Letters to the Editor

Electrodynamic Effects connected with the Motion of a Satellite of the Earth

Dear Sir,

During the International Geophysical Year a number of artificial satellites are planned to be launched into the earth's upper atmosphere. A satellite of the proposed type will move with a velocity of about 7.7×10^3 metres/sec. In the American project the motion is expected to take place in an orbit which has its nearest approach to the earth's surface at an altitude around 500 km. The satellite will have the shape of a sphere, about 0.5 metres in diameter.

A short discussion will be given here on the electrodynamic effects connected with the motion of such a satellite. From accepted data on the ionosphere (KUIPER 1954, ALLEN 1955) is concluded that the mean free path of charged and of neutral particles is much greater than the dimensions of the satellite. The ions at altitudes of 500 km have a thermal velocity of 1.7×10^3 metres/sec., a radius of curvature in the earth's magnetic field of 7 metres and a corresponding gyro time of 0.02 sec., approximately. CHAPMAN and COWLING (1939) state that the mean energy of electrons is likely to exceed the value corresponding to thermal equilibrium at the altitudes in question. The cross section for photo ionization of air is considerable down to wave lengths of about 300 Ångströms (VON ENGEL 1955). A large fraction of the electrons will be released with kinetic energies of the order of the ionization potentials of oxygen and nitrogen, i.e., of the order of 15 eV. The lifetime of electrons at these altitudes is about 10^5 sec. The mean collision time of electrons is approximately in the range from 0.1 to 10 sec., corresponding to between 10^4 and 10^6 collisions during the lifetime of an electron. NICOLET (1953) has shown that Coulomb scattering dominates the collision processes at high altitudes. However, even if inelastic collisions occur less frequently, they are more effective in reducing the electron energy. Thus, the mean energy of electrons should be somewhere between the ionization potential and the value corresponding to thermal equilibrium (0.26 eV at 2000° K), and probably closer to the latter value than to the former. On the night side the mean energy will be brought down by means of collisions to a value somewhat greater than that corresponding to thermal equilibrium. The gyro time of electrons is about 10^{-6} sec. Electrons with energies of the order of 1 eV have velocities of 6×10^5 metres/sec. and a radius of curvature in the earth's magnetic field of 0.07 metres.

An electrically neutral and unpolarized satellite is fed with an ion current directed towards its front half sphere. The electron current is directed mainly along the magnetic field lines and reaches the whole surface of the sphere. It is about 150 times greater than the ion current. Thus, the satellite will be charged to a negative potential such as to cut off almost the whole electron current. i.e., to a potential of the order of — 1 volt at least, i.e., to a potential slightly lower than — 0.7 volts which would be reached in a situation of thermal equilibrium. This value is hardly affected by the ion current which changes very little with potentials of this magnitude. Photo emission of electrons from the surface of the satellite may change its potential. This depends upon the special material which will be used for the construction and cannot be discussed here in detail. Further, the electric field caused by a polarization of the satellite in the earth's magnetic field can be neglected as compared to the field generated by the negative charge.

First consider the separate interaction between the charged satellite and each charged particle in its surroundings. Most of the momentum is transferred to the charged particles during a time which is short as compared to the gyro time of ions, and which is long as compared to that of electrons. This will cause a momentum transfer to ions in a direction perpendicular to the path of the satellite, and to electrons in a direction along the magnetic field lines (cf BOHR 1913, 1915 and FERMI 1951). For the sake of simplicity we assume the satellite to move in a direction nearly perpendicular to the magnetic field lines. When it passes through the ionosphere it repells the electrons in directions along the magnetic field lines and attracts ions in directions nearly perpendicular to its path. If space charge effects are neglected the charge of the satellite will be sufficiently large to cause a full momentum transfer to the scattered particles within a certain distance from its centre. This implies that, inside this distance, the scattered particles are given a momentum as if they were colliding with a rigid wall. In the region further out the momentum transfer decreases with the distance from the satellite. At large distances the collision times of electrons and ions will be longer than the pulse time, i.e., the time during which the greater part of momentum is transferred in the scattering process. In such a situation we assume that, on the average, the charged particles lose all their systematically directed velocity at each collision and start a new free flight with zero systematical velocity. The energy losses, W_e and W_i, caused per unit time by electron and ion scattering are compared to the energy loss, W_m, caused per unit time by the mechanical drag. On the day side the corresponding ratios become.

