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A FIRST ORDER TECHNIQUE FOR THE MEASUREMENT OF VEHICLE POTENTIAL IN THE IONOSPHERE

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ABSTRACT

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Under certain conditions, the potential of vehicles immersed in the ionospheric plasma can become very large. In addition, the presence of on-board equipment (dc sweeps, etc.) often gives rise to significant variations in this potential. The use of a small diameter, cylindrical Langmuir probe is suggested as a means of measuring the arificially induced variations of potential with good accuracy. This technique will also provide crude information (approximately 1 volt) on the vehicle potential as controlled by the geophysical parameters.

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A FIRST ORDER TECHNIQUE FOR THE MEASUREMENT OF VEHICLE POTENTIAL IN THE IONOSPHERE

The measurement of ionospheric properties by means of _in situ_ probes usually leads to the requirement for knowledge of the vehicle potential. In a well-behaved plasma, that is, one in which all constituents are completely thermalized at least by species, this potential is small, of the order of 4KT, (typically less than 1 volt). The potential of vehicles in the ionosphere is often not in accordance with this simple picture however, generally assuming values of from 1 to 3 volts when below the F maximum, and occasionally displaying much higher excursions. This value is also a sensitive function of such on-board parameters as external probe sweeps; of motional parameters, such as velocity and orientation with respect to the velocity vector; and of the magnetic field and the sun vector orientations. Thus, in general, the vehicle potential has a non-negligible value and is sensitively dependent on the large number of interrelated parameters. In particular, it is varying with time at rates which are related to the motional activity of the vehicle, external sweep programming, etc.

The rapid time variation in the vehicle potential has been largely ignored by many investigators but this can lead to significant errors. For instance, Figs. 1 and 2 show the applied voltage versus probe (to plasma) voltage characteristic of bipolar Langmuir probes of various area ratios and ambient conditions. It is evident that for an area ratio, of say 300, an appreciable portion of the applied sweep appears as "vehicle potential bounce" and that the probe potential is

