Reports

Apollo 11 Solar Wind Composition Experiment: First Results

Abstract. *The helium-4 solar wind flux during the Apollo 11 lunar surface excursion was $(6.3 \pm 1.2) \times 10^6$ atoms per square centimeter per second. The solar wind direction and energy are essentially not perturbed by the moon. Evidence for a lunar solar wind albedo was found.*

During the Apollo 11 mission the astronauts exposed an aluminum foil, 140 cm high, 30 cm wide, and 25 μm thick, to the solar wind on the lunar surface. The exposure was initiated on 21 July 1969 at 03:35 G.M.T. and lasted 77 minutes. The foil was returned to the earth in one of the lunar-sample containers. Approximately one-third of the foil was sterilized (125°C for 39 hours in a vacuum) and released from quarantine on 12 August for analysis of the trapped solar wind particles. The remainder of the foil was made available in September after termination of the quarantine period for lunar material. We have analyzed portions of the foil for particles of noble gases trapped from the solar wind and report here the first results.

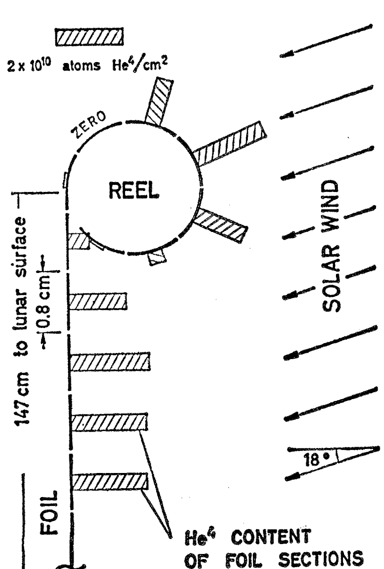
A thorough investigation of the foil at our laboratories with binocular microscopes and a scanning electron microscope revealed a nonnegligible contamination with fine lunar dust. This contamination originated most likely during the return of the foil to earth. The fine-grained lunar surface material is extremely rich in noble gases (*1*), and dust contamination, even in submicrogram quantities, would interfere with the measurements of trapped solar wind particles in the foil.

Our analytical blank for He^4 is 10^9 atoms, and we can make a determination of solar wind He^4 in the Apollo 11 foil with areas as small as 1 cm^2. A variety of procedures for cleaning the foil from lunar dust could thus be tested on a large number of small pieces of the foil. While the dust on the lower portion of the foil poses a substantial problem, the upper part can be completely and reliably cleaned by washing with detergent and then ultrasonically cleaning with acetone. No loss of trapped particles is introduced by this cleaning procedure. The results of the He^4 measurements on the 17 pieces of foil from the upper part of the foil are given in Table 1. The results are corrected for analytical blanks (always less than 5 percent) and for the blank He^4 content of the foil (approximately 10^8 atoms of He^4 per square centimeter). The average distance above lunar ground of these 17 pieces of foil was 135 cm. In addition to He^4 we have detected solar wind He^3 in the foil.

The efficiency of our decontamination procedure for lunar dust was determined as follows. During exposure on the lunar surface, the foil was fastened on a reel of 1.7 cm diameter, and the upper part of the foil remained rolled around the reel for approximately one turn (Fig. 1). Sections of the foil were thus shielded from the solar wind and shoud be free of He^4 if efficient decontamination is achieved. To test this, a strip, 2 cm wide and 10 cm long, from the uppermost part of the foil was cut in sections, 2 by 0.8 cm, and their individual He^4 content was measured (Fig. 1). The shaded bars represent the He^4 concentration in atoms per square centimeter in the individually analyzed sections. Foil sections shielded from the solar wind show virtually no He^4, confirming the efficiency of the decontamination procedure.

In addition, angular distribution of the incoming He^4 ions can be estimated from Fig. 1. From the pictures taken by Armstrong we measured that Aldrin erected the foil vertically to within $\pm 2°$. During exposure, the sun was 15° above the lunar horizon. Thus the angle between the expected, unperturbed solar wind direction and the normal to the foil was approximately 18° (*2, 3*). The angular spread of the unperturbed solar wind is about $\pm 5°$ corresponding to a helium temperature of 5×10^5 degrees Kelvin (*2, 4*). Our results are consistent with a directional flow coming from the unperturbed solar wind direction and with such an angular spread. Foil sections essentially shielded from the direct solar wind, but facing the lunar surface, show a small He^4 content which could originate from a solar wind albedo of the lunar surface.

The absolute He^4 solar wind flux can be obtained from our Apollo 11 data as follows. The trapping probability of the aluminum foil for ions with solar wind energies is high and depends only little on the ion energy (Fig. 2) (*5*). The trapping probability decreases approximately with the cosine of the angle of incidence (*5*). Saturation effects are nonexistent for the short exposure time (*5*). From simulation experiments we know that the foil temperature on



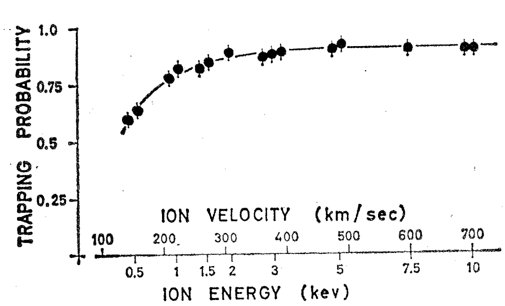


Fig. 1 (left). Upper part of foil with reel as exposed on the lunar surface. The shaded bars represent the measured He^4 concentrations in the foil pieces.

