Ricerche scientifiche e metodi della loro realizzazione:
esperienza mondiale e realtà domestiche

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IS IT POSSIBLE TO LIVE ON MERCURY?

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Abstract. *Mercury is the closest planet to the Sun, rotating in an elliptical orbit with an eccentricity of 0.2056. Therefore, the temperature at the subsolar point of Mercury is +410°C and +480°C at aphelion and perihelion, respectively; and before sunrise, the temperature at the equator drops to -183°C. This means that Mercury experiences the most dramatic temperature fluctuations in the Solar System. Mercury has a magnetic field with a strength of approximately 1% of Earth's. It traps a significant portion of the solar wind and cosmic radiation, reducing radiation on the planet's surface. However, the virtually complete absence of an atmosphere, its proximity to the Sun, and a day length of 59 Earth days pose serious obstacles to colonizing Mercury. Furthermore, Mercury is one of the most difficult planets to reach. The planet's surface heats up and cools down quickly; But even at a depth of 1 meter, diurnal temperature fluctuations are virtually nonexistent. Mercury's soil is believed to contain a large reserve of helium-3, which could become an important source of clean energy; Mercury may also contain large ore deposits accessible for mining; radar studies of the planet's polar regions have revealed the presence of water ice at the bottom of deep craters in both polar regions, where the Sun never shines. Conditions on Mercury are lethal to any protein-based life, with temperature fluctuations of approximately 650 degrees Celsius; and a standard spacesuit would be unable to withstand the powerful solar radiation. Therefore, human habitation would be possible only in a shelter with very thick walls on the planet's surface, or, better yet, beneath it. Near the poles, temperature fluctuations between day and night are not as noticeable as elsewhere on Mercury's surface. This makes the poles the most suitable location for establishing a habitable base. Even at a depth of 1 meter, the amplitude of diurnal temperature fluctuations is significantly reduced. At a certain distance from the surface, the fluctuations disappear completely, and a suitable average temperature is observed. Solving the problem of soil thermal conductivity on Mercury using the method of Academician V.A. Steklov, we found that for a latitude of |70-80°|, with a surface temperature difference ranging from +250°C to -210°C, the temperature*

below the surface at depths of 3-30 m will remain constant. Depending on latitude, the range of this constant temperature is within +(5□□□□□C. The area with such a comfortable temperature for biological life in the subsurface circumpolar areas is more than three million square kilometers. Thus, dozens of settlements could be located beneath Mercury's surface at depths of 3□30 m. The completed studies provide grounds to assert that beneath the surface of Mercury, in both its circumpolar regions, within latitudes from 70 to 80 degrees, there are zones with temperatures quite comfortable for human habitation. There, the temperature is constant and remains between +5 and +30□C.

Mercury is spherical in shape with an equatorial radius of R≈2440 km; this is approximately 2.6 times smaller than that of Earth. Mercury's mass is $M \approx 3.31 \cdot 10^{23}$ kg, which is approximately 18 times less than that of Earth; its average density is close to that of Earth and is $\rho \approx 5.44$ g/cm^3; the acceleration of gravity near the surface is $g \approx 3.7$ m/s^2, which is approximately 0.378 of that of Earth. Mercury is the closest planet to the Sun and revolves around it in an elliptical orbit with an eccentricity of 0.2056. This leads to a change in the distance to the Sun from 0.31 astronomical units (AU) at perihelion to 0.47 AU at aphelion. Therefore, the illumination of Mercury's subsolar point at aphelion is 4.6 times greater, and at perihelion 10.6 times greater, than at the subsolar point of Earth at a distance of 1 AU from the Sun. And the temperature at Mercury's subsolar point is +410°C and +480°C at aphelion and perihelion, respectively; before sunrise, the temperature at the equator drops to -183°C. The planet's proximity to the Sun and its relatively slow rotation, as well as its extremely thin atmosphere [11], lead to Mercury experiencing the most dramatic temperature variations in the Solar System; the average temperature of its daytime surface is 623 K (+350°C), while its nighttime surface is only 103 K (−170°C). Mercury has a massive iron core, which generates a noticeable magnetic field [12]. Its strength is approximately 1% of that of Earth's. Even this barrier blocks a significant portion of the solar wind and cosmic radiation, reducing radiation on the planet's surface. However, the virtually complete absence of an atmosphere, its extreme proximity to the Sun, and the long daylight hours (59 Earth days) pose serious obstacles to settling Mercury. Furthermore, Mercury is one of the most difficult planets to reach [5]. A flight from Earth to Mercury requires an energy expenditure comparable to a flight from Earth to Pluto. For example, to enter Mercury's orbit, the "Messenger" spacecraft [10] used six gravity assists. The planet's surface heats and cools rapidly, but at a depth of 1 m, diurnal fluctuations cease to be noticeable, and the temperature becomes stable at approximately 75 °C.