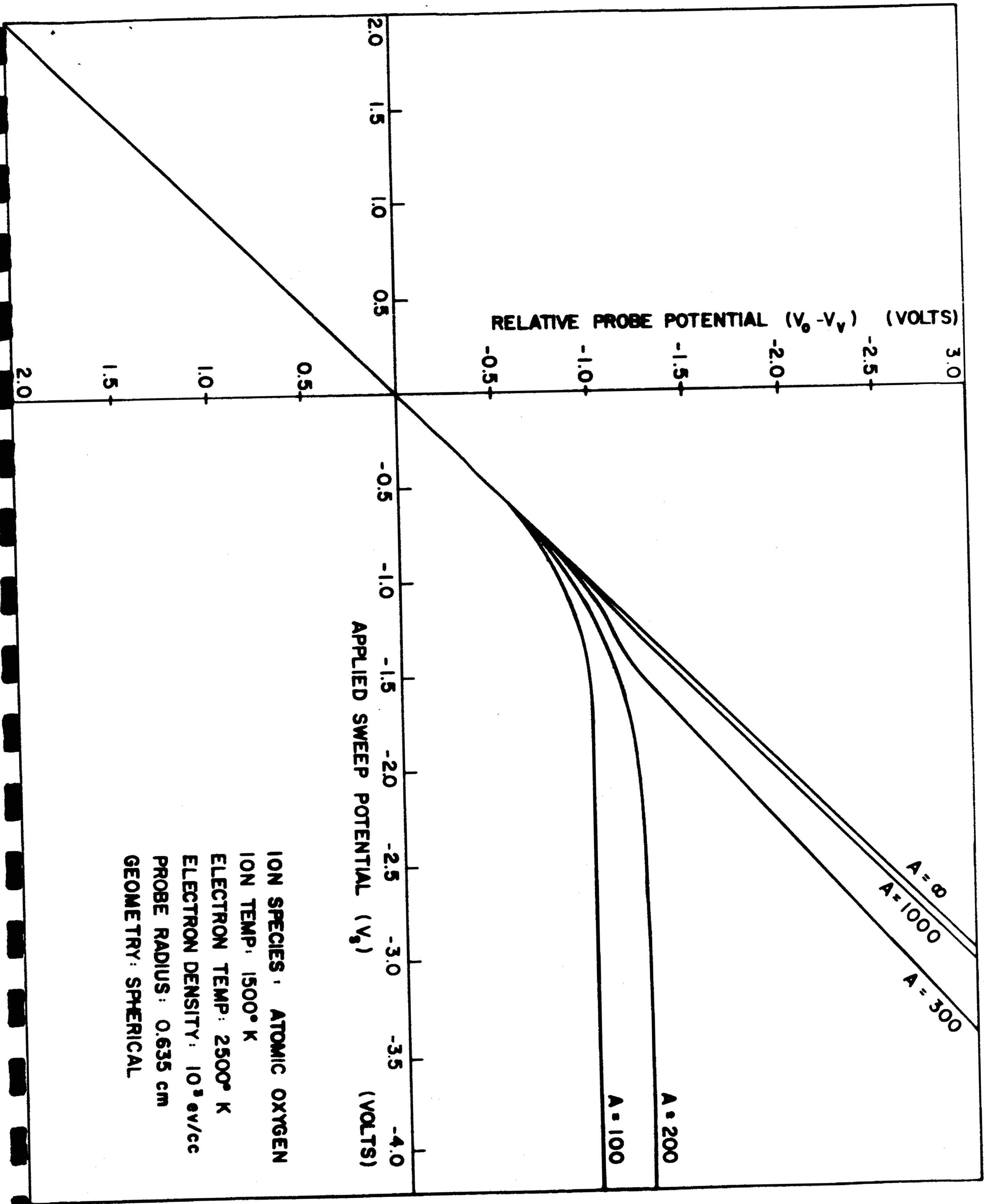
RELATIVE PROBE POTENTIAL (V_0 -V_V) (VOLTS)
APPLIED SWEEP POTENTIAL (V_s) (VOLTS)
A = ∞
A = 1000
A = 300
A = 200
A = 100
ION SPECIES: ATOMIC OXYGEN
ION TEMP: 1500° K
ELECTRON TEMP: 2500° K
ELECTRON DENSITY: 10^3 ev/cc
PROBE RADIUS: 0.635 cm
GEOMETRY: SPHERICAL

