NEWS AND VIEWS

Tracking Electrons in the Magnetosphere

THE discovery of the Van Allen belts of magnetically trapped particles surrounding the Earth was the precursor of a rapid increase in the use of satellites and rockets to probe both the radiation in the vicinity of the Earth and the Earth's magnetic field. During the past decade more and more experiments have been designed to examine in detail the properties of the Earth's magnetosphere—that region around the Earth in which the magnetic field is reasonably ordered and at least approximately characteristic of the field of a magnetic dipole, though distorted by the solar wind of plasma.

Such phenomena as auroras, for example, have been known for hundreds of years but it has only been the magnetospheric work of the past few years which has provided the real clue to their mechanism. It is now established with almost complete certainty that they are caused by electrons of energy a few keV impinging on the atmosphere and exciting atoms and molecules. Some of the techniques used for studying artificially generated auroras have not been as elegant as others, however; the Starfish nuclear detonation at a height of 400 km in 1962 was an example of a particularly uncontrolled and controversial experiment in which large numbers of electrons were released. But more finely controlled experiments have also been successfully used. In 1969, for example, pulses of electrons were fired from a rocket in such a way that they spiralled along the magnetic field lines and into the atmosphere. The photographic recording of the auroras generated by these electrons gave probably the first data on the sizes and locations of auroras created by electron beams of known intensity and energy.

Having succeeded in producing artificial auroras almost at will and measuring their properties from the ground, the next logical step was to look at the exact behaviour of electron beams of well defined energy and intensity as they follow their spiral paths and mirror near the magnetic poles. On page 564 of this issue of *Nature*, Hendrickson *et al.* describe their recent rocket experiment which was quite similar in principle to that carried out in 1969. Instead of injecting beams of electrons at such a height that most of them contribute to auroras in the upper atmosphere, the conditions of the flight were arranged so that a large proportion of the electrons were reflected magnetically back to the rocket where they could be detected and their energies and intensities measured.

Not surprisingly the height to which the Aerobee rocket had to be flown from the launching site at Wallops Island, Virginia, was rather higher than in 1969—about 350 km compared with 270 km. The exacting requirement that a beam of electrons a few tens of metres across should be intercepted by the rocket after reflexion made rocket control a critical feature of the experiment. The fact that the helical paths do not follow a simple north–south route but are deflected in an easterly direction because of the gradients in the Earth's magnetic field only serves to increase the problem.

The potential difficulties of experiments of this type are highlighted by the very small amount of time for which meaningful measurements can be made. Although the rocket flight lasted about ten minutes and the electron gun was firing for a substantial fraction of this time, the rocket was only moving on the correct magnetic shell and at the correct eastward velocity for about one minute. (The magnetic shells are imaginary surfaces along which electrons of given characteristics are constrained to spiral.) The spinning and precession of the rocket create another less serious problem but some electrons are inevitably injected towards the mirror point at the north and some to the southern point.

Surprisingly, some of the most useful data came from reflexion measurements made when the southward and upward motion of the rocket was such that the rocket was moving to a higher or lower magnetic shell during the bounce period (that is, between the time of injection of a particular pulse and the detection of its reflexion). It so happens that, because the magnetic dipole which approximates the Earth's magnetic field does not coincide with the Earth's centre, the altitudes at which genuine magnetic mirroring would take place for electrons from the rocket in the southern hemisphere are quite small. There is therefore a high probability that scattering by atoms, molecules and ions causes the electrons to undergo a mirroring process at a greater height than expected for true magnetic mirroring. It is clear that because the pitch angle of the helical path becomes smaller as the mirror point is reached the electrons spend a high proportion of their time near this point and the precise position at which the electrons are sent back the way they came has a marked effect on the bounce period. Hendrickson *et al.* have found that their observed bounce period is in quite close agreement with the predicted figure assuming that scattering plays an important part in the mirroring process. Another consequence of the scattering effect is that the beam will not be as well collimated after reflexion and some of the electrons will diffuse over a finite spread of magnetic shells. This explains why electron echoes could still be detected at the rocket even when it was not moving on the same magnetic shell for the whole of the bounce period. The effect of scattering and the nature of the transition region at which magnetic reflexion ceases to play a dominant part in changing the direction of an electron are, of course, important for the development of auroral theories and the data reported will be useful as a comparison with some theoretical Monte Carlo simulations.

A further parameter of the magnetosphere, the electric field, could also be important in the formation of auroras but direct field measurements at high altitudes are almost non-existent. The conclusions about the size of this field which Hendrickson *et al.* are able to make are very general and rather inexact, but this is inevitable. A radial electric field at the equator, for example, would modify the easterly drift of the electrons, and if it had been sufficiently large the rocket would never have been in the correct position to intercept the reflected bunches. The fact that echoes were actually detected leads Hendrickson *et al.* to place an upper limit of 700 $\mu V\ m^{-1}$ on this electric field configuration.

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