SIMULATION OF SOLAR WIND-MAGNETOSPHERE INTERACTION

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ABSTRACT. According to Bostik's (1956) generic definition, any plasma density irregularity observed in the solar wind and in the magnetosphere could be called a "plasmoid".

The motion of plasmoids across different non-uniform magnetic field configurations has been discussed from a theoretical point of view. When the dielectric constant of the streaming plasma is large enough for collective polarization effects to become important, an electric field develops which permits cross-B motions of all charged particles as a whole plasma entity. The intensity and direction of this E-field has been given for a plasmoid traversing a magnetic "tangential discontinuity".

It is reemphasized that the value of the integrated Pedersen conductivity is a determining factor in cross-B plasma motion, although it has been neglected in most reconnection theories. The proper scaling of the value of the integrated Pedersen conductivity is therefore also essential in Terrella simulation experiments.

It is argued that the magnetopause is located at the surface where the geomagnetic strength has a critical value and where the value of the integrated Pedersen changes abruptly from a typical solar wind value to magnetospheric value which is determined by the transverse conductivity in the Earth ionosphere.

The thickness of the Plasma Boundary Layer, where 'viscous-like' interaction is taking place as a result of Impulsive Penetration of solar wind plasmoids, is indeed determined by the Pedersen conductivity in the ionosphere and by the degree of inhomogeneity of the impinging solar wind stream. Consequently, the Impulsive Penetration model shares a feature in common with conventional "closed" magnetospheric models where 'viscous-like interaction' is essential to drive magnetospheric convection.

On the other hand, interconnection of interplanetary magnetic field lines and geomagnetic field lines, as in conventional "open" magnetospheric models results, in the Impulsive Penetration model, from collective diamagnetic effects produced by magnetized plasmoids injected into the magnetosphere. But in this more recent model, interconnection is an intermittent (i.e. a time dependent) and a

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patchy (i.e. localized in space) process.

Simple laboratory simulations have been suggested to verify the theoretical expectations discussed in this article.

INTRODUCTION .

A variety of names have been used to describe the plasma "inclusions", vortices, eddies, filaments, magnetic holes, irregularities or "flux transfert events" that are currently observed in the vicinity of the magnetopause. All these events are 'plasma-magnetic entities' like those studied by Bostik (1956) in his laboratory experiments. He has used the word 'plasmoids' to describe these plasma-magnetic entities. To avoid further proliferation of additional new synonyms for the same type of physical phenomenon or 'event', one should once and for all agree on a generic name : 'plasmoid' originally introduced in 1956 by Bostik, seems to be a most appropriate choice.

To illustrate the interaction of solar wind plasmoids with the geomagnetic field, and to model their impulsive penetration into the magnetosphere, let us first recall the important results deduced from Baker and Hamel's (1965) laboratory experiments.

BAKER AND HAMEL'S EXPERIMENTS .

Fig. 1 illustrates schematically these experiments and their results : a non-diamagnetic collisionless plasma stream can move with a constant velocity $\underline{v}_o$ across a uniform magnetic field if the magnetic field lines pass through insulating walls : i.e. if Σ_p, the Pedersen conductivity integrated along the magnetic field lines, is equal to zero or at least very small. Polarization charges of opposite sign accumulate respectively at the upper and lower surface of the injected plasma stream as a result of drifts acting in opposite directions on the ions and electrons. This action results in the production of a net positive charge on the upper boundary of the stream and an equal amount

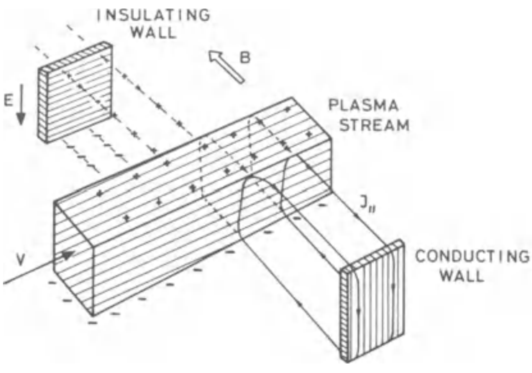


Figure 1. Simplified sketch of a non-diamagnetic plasma beam crossing a uniform magnetic field; a) the charging up effect of an insulating wall and b) the depolarizing effect of a conducting wall (Baker and Hamel 1965) are illustrated.