Fig. 2 (above). Trapping probability of aluminum foil for He^4 ions in the solar wind energy range (normal incidence).

the lunar surface was below 100°C and that no diffusion losses can have occurred (*5*). To detect possible losses of trapped solar wind particles during exposure, return flight, and subsequent handling and treatment, several pieces of the foil which had been irradiated earlier with a known neon ion flux of solar wind energy were attached to the foil. One of these test pieces has been analyzed so far, and no losses within 10 percent have been detected. If the solar wind arrived within 10° of the mean solar wind direction and an angular spread of ± 5° or less, we calculate from the measured average He^4 concentration in the foil (Table 1) a He^4 flux of $(6.3 \pm 1.2) \times 10^6/cm^2$ sec. This figure is in agreement with observations from satellites and space probes (*4, 6*) which show wide variations in the He^4 flux with a most probable value of about $7 \times 10^6/cm^2$ sec.

By stepwise heating of portions of the foil for 24 hours, we determined that less than 10 percent of the trapped He^4 is released at 150°C, and 25 percent is released at 250°C. This heat release pattern can be compared with laboratory experiments on the release of He^4 ions trapped at energies of a few kiloelectron volts (*5*). For an ion energy of 1 kev the corresponding figures were 10 and 59 percent; for an ion energy of 3 kev, less than 5 percent and 22 percent. The heat release pattern for the trapped solar wind He^4 is thus in agreement with a solar wind velocity at the lunar surface of approximately 300 to 400 km sec^{-1}.

Table 1. Results of He^4 measurements on 17 different pieces from the upper part of the Apollo 11 solar wind composition foil (G 15-7).

Sample No.	Area (cm^2)	He^4 (10^{10} atom/cm^2)
3-1	104	2.27
3-4	12.1	2.27
3-7	4.1	2.42
3-8	4.0	2.37
3-9	4.0	2.24
3-10	3.9	2.33
3-11	3.6	2.23
3-14	4.0	2.05
3-15	4.0	2.37
3-18	4.2	2.67
3-19	4.0	2.40
3-20	4.4	2.45
3-21	4.1	2.39
3-22	1.6	2.42
3-31	1.7	2.29
3-32	1.7	2.30
3-40	3.2	2.16
Average and standard deviation		2.33 ± 0.14

So far the Apollo 11 Solar Wind Composition Experiment has given the following results: Although during the time of foil exposure the sun was only 15° above the horizon, the solar wind penetrated to the lunar surface in accordance with the conclusion Lyon, Bridge, and Binsack (*7*) obtained from their Explorer 35 observations. The influx was highly directional, and the solar wind velocity was essentially unchanged. Our measurements indicate the presence of a solar wind albedo from the lunar surface.

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Interglacial High Sea Levels and the Control of Greenland Ice by the Precession of the Equinoxes

Abstract. *The precession of the equinoxes appears to control the occurrence of high sea levels by partial or even total melting of the Greenland ice cap during interglacial ages.*

A comparison of the generalized deep-sea core paleotemperature curve, calibrated in terms of the Th^{230}/Pa^{231} time scale, and the absolute ages obtained by uranium decay series methods for high sea level carbonates from various parts of the world, has shown that the sea level may rise to a maximum more than once during each interglacial age (*1*).

Figure 1 shows the relation between the paleotemperature curve and high sea levels. Table 1 shows the ages of the high sea level stands (from *1*) together with the ages of coincidence of perihelion with the northern summer solstice (from *2*). The fit is impressive: high sea levels appear to follow closely perihelion coincidences, with a not unexpected time delay of a few thousand years; this delay would be even smaller if perihelion coincidence with the warmest month of year were given more significance than coincidence with the summer solstice.

The observed remarkable fit suggests that the second-order oscillations which cause the high sea levels are the result of significant melting of the Greenland ice cap after interglacial conditions are established and when northern summer solstice occurs at perihelion. The total melting would raise present sea level about 10 m. In this context, Greenland appears more critical than Antarctica, apparently because it is not centrally located with respect to the pole and because it extends to considerably lower latitudes. It also appears that precession should be given more climatic significance, as proposed by Broecker (*3*). Today the earth receives about 7 percent more solar energy at perihelion than at aphelion. This change is certainly not insignificant, and, moreover,

Table 1. Ages of high sea levels (from *1*) and of coincidence of northern summer solstice with perihelion (from *2*). The two earliest high sea level ages carry a considerable error.

Ages of high sea levels (10^3 years ago)	Ages of coincidence of northern summer solstice with perihelion (10^3 years ago)
81	82.4
100	105.9
122	126.9
147	151.0
173	175.7
211	220.3
235	242.0