

Approximately 10 percent of the fluence was composed of neutrons with energies of 3 Mev or greater. The effects of this irradiation on the bulk coercive force and the a-c demagnetization spectrum of saturation isothermal remanence are summarized in Table 1 and Fig. 1, respectively. Increases in coercive force are substantial for both pure iron and kamacite. The larger increase in iron is probably due to its more complete state of anneal rather than to any compositional effect.

Two important conclusions can be drawn from the a-c demagnetization experiments. First, strong isothermal remanence is not destroyed by the flux of thermal neutrons or by the lattice damage produced by the high-energy neutrons; second, the coercive force of the isothermal remanence is increased. In fact, the reactor irradiation in this experiment decreased the intensity of the preirradiation saturation isothermal remanence by only 10 percent, whereas it *increased* the intensity of remanence with coercivity greater than 100 oersteds by 5 percent. This appears (Fig. 1) as a shift of the a-c demagnetization curve toward higher fields. Apparently the lattice damage has resulted in stronger pinning of some of the domain walls responsible for the original remanence. The introduction of anisotropic defects may also have produced an anisotropy that favors the domain configuration present during the irradiation.

Our conclusion is that the stability of isothermal remanence in meteorites and lunar lava samples may be increased by neutron irradiation of the type encountered during cosmic-ray exposure. Whether this process can account for the natural remanence of such samples depends on the answer to two questions. The first is whether the process here reported also occurs in samples with higher initial coercivities such as those found in meteorites and lunar samples. Experiments to determine this are in progress. The second is whether a mechanism exists by which the samples may acquire initial isothermal remanence. A possible mechanism is the production of interplanetary magnetic fields of from 10 to 20 gauss by strong solar magnetic flares, as has been proposed by Sonnet *et al.* (8). Only one such magnetic pulse would be needed during the history of the solar system if it occurred after the time of formation of the youngest lunar lavas. Subsequent conversion to more stable remanence

would then occur during exposure to cosmic radiation.

This explanation of natural remanence in chondritic meteorites and lunar samples does not require the possession of a magnetic field by the parent bodies. Natural remanence in chondritic meteorites has previously been considered as evidence that meteorites were derived from a lunar-sized parent planet whose iron-nickel core acted as a magnetohydrodynamic generator (9). The theory that meteorites originated in such a parent body was advanced by Ringwood (10). The findings of this report could bring paleomagnetic evidence into accord with the theory of meteorite origin proposed by Wood (11). The parent bodies in Wood's theory are asteroidal in size and would not be expected to possess a magnetic field. The present mechanism differs from earlier ones in not requiring a planetary magnetic field in each of the meteorite bodies.

If the remanent magnetization of lunar lavas is thermoremanence, then it is necessary to assume that a magnetic field existed at the time of formation of *each* of the lavas. Since the ages of the Apollo 11 and Apollo 12 lavas are approximately 3.6 and 3.3 billion years, respectively (12), the thermoremanence mechanism requires that the field, if it was not intermittent, persisted for an interval of at least 300 million years. The source of such a continuing field might be either the earth's field during a close orbit of the moon (which is unlikely) or a magnetohydrodynamic generator in a fluid lunar core. However, if the remanence of the lunar lavas was acquired by the

mechanism advanced in this report, only one magnetic pulse is required at some time subsequent to the age of the youngest lunar lavas.