FIGURE 1

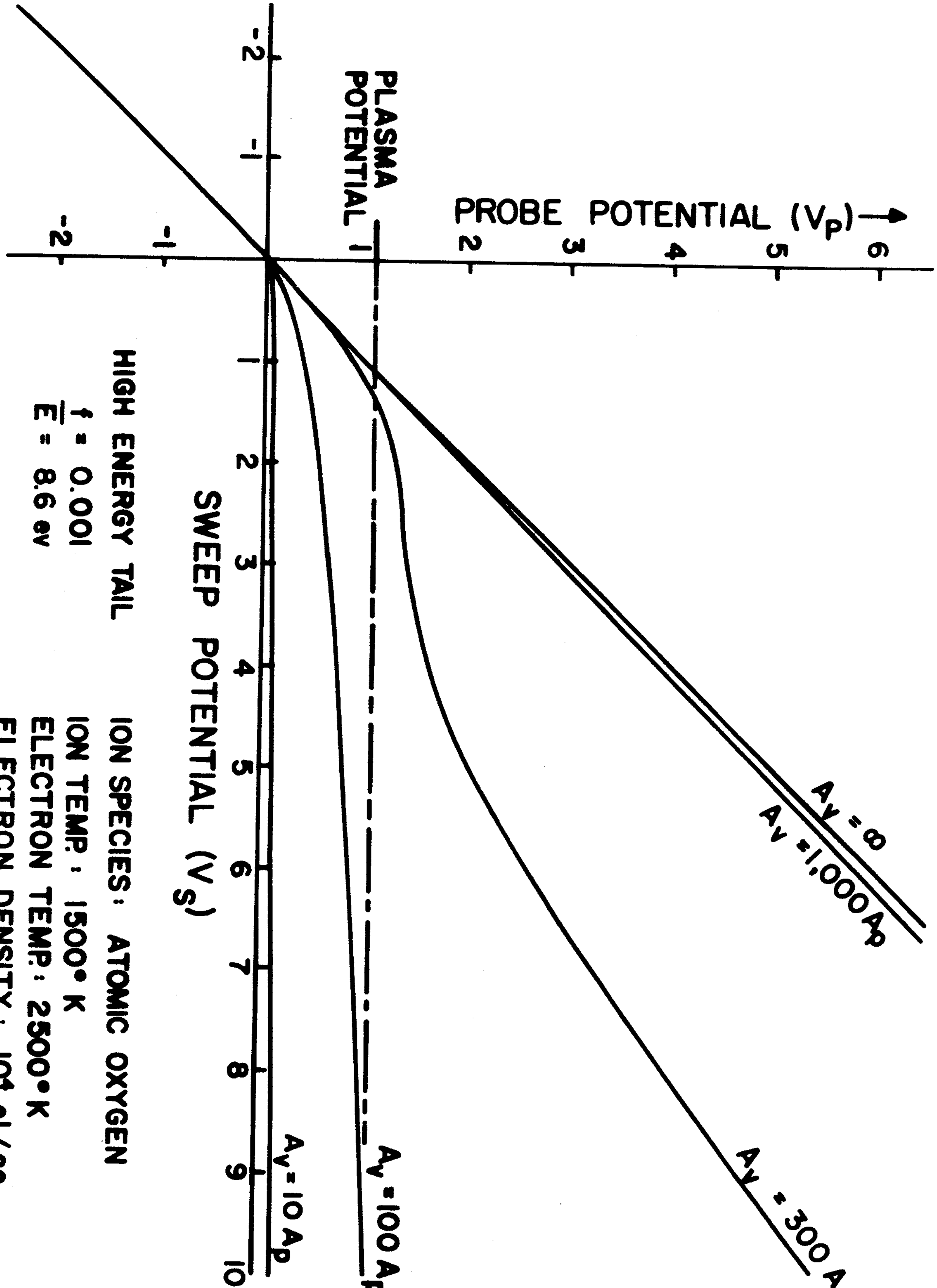
PROBE POTENTIAL (V_P)
PLASMA POTENTIAL
SWEEP POTENTIAL (V_S)
$A_V = \infty$
$A_V = 1{,}000\,A_P$
$A_V = 300\,A_P$
$A_V = 100\,A_P$
$A_V = 10\,A_P$
HIGH ENERGY TAIL
$f = 0.001$
$\bar{E} = 8.6$ ev
ION SPECIES: ATOMIC OXYGEN
ION TEMP.: 1500° K
ELECTRON TEMP.: 2500° K
ELECTRON DENSITY: 10^4 el/cc
GEOMETRY: SPHERICAL
PROBE RADIOS: 0.635 cm

FIGURE 2

appreciably less than that applied. If we should plot log of the current versus applied voltage, the resultant slope may be interpreted in terms of the electron temperature. The distortion in the applied sweep curve will cause us to over-estimate the temperature, but the error may or may not be serious depending upon the specifics of the situation. On the other hand, (as has been pointed out by Nagy[1]) attempts to measure the vehicle potential in terms of the point at which the curve departs from a straight line will be subject to large uncertainties as a result of finite measurement errors. Correspondingly large errors can also appear in the charge density depending upon the specific data analysis techniques employed.