of negative charge on the lower boundary as shown in fig. 1. Such a charge separation will continue until the resulting electric field is strong enough to cancel the deflecting effect of the magnetic field, i.e. until

$$\underline{E} = - \underline{v}_o \times \underline{B} \tag{1}$$

The plasma stream then continues to move across the uniform magnetic field with the velocity

$$\underline{v} = \underline{E} \times \underline{B}/B^2 = \underline{v}_o \tag{2}$$

Since the plasma is collisionless, its electric conductivity parallel to $\underline{B}$ is very large, and the polarization charge will be redistributed such that the magnetic field lines become lines of equal electric potential. Furthermore, in a collisionless plasma the transverse Pedersen conductivity σ_p is almost equal to zero. But when the magnetic field lines pass through a good conductor, the polarization charge will be neutralized by the short-circuiting effect in the plate as fast as it is produced by the action of the unbalanced cross-B drift currents. Depolarizing currents will continue to flow in the conducting walls as long as the plasma stream has forward momentum (Baker and Hamel 1965; Baum et al. 1984).

The above model of a polarized plasma stream will be extended to cases of non-uniform magnetic field distributions as well as to cases of non-uniform wall conductivities. When these extensions are applied to a diamagnetic plasma stream of finite length (i.e. a plasmoid), they become especially useful in explaining some of the phenomena observed near the magnetopause : e.g.(i) 'viscous-like interaction' in the Plasma Boundary Layers; (ii) intermittent and patchy interconnections of interplanetary and geomagnetic field lines.

PLASMA FLOW WITH A PARALLEL COMPONENT.

A first extension of Baker and Hamel's plasma experiment would be to inject a plasmoid with initial velocity components both perpendicular and parallel to the uniform B-field : i.e. $v_{o\perp} \neq 0$ and $v_{o\parallel} \neq 0$. This situation is illustrated in fig. 2a. It simulates the motion of solar wind plasma elements across the interplanetary magnetic field which is not perpendicular to the radial solar wind velocity.

When the integrated Pedersen conductivity is zero (i.e. for non-conducting walls or, equivalently, for a collisionless plasma unbounded along the magnetic field lines) the electric field which builds up within the plasmoid is perpendicular to $\underline{B}$ and is given by Eq. (1). The perpendicular component of the streaming velocity is given by Eq. (2) and is equal to the initial perpendicular velocity. In the absence of external forces the parallel component of $\underline{v}$ is conserved. As a consequence, the total velocity $\underline{v}$ of the plasma element remains also equal to the injection velocity $\underline{v}_o$, as in Baker and Hamel's experiment where $v_{o\parallel}$ was equal to zero.

The field-aligned electric conductivity is large in collisionless plasmas, so that parallel electric fields are almost everywhere equal to zero. However at the edge of a plasmoid, where magnetic field lines traverse its surface, a double potential layer is formed to prevent electrons from escaping out of the plasmoid (Lemaire and Scherer 1978).

Furthermore, when the total plasma pressure inside the plasmoid does not match the exterior field and kinetic pressure, the plasmoid expands or contracts. Field-aligned expansion of the plasmoid or cross-B expansion ceases when the net momentum flux across all parts of the surface of the plasmoid is equal to zero.

