

## 12. The Solar-Wind Composition Experiment

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Measurements of the relative ion abundances in the solar wind give information on the dynamics of the solar corona and constitute an important method for investigating elemental and isotopic abundances in the outer convective zone of the Sun. Furthermore, solar-wind-abundance data are essential for a detailed interpretation of the trapped gases in meteorites and lunar material. Based on these investigations, the evolution of the lunar surface and a possible transient lunar atmosphere can be studied. Noble-gas studies of the solar wind may also help in tracing the evolution of the terrestrial atmosphere.

It has been known for several years that the helium/hydrogen (He/H) ratio in the solar wind is highly variable and ranges from less than 0.01 to 0.25, with an average of approximately 0.04 (refs. 12-1 to 12-5). During periods of low solar-wind-ion temperature, the elements oxygen, silicon, and iron have been measured by means of the high-resolution electrostatic analyzers on board the Vela satellites and, in some cases, even <sup>3</sup>He has been detected (refs. 12-6 and 12-7). In the Apollo program, a different technique is used for studying elemental and isotopic abundances in the solar wind.

During the Apollo 11, 12, and 14 missions, aluminum foils were deployed at the lunar surface and used as targets for collecting solar-wind ions. The foils were returned to Earth, and the implanted solar-wind particles are being analyzed in the laboratory. The Apollo 11 and 12 solar-wind composition (SWC) experiments have so

far yielded absolute solar-wind fluxes of <sup>4</sup>He, <sup>3</sup>He, neon-20 (<sup>20</sup>Ne), and <sup>22</sup>Ne (refs. 12-8 and 12-9). In the case of the Apollo 12 experiment, an approximate figure for the abundance of <sup>22</sup>Ne was also obtained. In this report, preliminary results of the first analyses on sections of the Apollo 14 foil are presented.

Proton detectors and magnetometers have been used to establish that the Moon behaves like a passive obstacle to the solar wind, and no evidence of a lunar bow shock has been found (refs. 12-10 to 12-13).<sup>1</sup> Thus, during the normal lunar day, the solar-wind particles strike the lunar surface with essentially unchanged direction and energy, except perhaps in a few places where local magnetic fields are unusually high (ref. 12-14). It was, in fact, shown from the Apollo 11 and 12 SWC experiment data that He reaches the lunar surface in an undisturbed, highly directional flow (refs. 12-8 and 12-9). The Apollo 12 solar-wind spectrometer has recorded the plasma flow that arrives at the Apollo 12 lunar-surface experiments package site as a function of phase of the lunar day. The result is that, most of the time, the plasma flux is not affected by the proximity of the surface of the Moon.<sup>1</sup> Thus, the expectation is that experiments deployed on the lunar surface will yield solar-wind-abundance data that are valid for the undisturbed solar wind.

<sup>1</sup> D. R. Clay, M. Neugebauer, and C. W. Snyder: Solar Wind Observations on the Lunar Surface With the Apollo 12 ALSEP. Proc. Apollo 12 Lunar Sci. Conf. (Houston), Jan. 11-14, 1971. To be published in *Geochim. Cosmochim. Acta*.

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### Principle of the Experiment

An aluminum foil 30 cm wide and approximately 140 cm long, with an area of approximately 4000 cm<sup>2</sup>, was exposed to the solar wind at the lunar surface by the Apollo 14 crew on February 5, 1971, at 15:16 G.m.t. The foil was positioned perpendicular to the solar rays in the azimuthal direction (fig. 12-1), exposed for 21 hr, and returned to Earth. Laboratory experiments have determined that solar-wind ions arriving with an energy of approximately 1 keV/nucleon penetrate approximately 10<sup>-5</sup> cm into the foil (ref. 12-15), and a large and well-known fraction is firmly trapped (refs. 12-16 and 12-17). In the laboratory, the returned foil is analyzed for trapped solar-wind noble-gas atoms. Parts of the foil are melted in ultra-high-vacuum systems, and the noble-gas atoms of solar-wind origin thus released are analyzed with mass spectrometers for elemental abundance and isotopic composition. Further details of the principle and the procedures of this experiment have been discussed elsewhere (refs. 12-16, 12-18, and 12-19).