The functions which govern the vehicle potential are many and complex. Attempts to calculate this factor[2] are highly unrealistic. It is, therefore, essential to measure this parameter experimentally and this may be best accomplished by means of a unipotential cathode called a TEP[3]. While the TEP is a relatively simple device, it does require aprreciable amounts of heater power (of the order of watts). Alternatively, it is possible to make "first order" measurements of the vehicle potential by means of a small diameter Langmuir probe. This approach is even simpler than the TEP and requires considerably less power. The technique consists of physically placing the Langmuir probe outside the volume of influence of the spacecraft and allowing it to "float". Its potential is measured by means of a high impedance voltmeter with a frequency response in excess of the highest rate of anticipated time variation in the vehicle potential.

The use of a small diameter Langmuir probe as a voltage reference was

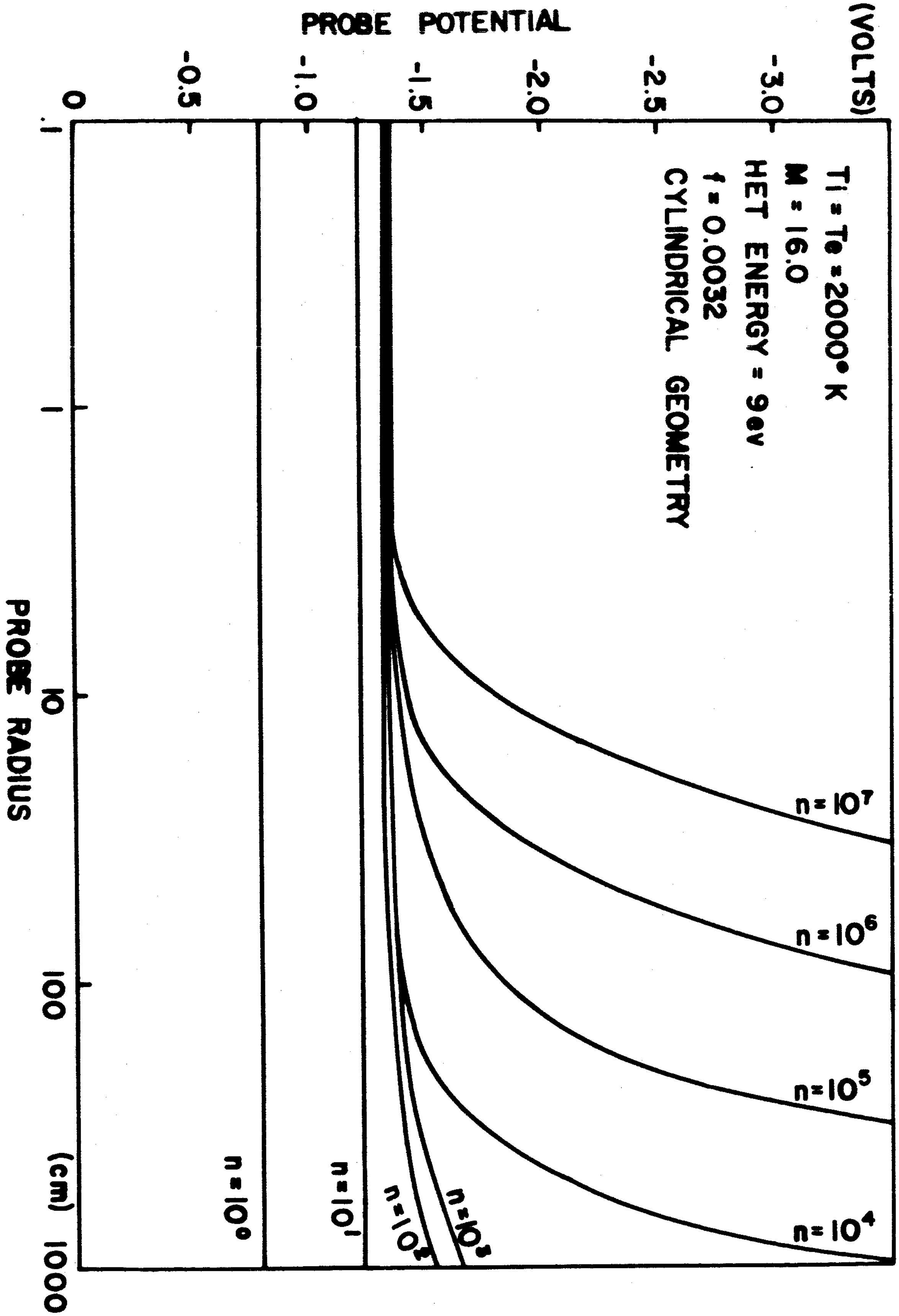
PROBE POTENTIAL
(VOLTS)
0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Ti = Te = 2000° K
M = 16.0
HET ENERGY = 9ev
f = 0.0032
CYLINDRICAL GEOMETRY
n = 10^7
n = 10^6
n = 10^5
n = 10^4
n = 10^3
n = 10^2
n = 10^1
n = 10^0
.1
1
10
100
(cm) 1000
PROBE RADIUS