The double potential layers form all around at the surface, and produce electric fields in a sheath whose thickness ranges between a

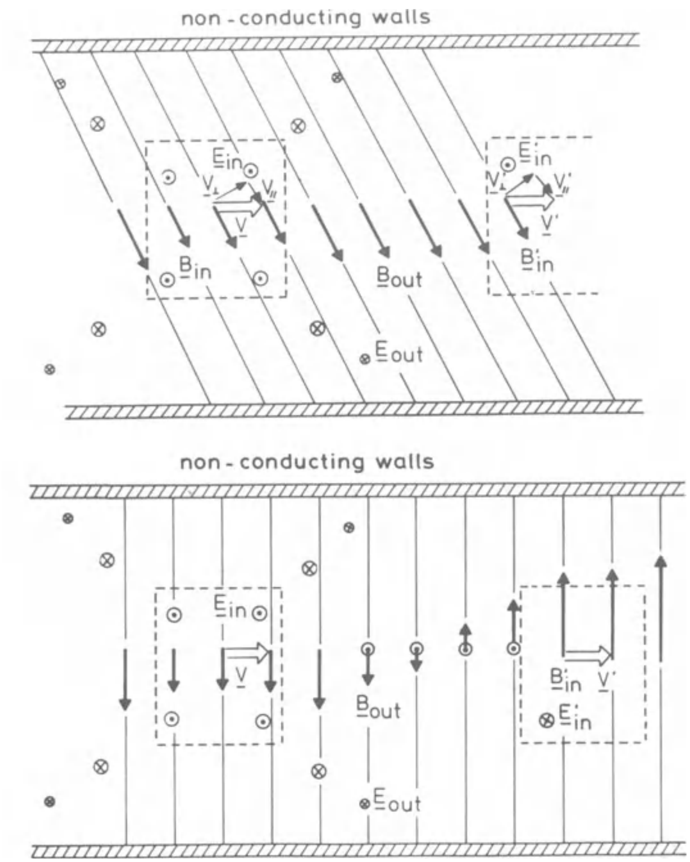


Figure 2. Schematic representation of plasmoids moving across magnetic field lines which pass through insulating walls. In 2a) the magnetic field is uniform, the initial bulk velocity of the injected plasmoid has components perpendicular and parallel to $\underline{B}$; its bulk velocity is conserved as well as the magnetic flux through a co-moving surface. In 2b) the magnetic field direction and strenght change along the ox-axis.

few Debye lengths and a few ion Larmor radii. These microscopic edge E-fields must be added to the large scale-polarization field (1) induced by the plasma motion.

Bostik (1956) observed that particles from the lateral periphery of the plasmoid are left behind. This result is obvious considering that particles in the surface sheaths find themselves in a weaker electric field than those inside. These particles experience smaller electric drifts than does the bulk of the plasma and are consequently left behind (Schmidt, 1960).

NON UNIFORM MAGNETIC FIELDS.

Another possible extension of Baker and Hamel's experiment would be to inject a non diamagnetic plasmoid into an external magnetic field whose direction and/or intensity change along its trajectory. A tangential discontinuity like that illustrated in fig. 3 corresponds to such a magnetic field distribution. Let us then assume that the initial injection velocity $\underline{v}_0$ is parallel to the x-axis; furthermore let us consider that $\underline{v}_0$ has no component along the magnetic field lines which are all perpendicular to ox.

Following a demonstration similar to that given by Schmidt (1960) for the two-stage plasma accelerator, Lemaire (1984) has shown how a charge separation electric field is produced in this case, inside the moving dielectric plasmoid, by the gradient-B and inertial drifts. Indeed ions and electrons drift in opposite directions toward the lateral surfaces of the plasma element. The resulting electric field direction remains always perpendicular to the $\underline{B}(x)$. The components of the electric field inside the plasmoid are then given by

$$E_x(x) = v_z B_y - v_y B_z \; ; \quad E_y(x) = v_x(x)\, B_z(x) \; ; \quad E_z(x) = -\, v_x(x)\, B_y\,(x) \qquad (3)$$