In addition to the solar-wind investigations, a search will be made for radon (Rn) emanating from the Moon by using a small portion of the

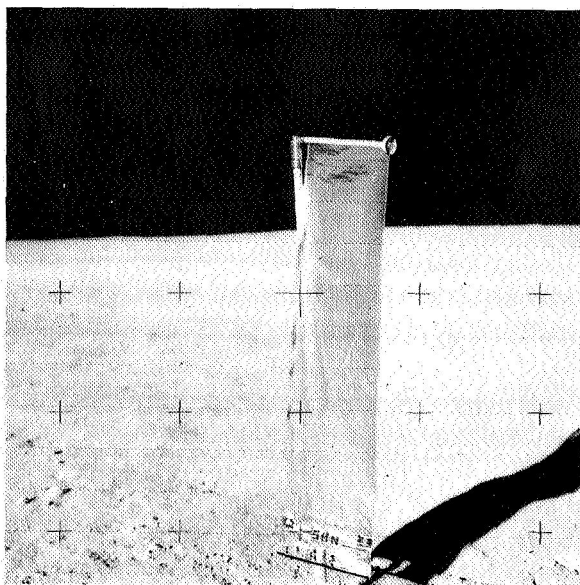


FIGURE 12-1.—Apollo 14 SWC experiment deployed on the lunar surface (AS14-64-9199).

Apollo 14 SWC foil. When Rn decays in the very thin lunar atmosphere, the recoil energy of the daughter nuclides is sufficient that any such atom striking the foil becomes firmly trapped. In the foil, the Rn decay product lead-210 will be searched for and, if found, its concentration will be determined to derive the ambient Rn concentration in the lunar atmosphere.

### Instrumentation and Lunar-Surface Operation

The experiment hardware was similar to the hardware used on the Apollo 11 and 12 missions (ref. 12-19). The experiment consisted of a metallic telescopic pole approximately 4 cm in diameter and 38 cm in length when collapsed. In the stowed position, the foil was enclosed in the tubing and rolled up on a spring-driven reel. The instrument weighed 430 g. When extended on the lunar surface, the pole was approximately 1.5 m long and a 30- by 125-cm foil area was exposed. Only the foil assembly was recovered at the end of the lunar-exposure period; it was rolled on the spring-driven reel and returned to Earth. The instrument is shown deployed on the lunar surface at the Apollo 14 landing site in figure 12-1. For the Apollo 14 SWC instrument, the reel handle was color coded to give the exact angular position during exposure of the reel and the portion of foil rolled around it. Detailed analyses of this portion of the foil are intended to yield the angular distribution of the arriving solar-wind ions. After evaluation of a number of Apollo 14 photographs, it was concluded that the foil was standing vertically (within a few degrees) at the lunar surface.

After retrieval, the return unit was placed in a special Teflon bag and returned to Earth in the interim stowage assembly. In the Lunar Receiving Laboratory (LRL) quarantine area, the foil was removed from the Teflon bag and found to be in good condition. No dust was detected on the foil with the unaided eye. The foil and reel were subsequently placed in a container and stored in the LRL crew reception area during the quarantine period.

### Preliminary Results

The Apollo 14 foil was made available for analysis after the lifting of the quarantine in early

TABLE 12-I. *First Preliminary Results From the Analyses of the Foil From the Apollo 14 SWC Experiment*

Sample no.	Area, cm <sup>2</sup>	<sup>4</sup> He concentration, × 10 <sup>10</sup> atoms/cm <sup>2</sup>	<sup>4</sup> He/ <sup>3</sup> He	<sup>4</sup> He/ <sup>20</sup> Ne	<sup>20</sup> Ne/ <sup>22</sup> Ne	<sup>20</sup> Ne/ <sup>36</sup> Ar
4-2.....	9.6	27.6	2360	460	13.2	34
4-3 <sup>a</sup> .....	10.0	26.8	2240	520	14.0	33
4-4 <sup>a</sup> .....	10.0	26.5	2280	500	13.5	38
4-5.....	20.7	25.9	2240	480	13.6	37
5-1.....	10.0	24.5	2300	480	13.9	40

<sup>a</sup> Oxide layer removed on back side of foil.

April. For the initial analyses, five small pieces from the upper part of the foil were decontaminated by means of the ultrasonic treatments that had proven effective during the Apollo 11 and 12 SWC experiment analyses. The results of these first measurements are presented in table 12-I. The data given should be considered as preliminary, because recalibration of the gas standards and reevaluation of the mass-spectrometer charts could lead to somewhat different final results. Along with these measurements on the flight foil, numerous pieces that had been cut from the Apollo 14 foil before flight for the purpose of noble-gas blank measurements were analyzed. The blanks that had been determined in this way were subtracted from the noble-gas concentrations measured in the pieces of the flight foil, and the solar-wind-particle concentrations presented in table 12-I were obtained. The foil blanks for He and Ne were 0.1 and 7 percent, respectively, relative to the solar-wind-particle content.

