Title
Helium on venus: implications for uranium and thorium.

Permalink
https://escholarship.org/uc/item/1ct8m5vd

Journal
Science (New York, N.Y.), 220(4595)

ISSN
0036-8075

Authors
Prather, MJ
McElroy, MB

Publication Date
1983-04-01

DOI
10.1126/science.220.4595.410

Copyright Information
This work is made available under the terms of a Creative Commons Attribution License, available at https://creativecommons.org/licenses/by/4.0/

Peer reviewed
Helium on Venus: Implications for Uranium and Thorium

Abstract. Helium is removed at an average rate of 10^10 atoms per square centimeter per second from Venus's atmosphere by the solar wind following ionization above the plasmapause. The surface source of helium-4 on Venus is similar to that on Earth, suggesting comparable abundances of crustal uranium and thorium.

Studies of helium in Earth's atmosphere have a long and checkered history ([1-4], providing valuable information on escape, on the composition of the solid body, and on the processes regulating release of volatiles from the interior. The atmosphere contains 5.3 × 10^{-6} by volume of 4He, formed by decay of uranium and thorium in crustal rocks, and 6.6 × 10^{-12} by volume of 3He, for the most part primordial, emanating from tectonically active regions of the sea floor (5).

Helium escapes from the atmosphere predominantly by nonthermal mechanisms, mainly as He^+ along magnetic field lines open to the interplanetary medium at high latitudes—the polar wind (4). Escape is efficient and must balance production on timescales of the order of 10^7 years. The rate of production of 4He, 4 atoms per square centimeter per second, may be derived from measurements of the gas dissolved in the ocean, with independent information on the oceanic mixing time (3) and allowing for a small additional source from cosmic rays. The rate of escape, or equivalently production, of 4He may be obtained by scaling results for 3He, using the observed ratio of the gases in the atmosphere and correcting for minor enrichment of 3He above the turbopause (4, 6). The source derived in this fashion, 2 × 10^{6} cm^{-2} sec^{-1}, is in good agreement with limits established by MacDonald (2) from considerations of the planetary heat flux and available data for uranium, thorium, and potassium.

Helium was first observed as a component of Venus's atmosphere by Mariner 10 (7), and more extensive measurements were made by Pioneer 10. The abundance of 4He in the upper atmosphere is known quite accurately (±20 percent) from mass spectrometric measurements on the Pioneer orbiter (8) and bus (9). Combined data from the orbiter, bus, and probe (10) indicate a mixing ratio for the gas in the bulk atmosphere of 1.2 × 10^{-5} with an uncertainty of about a factor of 2.

Helium ionized above the plasmapause on Venus is swept off by the solar wind, as discussed by Dessler (11). The ionization rate may be calculated as described by McElroy et al. (12) for oxygen. Using ionization rates for helium of 3.4 × 10^{-7} sec^{-1} for photoionization (13) and 6.4 × 10^{-7} sec^{-1} for electron impact (14), and measured concentrations of 4He, we estimate a loss rate of 10^{6} cm^{-2} sec^{-1}. We assume that loss of helium from the nightside is trivial and use data from Brace et al. (15) to define an empirical model for the height of the plasmapause. Collisions between hot oxygen atoms and helium were shown by Knudsen (16) to be important for escape of helium from Mars. They are not directly important for escape of helium from Venus but contribute an additional 20 percent to the abundance of helium above the dayside plasmapause. The loss rate for helium may be defined as about the same precision as that for oxygen; in both cases the uncertainty is related primarily to definition of the mean position of the plasmapause. McElroy et al. (12) argued that the momentum flux of solar wind is balanced mainly by addition of mass as O^+, allowing an independent estimate for escape of oxygen. These considerations suggest that escape rates for oxygen, and by extension for 4He, are determined to an accuracy of about ±30 percent.

The rate for escape of 4He derived here (10^{6} cm^{-2} sec^{-1}), combined with the abundance inferred from Pioneer (1.8 × 10^{22} cm^{-2}), indicates a lifetime for 4He in Venus's atmosphere of 3.8 × 10^{13} yrs.
6 × 10^8 years, about 300 times longer than that for Earth. The longer lifetime for Venus reflects the higher abundance of 4He (factor of 100) and the lower escape efficiency (factor of 3). Escape from Venus is limited by the relatively small quantities of gas which extend above the plasmapause.