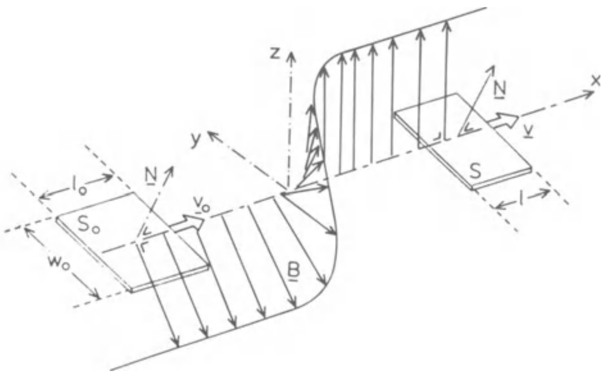


Figure 3. Magnetic field distribution across a tangential discontinuity. A plasmoid injected into such an external B- field can move through with a constant bulk velocity when the strength B is independent of x.

It can be verified that the bulk velocity of such a plasmoid is constant and equal to $\underline{v}_o$, when the magnetic field strength is independent of x :

$$\frac{d\underline{v}}{dt} = \frac{d(\underline{E} \times \underline{B})/B^2}{dt} \simeq 0 \quad \text{when } \frac{dB}{dx} = 0 \tag{4}$$

This result is slightly changed when $dB/dx \neq 0$. Indeed when the magnetic field strength as well as its direction are function of x, Lemaire (1984) has shown that

$$\frac{dv}{dt} = \frac{d|\underline{E} \times \underline{B}|/B^2}{dt} = - \frac{m^+\overline{(V_\perp^+)^2} + m^-\overline{(V_\perp^-)^2}}{2m^+B} \cdot \frac{dB}{dx} \tag{5}$$

Furthermore, taking into account conservation of the magnetic moment of charged particles

$$\mu = m(V_\perp)^2/2B \tag{6}$$

one obtains by integrating eq. (5)

$$v^2 + (V_\perp^+)^2 + (V_\perp^-)^2 = Cst = v_o^2 + (V_\perp^+)_o^2 + (V_\perp^-)_o^2 \tag{7}$$

This means that the sum of the translational, $1/2\ mv^2$, and thermal (gyration) energy, $1/2\ m(V_\perp^+)^2 + 1/2\ m(V_\perp^-)^2$, is a constant of motion. A similar result was first demonstrated by Schmidt (1960) but for non-rotating magnetic field distributions.

A plasmoid penetrating into a region of lower magnetic field intensity will therefore be accelerated due to adiabatic loss of thermal energy. Conversely, when a solar wind plasma element moves from the magnetosheath into the magnetosphere where the $\underline{B}$-field intensity is often higher, it can be seen by combining eqs.(6) and (7) that the velocity of the intruding plasmoid decreases as

$$v(x) = \left\{ v_o^2 + \frac{2(\overline{\mu^+} + \overline{\mu^-})}{m} [B_o - B(x)] \right\}^{1/2} \tag{8}$$

Demidenko et al. (1969) have shown experimentally that in a monetonically increasing magnetic field there is a critical field strenght $B(x_1)$ where the plasmoids are stopped and adiabatically reflected. This holds also for rotating B-field like those considered here. The value of the critical field can be deduced from eq. (8) by setting $v(x_1) = 0$. In the case of the geomagnetic field this critical value $B(x_1)$ determines the average magnetopause location.

As the vector $\underline{B}(x)$ rotates, the polarization electric field $\underline{E}(x)$ rotates through the same angle but, both vectors remain orthogonal to each other : see eq. (3).

An especially simple case (but often considered in reconnection theories) is when $B_y = 0$, and when the remaining component $B_z(x)$ changes sign at some distance x_2. It can be seen from eq. (3) that the only non-zero component of the electric field, $E_y(x)$, does then also change sign at x_2.