ROBERT F. BUTLER

ALLAN V. COX

Department of Geophysics, Stanford University, Stanford, California 94305

References and Notes

1. Results of several investigations of the magnetic effects of low-energy neutron irradiation on industrially important ferromagnetic materials have been reported [D. Gordon, R. Sery R. Fischell, *Nucleonics* 16, 73 (1958); R. Sery and D. Gordon, *Bull. Amer. Phys. Soc. Ser. 2* 3, 117 (1959)]. Large increases in coercivity were observed in materials with initially low coercive forces and high permeabilities. Permanent magnet materials were not affected by thermal neutron irradiation. An experiment on the influence of γ -radiation on viscous remanent magnetization of several rock specimens has recently been reported [S. Brodskaya, *Izv. Acad. Sci. USSR Phys. Solid Earth*, No. 7, 442 (1970)].
2. G. Biorci, A. Ferro, G. Montalenti, *J. Appl. Phys.* 31, 2046 (1960); *Nuovo Cimento* 20, 617 (1961). It should be noted that the fast fluence employed in these experiments is much larger than used in the present study. The iron used was also more severely annealed than the samples used in the present experiment.
3. C. Waddington, *Progr. Nucl. Phys.* 8, 1 (1960).
4. O. Eugster, F. Tera, D. Burnett, G. Wasserburg, *J. Geophys. Res.* 75, 2753 (1970).
5. G. J. Dienes and G. H. Vineyard, *Radiation Effects in Solids* (Interscience, New York, 1957), pp. 1-89.
6. D. S. Billington and J. H. Crawford, Jr., *Radiation Damage in Solids* (Princeton Univ. Press, Princeton, N.J., 1961), pp. 11-54.
7. V. Penkovskii, *Effect of Radiation on Metals* (Elsevier, New York, 1964), pp. 1-28.
8. C. Sonnet, D. Colburn, K. Schwartz, K. Keil, *Astrophys. Space Sci.* 7, 446 (1970).
9. F. Stacey, J. Lovering, L. Parry, *J. Geophys. Res.* 66, 1523 (1961).
10. A. Ringwood, *Geochim. Cosmochim. Acta* 24, 159 (1959).
11. J. Wood, *Icarus* 6, 1 (1967).
12. D. A. Papanastassiou and G. J. Wasserburg, *Earth Planet. Sci. Lett.* 8, 269 (1970).
13. We thank P. Kraker of the Reactor Support Project of the U.S. Geological Survey for assistance in sample irradiation, and S. Banerjee for helpful discussions of the project.

16 February 1971

Mariner 6 and Mariner 7 Ultraviolet Spectrometer:

In-Flight Measurements of Simulated Jupiter Atmosphere

Abstract. *An experiment has been performed in interplanetary space which closely simulates the observations that would be made by an ultraviolet spectrometer observing the atmospheres of the jovian planets. A mixture of ammonia, nitrogen, and hydrogen was released from the Mariner spacecraft, and spectra were recorded while these gases were illuminated by sunlight. The principal emissions observed were the H I 1216-angstrom Lyman- α line, the H₂ B-X Lyman bands, and the NH c-a and A-X bands.*

In December 1970, experiments were performed by the Mariner 6 and Mariner 7 spacecraft to simulate the ultraviolet spectrum that would be viewed by an ultraviolet spectrometer observing Jupiter or the other outer planets. The Mariner spacecraft were

in interplanetary flight 240 million km from Earth and 120 million km from the sun nearly in the plane of the ecliptic, after having made measurements on Mars 16 months earlier.

Sunlit gaseous dissociation products of the course-correction motor on the

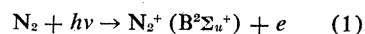
spacecraft were observed in the ultraviolet. Approximately 250 moles of liquid hydrazine (N_2H_4) was dissociated during the motor operation, which lasted about 80 seconds on each spacecraft. The products of the motor operation as determined in vacuum chamber tests are 25 percent NH_3 , 46 percent H_2 , and 29 percent N_2 , with the concentrations of N, H, NH , and NH_2 less than 50 parts per million. The hydrazine used in flight had 0.5 percent water present as an impurity. The dissociation products emerged as a directed supersonic stream from an expansion nozzle at a kinetic temperature of less than 200°K and a density low enough so that collisions are negligible.

The energy released during the motor operation is small enough so that ionization does not occur. The large number of collisions that take place before the gas enters the expansion nozzle ensures that the products are in their ground electronic states.

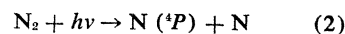
On both spacecraft the ultraviolet spectrometer was operated before, during, and after the motor operation. These spectrometers, which had previously been used to observe the atmosphere of Mars, scan the two spectral regions 1100 to 2100 Å and 1900 to 4300 Å simultaneously every 3 seconds (1). The spectral resolution of these instruments is 20 Å in the longer wavelength region and 10 Å in the shorter.