It is believed that Mercury's soil contains a large reserve of helium-3, which could become an important source of clean energy on Earth and a decisive factor in the future economic development of the solar system. In addition, Mercury may contain large ore reserves accessible for mining [4]. Radar studies of the planet's polar regions have revealed the presence of bright areas with depolarization ranging from 50 to 150 km in size in both polar regions of the planet [3]. The most likely candidate for the substance reflecting radio waves may be ordinary water ice. Water, arriving on Mercury's surface through impacts with cometary nuclei, evaporates and travels across the planet until it freezes in the polar regions at the bottom of deep craters, where the Sun never shines, and where the ice can persist indefinitely [15, 16]. It is believed that these areas may contain deposits of certain substances, including water ice, methane, carbon dioxide, and other substances similar to those found in craters near the south pole of the Moon [2]. Data obtained by the neutron spectrometer on board the "Messenger" probe confirmed these assumptions [4]. The most likely sources of volatiles on the surface are impacts from asteroids, comets, and meteorites [1]. The existence of such deposits is determined by their evaporation rate. Results from calculations of thermal conditions and illumination in several craters in Mercury's south polar region are presented in [6]. This allowed us to use data from [9] to study the stability of several volatile compounds, such as H_2O, CO, CO_2, CH_4, NH_3, H_2S, SO_2, C_2H_2, C_2H_4, and C_2H_6, in these regions. These results indicate that some of these compounds could persist for over a billion years on the surface in craters in permanently shadowed areas. If deposits of these volatile compounds are located beneath a layer of regolith, they could persist for even longer periods and at higher temperatures.

That is, despite Mercury's proximity to the Sun, ice caps have been theoretically predicted to exist at its poles. This makes the poles the most suitable location for establishing a colony. Furthermore, in the polar region, temperature fluctuations between day and night will be less noticeable than elsewhere on Mercury's surface. Due to some similarities, colonizing Mercury could be accomplished using essentially the same technologies, approaches, and equipment as colonizing the Moon. But Mercury is perhaps the most difficult planet in the Solar System to explore and colonize. A flight to Mercury requires a tremendous amount of energy. After all, traveling from Earth toward the Sun requires a significant change in orbital velocity. The conditions on Mercury are lethal to any protein-based life, with a temperature difference of approximately 650 degrees; and a standard spacesuit cannot withstand the powerful solar radiation. Therefore, human life would only be possible in a shelter with very thick walls on the planet's surface, or, better yet, beneath it. A spacecraft traveling to Mercury would also need to be equipped with powerful radiation shielding. Nevertheless, the task of delivering a human to Mercury and returning them is, in principle, feasible. Therefore, it is still possible and necessary to attempt to establish a habitable base on Mercury.

