of 410 MeV per nucleon from the post-flight calibration of the detector foils, which was performed at Lawrence Berkeley Laboratory.

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References and Notes

1. R. Beaujean and W. Enge, *Nucl. Track Detect.* **1**, 19 (1977).
2. *Spacelab 1 Flight Definition Document, JA-024* (NASA–Marshall Space Flight Center, Huntsville, Ala., June 1983).
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Space Experiments with Particle Accelerators

Abstract. *Electron and plasma beams and neutral gas plumes were injected into the space environment by instruments on Spacelab 1, and various diagnostic measurements including television camera observations were performed. The results yield information on vehicle charging and neutralization, beam-plasma interactions, and ionization enhancement by neutral beam injection.*

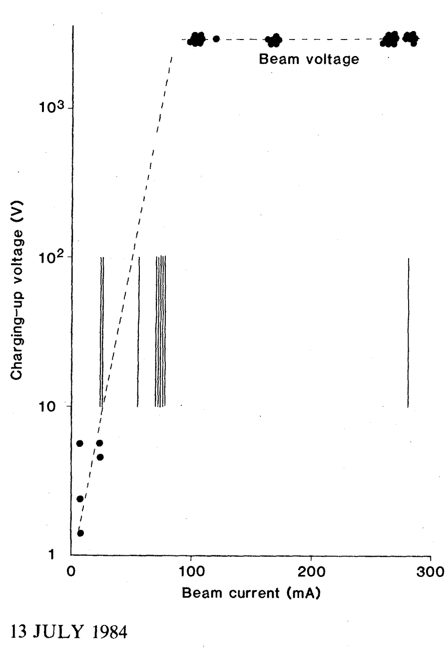
Space experiments with particle accelerators (SEPAC) constituted experiment 1NS002 on Spacelab 1. The program included active and interactive experiments on and in the earth's upper atmosphere and magnetosphere. The purpose was to gain insight into the physical processes that take place in the envelope of magnetic fields and charged particles surrounding the earth as well as in magnetic environments elsewhere in the universe (*1, 2*). Significant results were obtained on (i) vehicle charging and neutralization effects, (ii) beam-plasma interactions associated with electron beam emissions, and (iii) ionization enhancement by neutral beam injection.

The SEPAC experiments involved injection of electron and plasma beams and neutral gas clouds into the space environment. This was accomplished with an electron beam accelerator (EBA), operating at 7.5 kV with a maximum current of 1.6 A and a pulse duration of 10 to 5000 msec, a magneto-plasma dynamic (MPD) arcjet, which injected Ar gas at 2 kJ per 1-msec pulse, and a neutral gas plume injector, which injected N_2 gas at 10^{23} molecules per 100-msec pulse. In addition, the instrumentation included a monitor television camera (low-light-level TV), a diagnostic package consisting of a photometer and particle and wave probes, and control and display hardware consisting of an interface unit, dedicated experiment processor, and control panel.

Before the various scientific experiments were carried out, an instrument performance test and MPD and EBA beam-firing tests were performed. The instruments and their operational capabilities were tested successfully. After this initial feasibility test was completed several scientific functional objectives were followed. However, a malfunction of the EBA occurred later in the mission, and operation of high-power modes of the EBA was not possible. Consequently, the SEPAC experiments thereafter were performed with the MPD arcjet, neutral gas plume, diagnostic package, and monitor TV only.

Vehicle charge buildup and neutralization. It was observed that when the EBA was operated at a power level above approximately 100 W the payload bay was so brightly illuminated by the bombarding return electrons that a definite beam shape was difficult to observe. The glow occupied a broad area above the EBA accelerator, suggesting that a glow discharge took place in the vicinity of the spacecraft. The charge buildup on the vehicle body due to EBA electron beam emissions was quantitatively determined by means of a Langmuir probe, a floating charge probe, and a particle energy analyzer. The particle energy analyzer monitored the energy spectrum of returning electrons, the peak in the energy spectrum being used to estimate the electrical potential due to vehicle charge buildup. In the very-low-power mode of EBA operation, the charging potential is proportional to the EBA beam current. As shown in Fig. 1, however, at an EBA current above 100 mA, the vehicle charge potential sometimes shows a saturation effect, giving a value equal to the beam energy. The spread of vehicle potential is due to the different attitudes of the spacecraft and the variety of ionospheric conditions.

An attempt to neutralize vehicle charge buildup was made by injecting an



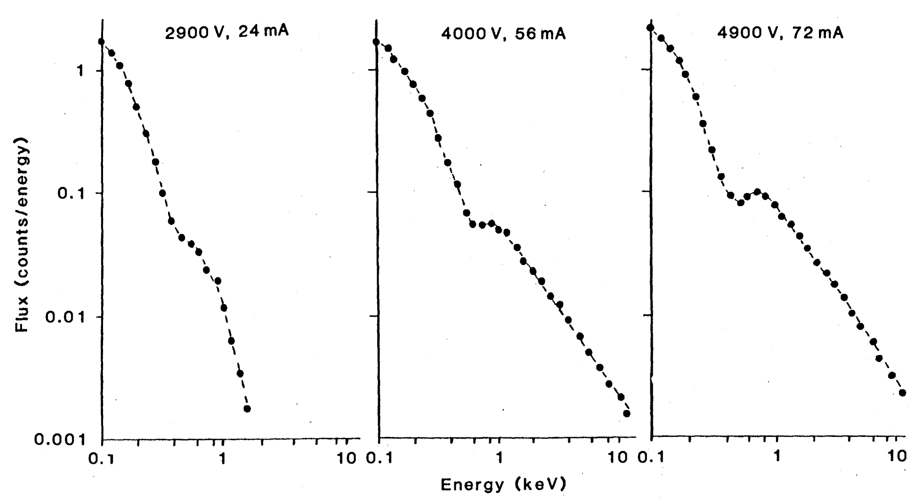


Fig. 1 (left). Vehicle charging-up potential plotted against electron beam current. Closed circles include data from the Langmuir probe, the floating charge probe, and the particle energy analyzer. Vertical lines indicate probable values, which are not determined without ambiguity. Fig. 2 (right). Energy spectrum of returning electrons measured by the particle energy analyzer.