The oxide layer on the back side was removed from two of the investigated pieces of the Apollo 14 foil before analysis. The expectation was that this procedure would reduce a possible residual-dust contamination. Examinations of contaminated portions of the Apollo 12 foil have shown that, after ultrasonic treatment, 50 to 80 percent of the residual dust was located on the back side of the foil.

For the He and Ne isotopes, the results from the five foil pieces are in good agreement. This agreement is further evidence that the He and Ne data given in table 12-I are not appreciably affected by a residual-dust contamination. Further

analyses will be conducted to substantiate this conclusion. In particular, measurements on a shielded portion of the flight foil and on the section of the foil that had been exposed on the back side of the reel (facing away from the Sun) will be used to demonstrate the absence of significant lunar-dust contamination.

Neon-21 has been detected in the five foil pieces listed in table 12-I. Within the limits of error, the <sup>21</sup>Ne data agree with the results obtained from the Apollo 12 SWC experiment (ref. 12-9). By using larger portions of the foil, it is expected that the <sup>21</sup>Ne abundance can be determined from the Apollo 14 SWC experiment with good accuracy. To obtain the <sup>4</sup>He/<sup>20</sup>Ne ratio in the solar wind, the data given in table 12-I must be corrected for the difference in the He- and Ne-trapping efficiencies. A preliminary <sup>4</sup>He/<sup>20</sup>Ne value of 550 has been obtained.

The argon (Ar) content of the solar wind has been determined for the first time. For <sup>36</sup>Ar and <sup>38</sup>Ar, the foil blank is actually higher than the solar-wind-particle content. However, in this case, the blank can be uniquely determined for each analyzed foil piece from the <sup>40</sup>Ar content. Virtually all the <sup>40</sup>Ar that was detected in the foil is of atmospheric origin, because the <sup>40</sup>Ar/<sup>38</sup>Ar ratio of 295 in terrestrial Ar is much larger than the solar-wind <sup>40</sup>Ar/<sup>38</sup>Ar ratio, which is estimated to be smaller than unity (refs. 12-20 and 12-21). The <sup>40</sup>Ar/<sup>38</sup>Ar ratios that were actually measured in the foil pieces range from 240 to 260 (i.e., between 10 and 20 percent of the <sup>38</sup>Ar was of solar-wind origin). The solar-wind <sup>38</sup>Ar concentrations obtained after blank correction are used to calcu-

late the  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios given in table 12-I. Argon-38 has also been detected in the five foil pieces that have been analyzed. Values between 4.2 and 5.9 for the  $^{38}\text{Ar}-^{38}\text{Ar}$  ratio were obtained. This ratio will be determined more accurately by analysis of the Ar contained in larger pieces of the foil.

The  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios in the five foil pieces agree within  $\pm 10$  percent. This variation corresponds approximately to the analytical errors. It should be noted in particular that the Ar concentration is not reduced by the removal of the oxide layer on the back side of the foil. On the basis of this observation, it is estimated that a possible residual-dust contamination has not greatly affected the five  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios given in table 12-I. By taking the average of the measured  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios for the five foil pieces, an estimated value of  $37_{-5}^{+10}$  is obtained for the  $^{20}\text{Ne}/^{38}\text{Ar}$  ratio in the solar wind during the Apollo 14 foil exposure. This value is much higher than the  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios (between 5 and 10) found in unseparated lunar dust. In ilmenite samples that have been separated from the Apollo 11 lunar-fines material,  $^{20}\text{Ne}/^{38}\text{Ar}$  ratios between 25 and 33 have been found (ref. 12-21). The ilmenite values are fairly close to the values obtained from the Apollo 14 SWC experiment and indicate that the composition of the trapped solar-wind particles in ilmenite is much less affected by diffusion or other processes than is the composition in the bulk material.