With a virtually nonexistent atmosphere, heat can only be transferred deep into the surface by conduction. It is well known that loose soil conducts heat very poorly. Therefore, already at a depth of 1 meter, the amplitude of diurnal temperature fluctuations decreases significantly. At a certain distance from the surface, the fluctuations disappear completely, and a uniform, consistent average annual temperature is observed. This phenomenon was discovered over 200 years ago by the French scientist Antoine Lavoisier. He demonstrated the year-round constancy of the temperature at +11.7°C at a depth of 28 meters below the Earth's surface near Paris. At the beginning of the 20th century, mathematician and academician V.A. Steklov solved a mathematical physics problem for the thermal conductivity of a semi-infinite rod. This solution was able to explain similar planetary phenomena.

Solving a similar problem for Mercury, using the temperature difference in the equatorial part of its surface, ranging from +430°C to -180°C, we obtained a surface temperature difference for a latitude of |80°| Between +250°C and -210°C (Table 1). It turned out that at latitudes of |70°C□85°C|, the subsurface temperature at depths of 3 to 30 m is guaranteed to be constant. And depending on latitude, the range of this constant temperature is +(5□35)°C. Moreover, the range of temperatures comfortable for biological life (in the range of +(15°C□25°C) for subsurface circumpolar areas is more than three million square kilometers. This is at least five times the size of Ukraine!

Table 1

Temperature values of maximum, minimum, average, and constant subsurface temperatures on the planet Mercury

φ,°	T_{max}°C	T_{min}°C	T_{avr}°C	T_{const}°C
0	+430	-180	+125	+50
30	+414	-195	+110	+40
50	+385	-205	+90	+30
70	+329	-215	+57	+27
80	+277	-220	+29	+15
85	+233	-225	+4	+2

Thus, dozens of under-surface settlements could be located at depths of 3-30 m beneath Mercury's surface [7, 8]. These include small "settlements" and even "cities." All that remains is to provide them with water and specialized spacesuits for long-term habitation and resource extraction. Therefore, work is now needed to create specialized symbiotic self-burrowing "cocoons" for equipping long-term Uuder-surface settlements, as well as to deploy closed, ring-shaped, circumpolar solar power grids for them. Based on available information about Mercury, which was received from two American spacecraft ("Mariner 10" in 1974-75 and "Messenger", which entered Mercury's orbit in March 2011), we investigated the fundamental possibility of the existence of regions with comfortable conditions for humans on a planet like Mercury. By comfortable habitable zones, we mean, first and foremost, the presence of a temperature regime on the planet in which humans feel comfortable [7, 8]. Such zones do not exist on the surface of Mercury; instead, they exist beneath its surface.

Our research suggests that beneath the surface of Mercury, in both its circumpolar regions, at latitudes between 70 and 80 degrees, there are zones with temperatures quite comfortable for human habitation. There, temperatures consistently range from +5 to +30°C. The above data indicate the need to devote increasing attention to the exploration of Mercury. For example, due to its proximity to the Sun, Mercury has significantly superior solar energy reserves compared to Mars. It is entirely possible that the current categorical opinion regarding the impossibility of human habitation on this planet may change. We believe that continued research in this area will be very interesting and promising.

Terraforming Mercury may be a more challenging task than terraforming the Moon, Mars, or even Venus [13, 14, 17, 18]. The greatest obstacles to terraforming Mercury are its close proximity to the Sun and its extremely slow rotation around its axis. The level of solar energy falling on Mercury's surface varies greatly, and depending on the season and latitude, ranges from 0 (in craters at the poles, which never see sunlight) to 11 kW/m² (for Earth and the Moon, it is about 1.36 kW/m²). Since Mercury's axis is tilted slightly to the axis of ecliptic [1], the polar elevations have mountain peaks with continuous illumination. It is also possible to construct a closed ring of solar power plants around the poles, capable of providing a continuous supply of energy. Mercury is a fairly dense planet and contains a large amount of metals (iron, nickel), and possibly a significant amount of nuclear fuel (uranium, thorium), which can be used for the exploration of the planet.

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