$$W_e/W_m \approx 40\ X \text{ and } W_i/W_m \approx 0.16\ X,$$

where the ionization degree, X, is likely to be in the range from 10^{-2} to 10^{-1}. A detailed description of the derivation of these expressions requires too much space to be given here.

These results seem to indicate that the electrodynamic effects should be of considerable importance. However, for a satellite of the present size, they are applicable to regions having very low densities only, and not to the ionosphere around altitudes of 500 km. The charge of the satellite is large enough to "blast off" electrons in front of it in directions along the magnetic field lines. The remaining positive ion charge generates an electric field which screens off the field from the satellite. At an altitude of 500 km the charge of the satellite becomes equal to the total electron charge within a volume of the ionosphere comparable to that of the satellite. This indicates that momentum transfer will take place in its immediate neighbourhood only, essentially inside the Debye distance from the satellite (cf. SPITZER 1956). Thus, the ratios W_e/W_m and W_i/W_m given by the expressions above will be reduced appreciably.

The separation of charge caused by the motion gives rise to an increase in electrostatic energy and in plasma oscillations. Further, the interaction with the ionized gas in the neigbourhood will generate magneto-ionic waves propagated into the external regions (ÅSTRÖM 1950). Electrodynamic forces caused by the interaction between the earth's magnetic field and electric currents will be of the same order as the mechanical drag, provided that a current density of 0.2 amp./metre^2 exists within a volume comparable to that of the satellite. This is a very high value which can hardly be obtained by moving all the charges within the volume with velocities corresponding to the ionization energy. Further investigations are necessary for a definite answer to these questions.

An acknowledgement is gratefully addressed to Prof. H. Alfvén for drawing the author's attention to these problems.

Yours sincerely,

B. LEHNERT
The Royal Institute of Technology, Stockholm

July 11, 1956.

REFERENCES

ALLEN, C. W., 1955: *Astrophysical quantities*, Univ. of London, The Athlone Press.

ÅSTRÖM, E., 1950: On waves in an ionized gas. *Ark. f. fysik*, **2**, p. 443.

BOHR, N., 1913: On the theory of the decrease of velocity of moving electrified particles on passing through matter. *Phil. Mag.* [6], **25**, p. 10.

— 1915: On the decrease of velocity of swiftly moving electrified particles in passing through matter, *ibid.*, **30**, p. 581.

CHAPMAN, S., and COWLING, T. G., 1939: *The mathematical theory of non-uniform gases*, Cambridge Univ. Press, p. 346.

ENGEL, A. VON, 1955: *Ionized gases*, Oxford, Clarendon Press, p. 60—65.

FERMI, E., 1951: *Nuclear physics*, Univ. of Chicago Press, p. 27.

KUIPER, G. P., 1954: *The earth as a planet*, Univ. of Chicago Press.

NICOLET, M., 1953: The collision frequency of electrons in the ionosphere. *J. Atmosph. Terr. Phys.*, **3**, p. 200.

SPITZER, L., 1956: *Physics of fully ionized gases*, Interscience Publ., N.Y.

The reader is also referred to:

SINGER, S. F., 1956 a: Measurements of interplanetary dust, Physics Dept. *Techn. Rep. No. 33, Univ. of Maryland.*

— 1956 b: Studies of a minimum orbital unmanned satellite of the earth (MOUSE). Part II. Orbits and lifetimes of minimum satellites. *Astronautica Acta*, **2**, p. 125.

International Geophysical Year, A special report prepared by the National Academy of Sciences for the Committee on Appropriations of the United States Senate, presented by Mr. Hayden, May 28, 1956, United States Government Printing Office, Washington: 1956.