{sun} = 228*10^9 m), M_1 is the mass of the Sun (M_1 = 1.98x10^{30} kg), and M_2 is the mass of Mars (M_2 = 6.39x10^{23} kg).

$$r = (228 \cdot 10^{9})^3 \frac{\sqrt{6.39 \cdot 10^{23}}}{3 \cdot 1.98 \cdot 10^{30}} = 1.08 \cdot 10^{9} m \qquad \text{(Eq. 14)}$$

Forces acting on Lagrange point to solar sail should be equal to each other, so the force of gravity and the centripetal force acting on Mars must be equal.

$$F1 = F2 \qquad \text{(Eq. 15)}$$

$$\frac{G M_1 m}{R^2} = \frac{m v^2}{R} \qquad \text{(Eq. 16)}$$

$$v = \sqrt{\frac{GM}{R}} \qquad \text{(Eq. 17)}$$

$$v = \sqrt{\frac{6.67 \cdot 10^{-11} \cdot 6.39 \cdot 10^{23}}{3.38 \cdot 10^{6}}} = 3.55 \text{km/s} \qquad \text{(Eq. 18)}$$

Where G is the gravitational constant, M is the mass of Mars, and R is the radius of Mars, and v is the speed of movement of the space sail.

Received: August 2, 2023
Accepted: December 5, 2023
Published: September 13, 2024

REFERENCES

1. Sutter, Paul M. "What's the Best Shielding to Protect Astronauts on Mars?" *Universe Today,* 20 Oct. 2022, www.universetoday.com/158091/whats-the-best-shielding-to-protect-astronauts-on-mars/. Accessed 18 June 2023.
2. Redd, Nola Taylor. "What Is Solar Wind?" *Space.com*, 19 May 2018, www.researchgate.net/publication/365186053_The_Solar_Winds_Cyber-Attack_the_Federal_and_Private_Sector_Response_and_the_Recommendations_and_Lessons_Learned
3. Lathrop, Daniel. "Daniel Lathrop's Nonlinear Dynamics Lab// MHD turbulence and dynamos-2013." complex.umd.edu
4. Green, J. L., et al. "A FUTURE MARSENVIRONMENT FOR SCIENCE AND EXPLORATION." *Planetary Science Vision 2050 Workshop, 2017.*
5. Park, Dongkeun, et al. "Design Overview of the MIT 1.3-Ghz LTS/HTS NMR Magnet with a New REBCO INSERT." *IEEE Transactions on Applied Superconductivity*, Aug.

2021, ieeexplore.ieee.org/abstract/document/9369840. Accessed 21 Oct. 2023.

6. “Superconducting magnets. Device and operation. Application.” *Electrosam*, 24 Oct. 2018, electrosam.ru/glavnaja/jelektrotehnika/sverkhprovodiashchie-magnity/. Accessed 18 June 2023.
7. Green, M. A. “Superconducting Magnets in Space.” *Superconducting Magnets in Space (Conference),* 1 Aug. 1989, https://www.osti.gov/servlets/purl/5486791. Accessed 21 Oct. 2023.
8. NASA to Begin Test of 20-Meter Solar Sail.” *Phys.org*, phys.org/news/2005-04-nasa-meter-solar.html. Accessed 11 July 2024.
9. “Photovoltaics and Electricity - U.S. Energy Information Administration (EIA).” www.eia.gov/energyexplained/solar/photovoltaics-and-electricity.php . Accessed 18 June 2023.
10. *Solar Energy Technologies Office*. “How Does Solar Work*?” Energy.gov*, U.S. Department of Energy, 2022, www.energy.gov/eere/solar/how-does-solar-work.
11. “Wayback Machine.” *Archive.org*, 2009, web.archive.org/web/20090326150713/www.pluginhighway.ca/PHEV2007/proceedings/PluginHwy_PHEV2007_PaperReviewed_Valoen.pdf.
12. Widnall, S. “Lecture L18 -Exploring the Neighborhood: The Restricted Three-Body Problem the Three-Body Problem.”*MITOpenCourseWare,* Fall 2008, ocw.mit.edu/courses/16-07-dynamics-fall-2009/841521e447f7e8ef98d92c4a9755eef2_MIT16_07F09_Lec18.pdf. Accessed 11 July 2024.
13. 13.enel x. “What Is Solar Panel Energy Efficiency?” *Enel X*, corporate.enelx.com/en/question-and-answers/are-solar-panels-energy-efficient.Accessed 11 July 2024.

Copyright: © 2024 Galymova, Anibayev, and Smagulova. All JEI articles are distributed under the attribution non-commercial, no derivative license (http://creativecommons.org/licenses/by-nc-nd/4.0/). This means that anyone is free to share, copy and distribute an unaltered article for non-commercial purposes provided the original author and source is credited.