FIGURE 3

was suggested to us by calculations[4] of the equilibrium potential of various idealized geometries (see Fig. 3) in which the potential for a sufficiently small diameter was found to be largely uneffected by the perturbing element; the high energy electron tail in this case. For instance, let us consider a cylindrical probe of sufficiently small diameter so that the ratio of the sheath radius to the probe radius is very large. Employing the equations of Mott-Smith and Langmuir[5], we may write

$$i = 2r\ell N_e e(2kT/m)^{\frac{1}{2}} \left(1 + \frac{eV_p}{kT}\right)^{\frac{1}{2}} \qquad eV_p > 2kT, \qquad (1a)$$

$$= r\ell N_e e(2\pi kT/m)^{\frac{1}{2}} \exp\left(\frac{eV_p}{kT}\right) \qquad eV_p < 0, \qquad (1b)$$

where r is the probe radius and ℓ the probe length, N_e is the ambient charge concentration, e the electronic charge, k the Boltzmann constant, T the temperature of the constituent under consideration, m its mass, V_p the potential of the probe with respect to the plasma at infinity. If we assume a negative probe potential and a plasma which is thermalized, at least by species, then by equating the ion and electron currents and assuming no reflections at the surface of the collector, we obtain

$$\left\{\frac{4m_e T_i}{\pi m_i T_e} \quad (1 + \psi_i)\right\}^{\frac{1}{2}} = \exp(\psi_e) \quad , \qquad (2)$$

where the indices refer to the ions and the electrons respectively. The nondimensional potential is given by

$$\psi_m = \frac{eV_p}{kT_m} \quad . \qquad (3)$$

Equation (2) contains the ½ power of the ratio of masses which reflects the fact that this is a flux collection process. The ions are assumed singly charged so that the nondimensional potentials differ only in their sign and perhaps in the temperature. Equation (2) may be solved by graphic techniques or by iteration and, for typical ionospheric temperatures of the order of 2000^{0}K, yields equilibrium potentials of less than 1 volt.

For comparison let us now consider another cylinrical probe whose radius is large compared to that of the sheath. If the probe potential is again negative, the form of the electron current is unchanged (Eq. 1b), but the ion current now is simply the random current to the area of the probe; that is

$$i = 2\pi r \ell N_e e \left(\frac{kT}{2\pi m}\right)^{\frac{1}{2}} \quad . \tag{4}$$

Equating the ion and electron currents, we obtain

$$\left\{\frac{m_e T_i}{m_i T_e}\right\}^{\frac{1}{2}} = \exp(\psi_e) \quad . \tag{5}$$

The right hand sides of Eqs. 2 and 5 are identical; however, the left hand side of Eq. (5) is independent of potential. This accounts for the sensitivity in the equilibrium potential of typical carrier vehicles to high energy electrons in the ionosphere. In order to illustrate this point we will divide the electron population into two groups: one containing the fraction f of the total population, satisfying a