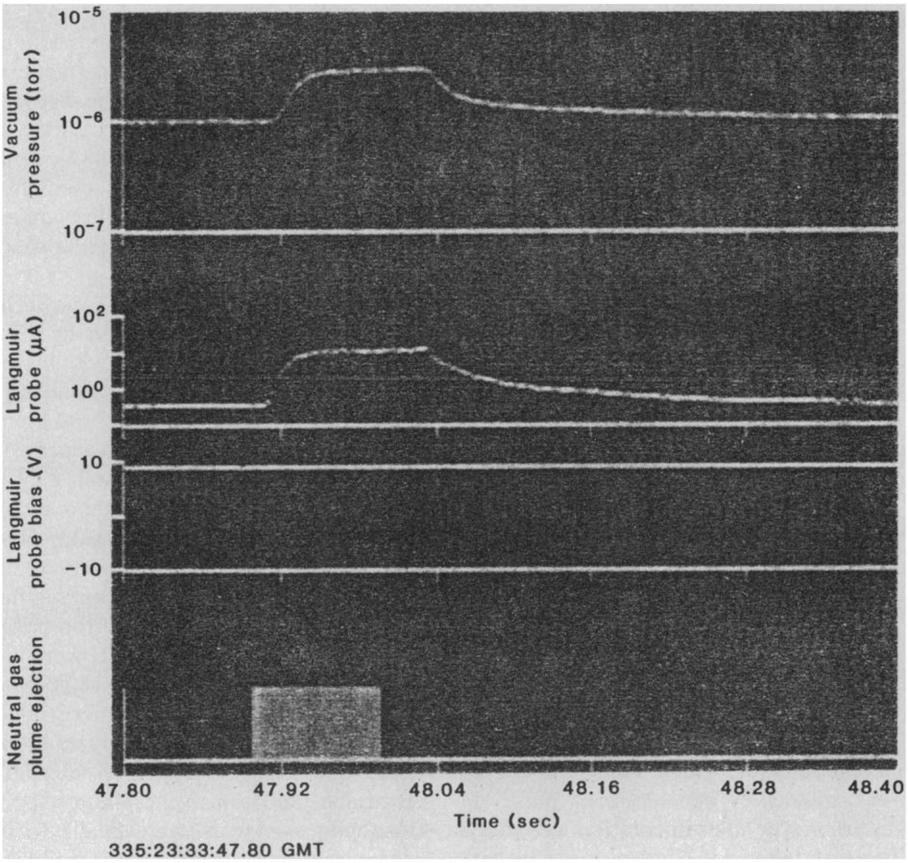


Fig. 3. Injection of a neutral gas (N_2) and associated enhanced ionization measured by the Langmuir probe.

MPD plasma plume simultaneously with the EBA beam. The charge on the vehicle from the EBA operation was suddenly neutralized at the time of an MPD shot. Although the injection time of the plasma plume was of the order of 1 msec, the neutralization effect persisted as long as 30 to 60 msec. It is concluded that the MPD injection method is effective for the neutralization of vehicle charge potential.

Beam-plasma interactions associated with electron beam emissions. As mentioned above, a broad glow was observed above a certain level of EBA operation and the vehicle charge potential was saturated for EBA beam currents above 100 mA. These observations seem to indicate that a beam-plasma discharge was taking place in the vicinity of the electron beam. The effect was confirmed by the particle energy spectrum of electrons returning to the spacecraft. Examples of electron energy spectra are shown in Fig. 2. Subpeaks are observed at 500 to 800 eV, and there is a significant flux of electrons above the beam energy of the EBA ($\sim$3 to 5 keV). This suggests that there is some kind of accelerating mechanism for electrons operating near the electronic beam.

Ionization enhanced by neutral beam injection. One interesting phenomenon observed during SEPAC was the enhancement of ionization in the ambient space—that is, the increase in electron density occurring during the period of neutral gas injection. The neutral gas plume injector was operated several times during the period when the EBA was not used. Some of the results obtained are shown in Fig. 3. The injection of 1 mole of N_2 was made toward the ram direction. During this period the Langmuir probe showed a significant increase in ionization, which was enhanced 10 to 100 times in comparison with the ambient electron density. This effect may deserve further attention; however, since no significant collisional ionization occurs at these altitudes, the effect of critical ionization velocity (*3*) may be important. The orbital velocity of the spacecraft was on the order of 8 km/sec, and therefore the injection speed of neutral gas with respect to the space magnetic field may be of the same order of magnitude as the critical ionization velocity.

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References and Notes

1. T. Obayashi, *Rep. Ionos. Space Res. Jpn.* **2**, 159 (1978).
2. ———, *ibid.* **6**, 13 (1982).
3. E. Mobius, R. W. Boswell, A. Piel, D. Henry, *Geophys. Res. Lett.* **6**, 29 (1979).

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