In stationary reconnection models where $B_z(x)$ changes sign at a neutral line, one has traditionally forced the electric field to have non-zero component in the y direction at $x = x_2$. This assumption has been introduced by Petschek (1964) to make the flow velocity $\underline{v}$ singular at the $x = x_2$; indeed when $B_z(x)$ changes sign at x_2 but not $\overline{E_y}(x)$, it results then that $v(x) = E_y(x)/B_z(x)$ must tend to infinity as $x \rightarrow x_2$. To resolve this question in the framework of a steady-state ideal MHD flow theory, the 'reconnectionists' suggested that jetting should take place at x_2 in directions parallel to the oyz plane. On both sides the plasma is supposed to converge toward this plane of discontinuity which is then imagined to coincide with the magnetopause; the converging plasma flows are assumed to be deflected through a right angle, and to diverge away from a narrow "diffusion region" surrounding the neutral point or the X-line (Petschek 1964; Semenov et al. 1983).

However, it must certainly not be assumed, a priori, that this very particular type of flow pattern is necessarily imposed on nature by any pressure from any external physical factors - except for pressure from the MHD community. The flow stream described by eqs. (3-8) has the new advantage of being non-singular at x_2. It is based on simple plasma kinetic and electromagnetic theory without the need to invoke anomalous or undefined physical processes ('some kind of instability') anywhere in space, not even in a small "diffusion region".

DISCONTINUOUS VALUES FOR THE INTEGRATED PEDERSEN CONDUCTIVITY.

Let us once again return to Baker and Hamel's simple experimental set up. However, consider now that only the first section of the tank is made of insulating walls ($\Sigma_p = 0$), while the second part is coated with highly conducting material such that $\Sigma_p = \infty$ (see fig. 4a). The magnetic field $\underline{B}$ is uniform, and a plasmoid is injected with an initial

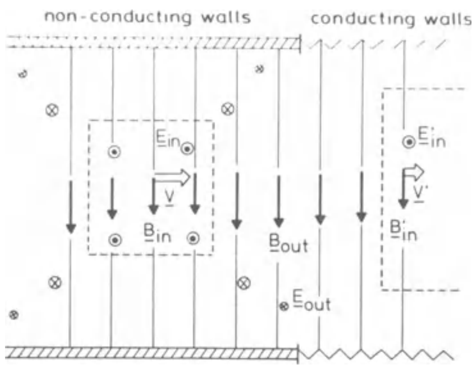


Figure 4a. Schematic representation of plasmoids moving across magnetic field lines of which some pass through insulating walls and others through conducting plates. In 4a) the applied magnetic field is uniform; the injected plasmoid is braked in the conducting section of the tank like a bullet in a viscous fluid.

velocity $\underline{v}_o$ parallel to the ox axis. It has been shown above and demonstrated experimentally that, in the first portion of the tank, the velocity $\underline{v}$ of the plasmoid remains constant and equal to $\underline{v}_o$ as a consequence of the vanishingly small value of Σ_p and of the high value of the dielectric constant (Schmidt 1960).

But as soon as the front edge of the plasmoid penetrates into the region where the field lines are connected to the conducting walls, the forward motion of the plasma is stopped as a consequence of the depolarization currents which flow through the walls and neutralize all space charges and all interior potential differences in the plasmoid (Baker and Hamel 1965; Baum et al. 1984;see also the Introduction of this article).

Because of the strong electromagnetic coupling been the collisionless plasma and the conducting walls, its forward momentum is transferred to the walls. By reaction, the incident plasmoid can be deflected or reflected backwards when the walls are superconductors, and when they have much larger inertia than the plasmoid itself. In this ideal MHD case, no energy dissipation is involved during the bouncing back.