Maxwellian distribution described by temperature T_{e2}, and the group containing 1-f electrons at a temperature T_e. The fraction f is relatively small (less than 1%) and the associated temperature is relatively high corresponding typically to energies of 5 to 10 electron volts. The voltage equivalent of the low energy electrons is of the order of a few tenths of a volt. In this case we obtain

$$\left(\frac{T_i}{m_i}\right)^{\frac{1}{2}} - (1-f)\left(\frac{T_e}{m_e}\right)^{\frac{1}{2}} \exp \psi_e - f\left(\frac{T_e}{m_e}\right)^{\frac{1}{2}} \exp \psi_{e2} = 0. \tag{6}$$

When the third term of (6) is larger than the first then the vehicle potential will be nearly completely dominated by the high energy component. This condition is satisfied when

$$f > \left(\frac{m_e}{m_i} \cdot \frac{T_i}{T_{e2}}\right)^{\frac{1}{2}} \quad , \tag{7}$$

If we assume atomic oxygen as the ion species and 10 electron volts as the equivalent temperature of the high energy electrons, transition value of the fraction f is approximately .25%. The constancy of the first term of equation (6) then leads to a condition which we might term "potential run away". With small probes, however, this behavior is considerably modified by the presence of the potential dependent term on the left side of Equation (2). A high energy electron tail will be effective in increasing the equilibrium potential of such a probe, but the effect is considerably less than the case of a large probe and only under very severe conditions less than the case of a large probe and only under very severe conditions will the high energy electron component dominate the behavior of the equilibrium potential.

A number of other factors can affect the equilibrium potential, of course. One of these is the photo-electric current resulting from solar radiation, but its contribution can be approximated as a constant term added to the ion current. This term is not generally of numerical importance except at extreme altitudes (greater than 500KM). The photo-electric current acts to reduce the large negative equilibrium potentials by effectively increasing the first term of Equation(6) (the ion current contribution). It can be very effective in keeping the equilibrium potential in the "thermal" range ($o<V_v<1.0$) but it must become very large, of the order of the random current of the electrons, in order to generate positive vehicle potentials. This condition is not generally satisfied.

Vehicle velocity and aspect with respect to this velocity are other important factors which need to be considered in these calculations. The vehicle velocities are typically small compared to the electron thermal velocities but of the order of, or large, compared to the ion thermal motions. This generally has the effect of increasing the ion current by an amount dependent upon the specifics of the situation. As with photo-electrons, its most important effect in the present context is to increase the critical value of the fraction of high energy electrons given by Equation (7).

Although both the photoelectric and vehicle velocity effects can be very important in determining the value of the equilibrium potential in a given situation, they will not alter our basic conclusion; a small diameter Langmuir probe will maintain a relatively low equilibrium potential which may be used as a reference.

Several obvious practical considerations need to be satisfied. First, the probe needs to be physically located outside of the effective sheath of the main vehicle. This presents a support problem which may be handled in several ways, one of which is indicated schematically in Figure 4. A guard electrode, of sufficient length to place the probe outside the sheath of the main vehicle, is maintained at the probe potential by means of a unity gain amplifier. The amplifier introduces our second limitation. The size of the probe must be large enough so that the loading of the amplifier is not serious; that is, the current drown by the detector must be small when compared to that of Equation (1). This is the main reason for selecting cylindrical over spherical geometry since one dimension is largely unrestrained. In practice the length of the probe is limited by the voltage induced by the earths field.

The proposed approach may be used to measure the variations of the vehicle potential induced by on-board systems with excellent accuracy. Since its sensitivity is inherently low, it will also supply first order information on "geophysically induced" potential variations. Thus it may be used to provide a continuous on-board reference of the plasma potential.