During the experiment the sunlit gases released by the motor were observed by the spectrometer in a plane approximately perpendicular to the sun-spacecraft line. In Fig. 1 the sum of ten spectra obtained by the Mariner 7 spectrometer while viewing the gas stream is shown. A Lyman- α signal, greatly enhanced above the sky background (2), and the Lyman bands ($\text{B}^1\Sigma_u^+ - \text{X}^1\Sigma_g^+$) of molecular hydrogen are present in the wavelength region 1100 to 1900 Å. These were identified by comparison with a laboratory spectrum of molecular hydrogen excited with 20-ev electrons. This comparison spectrum was obtained with a flight prototype instrument in preparation for the Mariner mission. The 1200-Å resonance line of atomic nitrogen is present as an unresolved wing on the Lyman- α feature. The features in the 1900- to 4300-Å spectral region are the first negative system of N_2^+ ($\text{B}^2\Sigma_u^+ - \text{X}^2\Sigma_g^+$) and bands of the $\text{A}^3\Pi - \text{X}^3\Sigma^-$ and $\text{c}^1\Pi - \text{a}^1\Delta$ systems of NH . This spectrum is similar to the one that Smith (3) obtained by exciting NH_3 with 150-ev electrons.

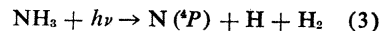
All these emissions, with the exception of the very small contribution to the Lyman- α line by the sky background, are believed to be due to the action of sunlight on NH_3 , N_2 , H_2 , and possibly H_2O , the gases released during motor operation. Solar radiation produces a strong ultraviolet airglow on Earth and on Mars (4). In this experiment, the N_2^+ first negative bands are probably produced by photoionization excitation of molecular nitrogen:



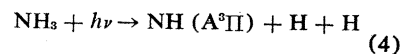
This process occurs in the Earth's atmosphere (5). The atomic nitrogen resonance line may be produced by photodissociative excitation of either molecular nitrogen or ammonia:



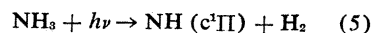
or



The NH ($\text{A}^3\Pi$) and NH ($\text{c}^1\Pi$) excited states are most likely produced by photodissociative excitation of ammonia:



and



Mechanisms of this type have been measured in the laboratory by Okabe and Lenzi (6). The H_2 Lyman bands