The  $^{20}\text{Ne}/^{38}\text{Ar}$  ratio of 37 is considerably higher than solar-corona values and cosmic-abundance estimates. Measurements on forbidden lines and ultraviolet analysis (ref. 12-22) indicate that a  $^{20}\text{Ne}/^{38}\text{Ar}$  ratio of 3 would be expected for the solar corona. Cameron (ref. 12-23) estimates a  $^{20}\text{Ne}/^{38}\text{Ar}$  abundance ratio of 11 for the solar system, and the earlier Suess-Urey abundance compilation predicted a higher value of 67 for the  $^{20}\text{Ne}/^{38}\text{Ar}$  ratio (ref. 12-24). The results from the Apollo 14 SWC experiment seem to indicate that an intermediate value for the  $^{20}\text{Ne}/^{38}\text{Ar}$  ratio might be appropriate. However, in the solar-wind-acceleration process, fractionation between  $^{20}\text{Ne}$  and  $^{38}\text{Ar}$  might occur. Both  $^{20}\text{Ne}$  and the much heavier  $^{38}\text{Ar}$  are most likely eightfold charged in the solar wind. Separation processes caused by quasi-static electromagnetic fields or dynamical

friction could thus deplete  $^{38}\text{Ar}$  in the solar wind.<sup>2</sup>

The average  $^4\text{He}$  flux during the Apollo 14 exposure period can be calculated by using the data given in table 12-I. The trapping probabilities of the foil for noble-gas ions depend only slightly on energy in the general solar-wind-velocity region. For He with a velocity of approximately 300 km/sec, the trapping probability is  $89 \pm 2$  percent for normal incidence and approximately 9 percent less for an incidence angle of  $65^\circ$ .

The angular distribution and the average angle of incidence on the Apollo 14 foil have not yet been determined. Thus, for the purpose of this report, the average angle of incidence is estimated. The average solar elevation during the foil exposure was  $19^\circ$ . By taking into account the effects of aberration and corotation, an angle of incidence on the foil of  $68^\circ$  is obtained for the undisturbed solar wind. At the present time, it is not known whether the Moon had already passed through the shockfront of the Earth during the Apollo 14 foil exposure. If such were the case, the angle of incidence would be further lowered by  $5^\circ$  to  $7^\circ$  (ref. 12-25). The assumption is therefore made for this report that the average angle of incidence of the solar-wind particles on the foil was approximately  $65^\circ$ . With this assumption, the  $^4\text{He}$  flux during the Apollo 14 SWC foil exposure can be calculated and is given in table 12-II, together with the  $^4\text{He}$  fluxes previously determined for the Apollo 11 and 12 exposure periods (refs. 12-8 and 12-9).

The flux obtained for the Apollo 14 exposure period is definitely lower than the flux determined during the Apollo 12 mission. However, the He/Ne and  $^4\text{He}/^3\text{He}$  ratios are closer to the results of the Apollo 12 SWC experiment than to those of the Apollo 11 mission. It will be interesting to compare the Apollo 14 SWC experiment data with proton fluxes measured simultaneously by the Apollo 12 solar-wind spectrometer or by instrumentation on unmanned spacecraft to determine whether the flux for all ion species was generally low during the Apollo 14 exposure time, or whether the heavier ions were all depleted relative to H by a similar factor.

<sup>2</sup> J. Geiss: On Elemental and Isotopic Composition of the Solar Wind. Proc. Asilomar Conf. Solar Wind, Mar. 1971.

TABLE 12-II. Comparison Between the Preliminary Average  ${}^4\text{He}$  Flux Obtained From the Apollo 14 SWC Experiment With Solar-Wind Fluxes Obtained From the Apollo 11 and 12 SWC Experiments

Mission	Exposure date	Time of exposure initiation, G.m.t., hr:min	Exposure duration, hr:min	Average solar-wind ${}^4\text{He}$ flux, $\times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$
Apollo 11.....	July 21, 1969	03:35	01:17	6.2±1.2
Apollo 12.....	Nov. 19, 1969	12:35	18:42	8.1±1.0
Apollo 14.....	Feb. 5, 1971	15:16	21:00	4.2±0.8

The  ${}^4\text{He}/{}^3\text{He}$  ratio that was obtained from the Apollo 14 SWC experiment is again significantly lower than the ratios found in ilmenite separated from lunar fine material (ref. 12-21) and in the returned Surveyor 3 material (ref. 12-26). It appears that the  ${}^4\text{He}/{}^3\text{He}$  ratio varies, even when averaged over times of one or several years, and even a secular change in the  ${}^4\text{He}/{}^3\text{He}$  ratio in the outer convective zone of the Sun cannot be excluded.

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