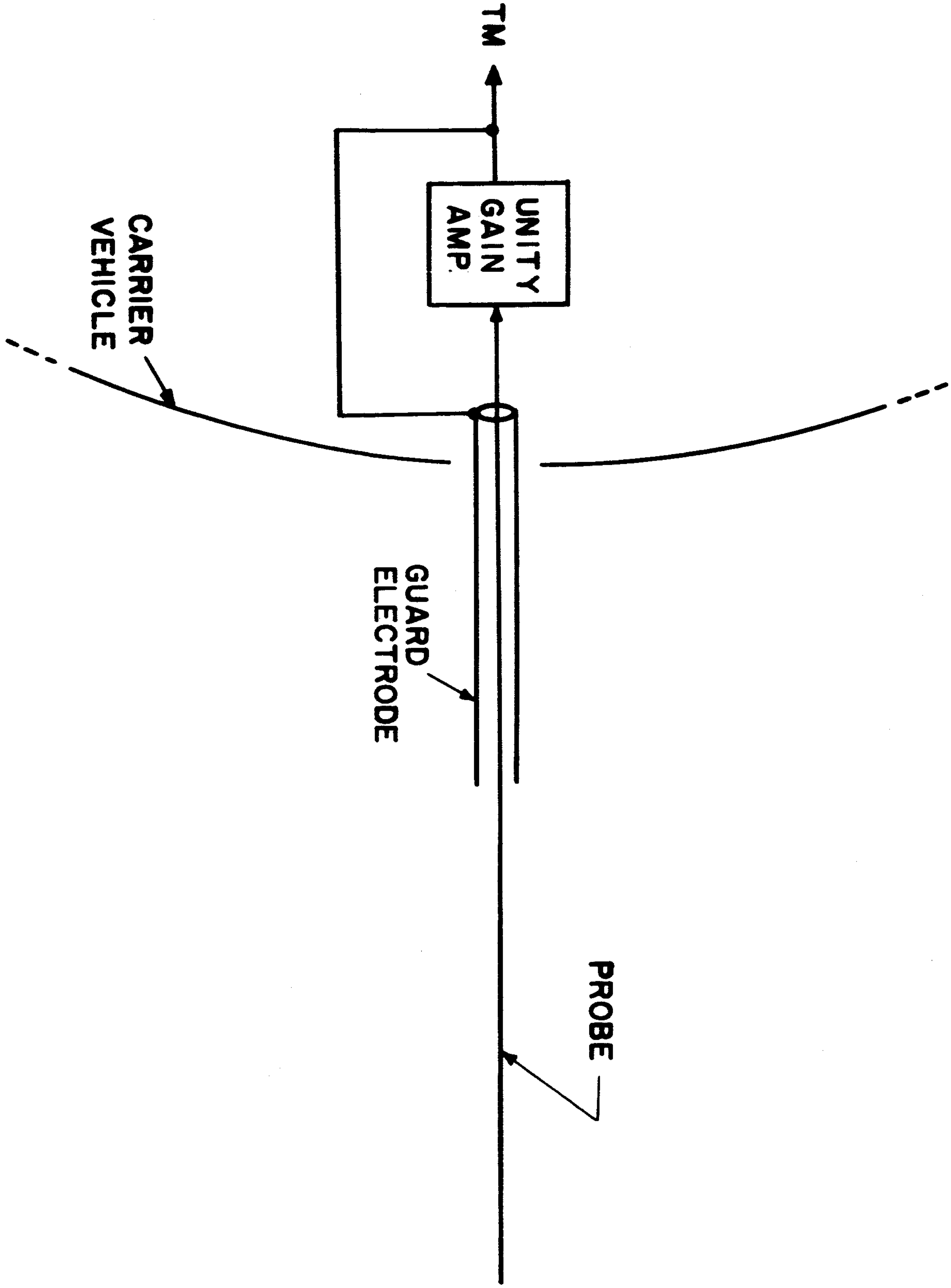

FIGURE 4

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