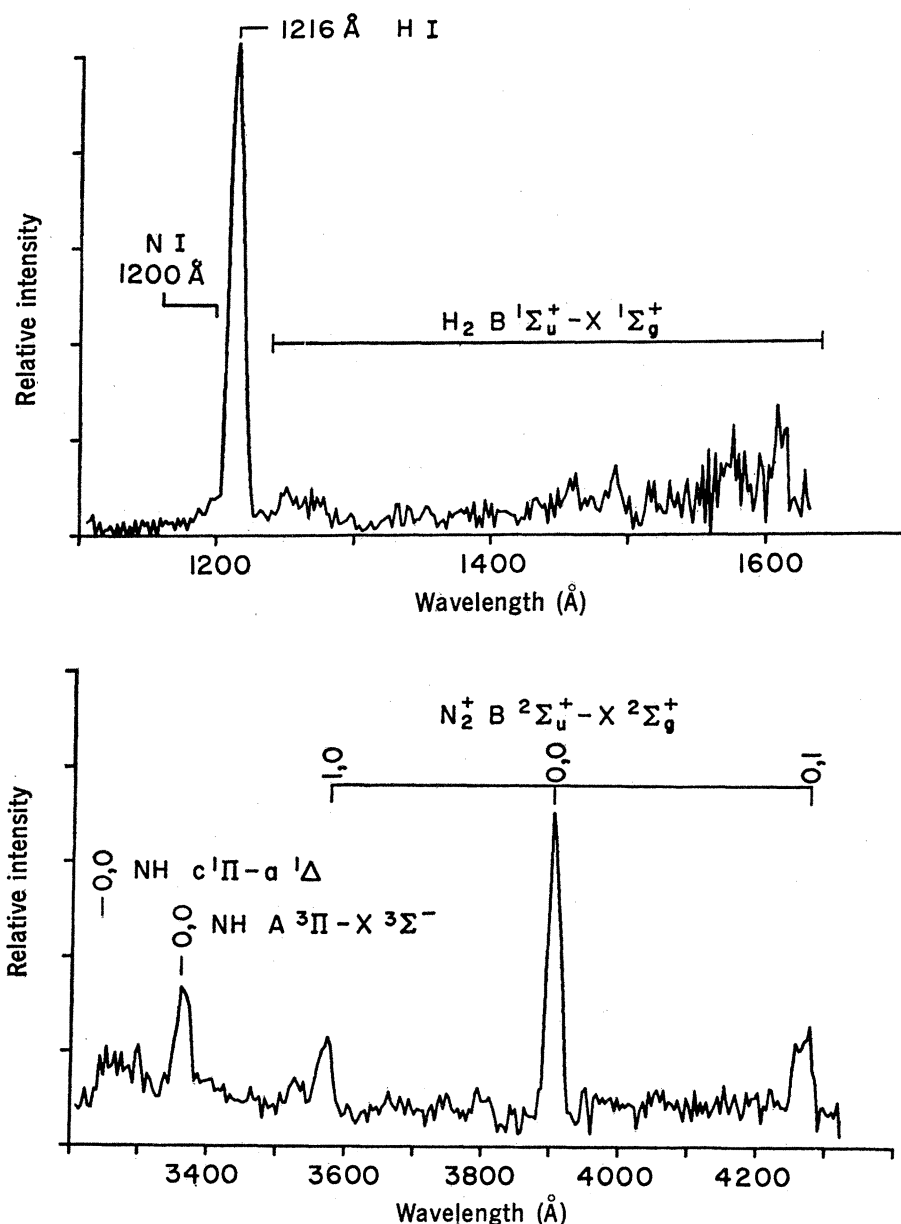
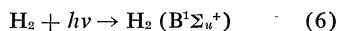
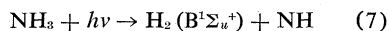


Fig. 1. The ultraviolet spectrum of the sunlit gases NH_3 , N_2 , and H_2 released from Mariner 7 in interplanetary space. The resolution is 10 Å in the upper spectrum and 20 Å in the lower spectrum.

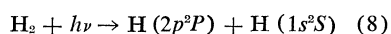
($B^1\Sigma_u^+-X^1\Sigma_g^+$) may arise from fluorescent scattering by molecular hydrogen or the photodissociative excitation of ammonia:



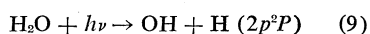
or



The Lyman- α line originates from the photodissociative excitation of NH_3 , from the resonance scattering of solar Lyman- α radiation by atomic hydrogen, or from the photodissociative excitation of molecular hydrogen:



In addition, the Lyman- α line could be produced by photodissociative excitation of any water vapor that might be present in the effluent gas:



These observations demonstrate the usefulness of making ultraviolet spectroscopic measurements of the atmospheres of the jovian planets. Fluorescence in the molecular hydrogen Lyman bands can be measured against the dark background produced by NH_3 and CH_4 which strongly absorb at wavelengths shortward of 1800 Å. All the emissions observed in this experiment can be measured on the limb and

terminator of the planets. Airglow observations of this type may be used to determine the structure of the atmosphere, as has been done for Mars (4, 7).

J. B. PEARCE

Department of Astro-Geophysics and Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder 80302

A. L. LANE

Space Sciences Division, Jet Propulsion Laboratory, Pasadena, California 91103

K. K. KELLY, C. A. BARTH
Department of Astro-Geophysics and Laboratory for Atmospheric and Space Physics, University of Colorado

References and Notes

1. J. B. Pearce, *et al.*, *Appl. Opt.* **10**, 805 (1971).
2. C. A. Barth, *Astrophys. J.* **161**, L181 (1970).
3. W. H. Smith, *J. Chem. Phys.* **51**, 520 (1969).
4. C. A. Barth, *et al.*, *Science* **165**, 1005 (1969); C. A. Barth, *et al.*, *J. Geophys. Res.* **76**, 2213 (1971).
5. L. Wallace and M. B. McElroy, *Planet. Space Sci.* **14**, 677 (1966).
6. H. Okabe and M. Lenzi, *J. Chem. Phys.* **47**, 5241 (1967).
7. We thank J. Casani, N. Medici, D. Beauchamp, E. Goldyn, R. Rowley, and D. Preska of the Jet Propulsion Laboratory's Mariner 6 and Mariner 7 staff for the considerable effort necessary to perform these experiments. We also thank H. P. Broida and G. M. Lawrence for aid in making the spectroscopic identifications. Supported by NASA grant NGL 06-003-052 and NASA contract NAS-7-100.