Venus has lost a quantity of 4He equivalent to 1.8 × 10^{22} cm^-2 over the past 6 × 10^8 years. The present atmospheric is unlikely to retain appreciable quantities of its initial helium—escape would lead to a reduction of the primordial abundance by a factor of 5 × 10^-4 (17). Contemporary escape should mirror the average quantity of 4He released by the solid planet over the past 10^9 years. The necessary source would be supplied by decay of uranium and thorium if the abundance of these elements in Venus's lithosphere were similar to that for Earth (18).

Venus's atmosphere also includes measurable quantities of 40Ar, formed by decay of 40K. The relative abundances of 40Ar in the terrestrial and Venus atmospheres suggest that the average source of 40Ar at Venus's surface is less than that for Earth by about a factor of 4 (19, 20). The lower release rate could reflect either smaller abundances of 40K or less efficient mechanisms for transfer of gas to the atmosphere. Measurements by Venera 13 and Venera 14 (21) suggest that potassium in Venus's surface material is similar to that for typical terrestrial basalts. In this case the lower abundance of 40Ar on Venus could be due to less efficient degassing, perhaps reflecting a reduced role for tectonic activity in the presence of high surface temperatures (22). However, we might expect a differential effect for helium. Helium can escape by molecular diffusion from a depth of 1 km on Venus, aided by the high surface temperature, while the corresponding diffusion length for Earth is only 400 cm (23).

In summary, Venus's atmosphere contains 160 times more 4He than the atmosphere of Earth. The source of 4He is similar in magnitude for both planets, suggesting comparable abundances of uranium and thorium. Independent arguments suggest that the two planets have similar abundances of potassium, and it follows that the magnitude of the planetary heat flux should be similar for both bodies. From these results, together with information for nitrogen (24), carbon, water (25), and noble gases (19), we conclude that Venus and Earth had similar origins. The high concentration of primordial noble gases on Venus is attributed to capture of solar wind material prior to planetary formation (19, 26), the low abundance of H_2O is due to escape of H and O (12, 25, 27) evidenced by enrichment of contemporary deuterium (28).

Michael J. Prather

Center for Earth and Planetary Physics, Harvard University, Cambridge, Massachusetts 02138

References and Notes


6. In initial calculations indicating significant thermal escape of 4He, unrealistically large values were assumed for the exospheric temperature (2).


17. The largest error in our calculated lifetime for atmospheric helium is related to the uncertainty (a factor of 2) in definition of the total atmospheric abundance. If the volume mixing ratio of helium were as large as 24 × 10^-4 the lifetime would be 1.2-1.5 years and the present abundance could have resulted from an initial concentration as low as 0.1 percent.


21. V. I. Moroz, report to COSPAR (the Committee on Space Research) (1983); see Science News 121, 214 (1982).


23. The diffusion coefficient for 4He is taken as 5 - 10^3 exp(-600/t) cm^2 sec^-1 based on W. G. Perkins and D. R. I. Begelau, J. Chem. Phys. 54, 1063 (1971). Ten kilometers of crust with 5 ppm of thorium and 1 ppm of uranium would produce 10^6 alpha particles per square centimeter per second. Additional mechanisms, such as shallow melting in the lithosphere (23), are needed to account for a helium flux of 10^-18 cm^-2 sec^-1.


29. Supported by NSF grant NSF-ATM-81-17009 and NASA grant NAGW-417.

12 October 1982; revised 1 February 1983

Desickling of Sickled Erythrocytes by Pulsed Radio-Frequency Field

Abstract. Electric fields were found to deform sickled erythrocytes. When the intensity of applied fields exceeded a threshold value, sickled erythrocytes transformed into a spherical shape. Prolonged application of the field usually caused hemolysis of erythrocytes. Deformation of red blood cells could be partly reversed if the field was turned off at an early stage. The cause of desickling may be the interaction of the field with the erythrocyte membrane and also with gelled intracellular hemoglobin S molecules.

In patients with sickle cell anemia, red cell sickling is caused by the intracellular polymerization of deoxy-hemoglobin-S molecules. This polymerization can be inhibited by chemicals that interact with the hemoglobin molecule (1, 2) or with the erythrocyte membrane (3, 4). Chemicals such as cetyltrimethylammonium chloride interact with the red cell membrane to increase water intake and inhibit red cell sickling at a concentration of 1 to 3 percent of intracellular hemoglobin (3, 5).

We report a method for reversing red cell sickling without using chemicals. We found that sickled cells were converted within several minutes to a spherical shape by the application of pulsed radio-frequency (RF) fields. Experiments were carried out by placing a suspension of sickled red blood cells in an isotonic saline solution between two parallel Pt-Ir wires (see legends to Figs. 1 and 2 for details). We chose a short pulse width of 5 msec with an interval of 1 second to