22 January 1971

Carbon Monoxide in Rainwater

Abstract. Concentrations of carbon monoxide in rainwater collected at widely diverse locations show up to a 200-fold supersaturation relative to the partial pressure of the gas in the atmosphere. These results indicate the existence of an additional natural source of carbon monoxide not heretofore considered. Production of carbon monoxide in clouds is tentatively attributed to the photochemical oxidation of organic matter or the slight dissociation of carbon dioxide induced by electrical discharges, or both. Methane concentrations measured in the same rainwater show that the partitioning of this gas, unlike that of carbon monoxide, is very close to a state of equilibrium.

During the past several years a number of reports have appeared on the origin and fate of atmospheric carbon monoxide. Although there is general agreement that the residence time of carbon monoxide in the atmosphere is short, it is not yet possible to specify completely the various sources and sinks which play essential roles in its geochemical cycle. In particular, it now appears that natural sources can no longer be neglected. Measurements in the Atlantic Ocean (1-3) have shown that the ocean is an important natural source of this gas; recent measurements made by us in the Pacific (4) have con-

firmed this conclusion. It is quite likely that the oceans may be the largest natural source of carbon monoxide. A conservative estimate shows that oceanic carbon monoxide, as a lower limit, contributes at least 5 percent of the amount generated by the burning of fuels by man (2); the correct value is probably much higher.

There are other natural sources which have not as yet been clearly identified. We report here the results of a series of measurements on carbon monoxide in rainwater. These measurements show a high degree of supersaturation of carbon monoxide in rain-

water, relative to the partial pressure of carbon monoxide in the atmosphere, and indicate the possible existence of an additional natural source not heretofore considered. For purposes of comparison, methane measurements made at the same time are also reported; these show that, unlike carbon monoxide, methane partition between rainwater and the atmosphere is close to a state of equilibrium.

The rainwater and air samples were collected at three different locations—in Washington, D.C., over the Pacific Ocean, and on the island of Hawaii. In Washington the rain was collected at rooftop level at the Naval Research Laboratory (NRL) by means of a V-shaped trough, inclined at a 20° slope so that the rain could be easily collected in a glass sample bottle. In a moderate rainfall, filling of the bottle took less than 2 minutes. Samples of air were taken simultaneously at the same location. Samples over the Pacific were taken aboard ship by means of the same collection technique while en route from Panama to Hawaii in June 1970. Care was taken to place the V-shaped trough well forward of the ship's stacks; during collection of the samples, the ship was always headed into the wind. Both in Washington and aboard ship, all samples were analyzed immediately after collection.

On the island of Hawaii, samples were collected at two locations, the Cloud Physics Observatory (CPO) on the Hilo campus of the University of Hawaii (5), and along Saddle Road which runs between the volcanic peaks of Mauna Loa and Mauna Kea. Samples were collected during the period from 16 to 22 June 1970. Saddle Road is an excellent sampling site in the interior of the island with minimum danger of pollution, since there is very little traffic during the day and virtually none at night. Sampling sites along this road were located along the windward side, facing the oncoming trade winds, and at a considerable distance upward from the active volcano sites on Mauna Loa. Orographic rain samples were taken at various altitudes, ranging from 1500 to 5000 feet (460 to 1500 m) above sea level. Several of the samples, both rainwater and air, were taken within the clouds, which in the interior are generally found at altitudes between 2000 and 5000 feet. Samples collected at CPO were analyzed immediately; those collected along Saddle Road were analyzed at the CPO laboratory within 1 to 2 hours after collection.