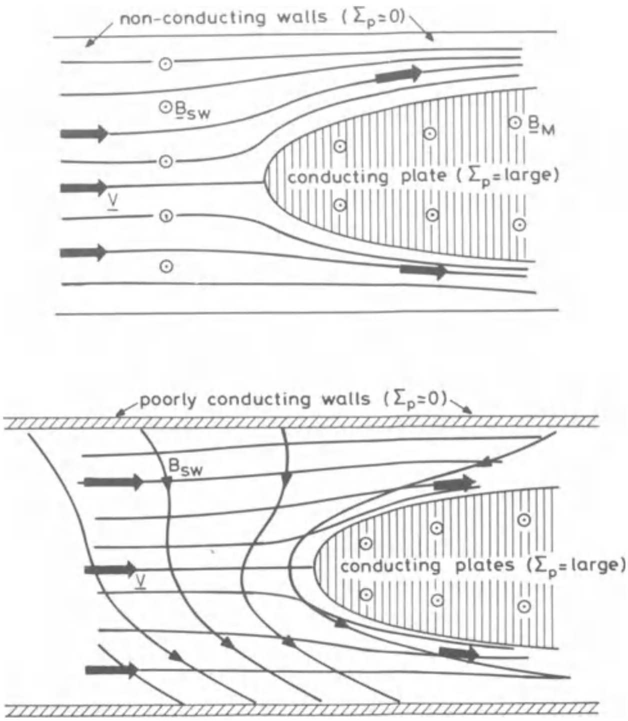
When the conductivity of the walls is not too large, and consequently when Σ_p has intermediate values the plasmoid does not bounce back but it is braked over a finite distance like a bullet being decelerated in a viscous fluid. The penetration depth, d, is almost inversely proportional to the integrated Pedersen conductivity (Lemaire 1977). Therefore, when $\Sigma_p = 0$ the penetration depth is infinitely large (i.e., there is no braking like that in the first section of the tank where magnetic field lines pass through insulating walls); on the contrary, when $\Sigma_p = \infty$, one has $d = 0$ as expected in the ideal MHD approximation, and as already discussed in the previous paragraph.

Consider now that the second portion of the plasma tank is also constructed with poorly conducting wall material, but that two conducting plates are placed on both sides of the plasma stream, perpendicular to the uniform magnetic field $\underline{B}$ as illustrated in fig. 4b. A parabolic shape has been given to the plates so as to simulate the Earth's magnetospheric cavity containing all magnetic field lines passing through the conducting ionosphere.

The non-diamagnetic plasma flow convecting freely across magnetic field lines with small integrated Pedersen conductivity eventually impinges on a region where this conductivity is significantly enhanced. For physical reasons already explained above, the flow will lose momentum in the forward ox direction and, by partial reflection at the interface of both regions, it will be deflected along the surface of the electromagnetic obstacle formed by the bunch of magnetic field lines passing through one of the conducting plates. When the value of Σ_p in the conducting plates is adjusted to vary from a very large to a very small value, the penetration depth changes from almost zero (i.e. the MHD limit) to infinity (i.e. free cross-B flow).

Note that in the simulation experiment proposed in fig. 4b, the magnetic field intensity is "northward" in both sections of the tank. But the conclusions reached above do not directly depend on the direction of the magnetic field in the incident plasma flow relative to the magnetic field orientation in the conducting section. Indeed it has been indicated already that the cross-B bulk velocity of a non-diamagnetic plasmoid does not depend on the rotation angle of the external B-field distribution.

Fig. 4c illustrates the streamlines and magnetic field line topology for the case in which the magnetic field in the source region



Figures 4b and c. Schematic representation of plasmoids moving across magnetic field lines of which some pass through insulating walls and others through conducting plates. In 4b) the applied magnetic field is uniform, but the distribution of wall conductivities is discontinuous; the non-diamagnetic plasma beam moving across the magnetic field is deflected sideward around the conducting electromagnetic obstacle. In 4c) the magnetic field direction in the source region of the diamagnetic plasma beam is no longer parallel to the applied field in the conducting region; diamagnetic effects produced by Chapman-Ferraro currents determine the final magnetic field line distribution; impulsive penetration of small scale plasma irregularities result in the formation of an Plasma Boundary Layer whose thickness is a function of the value of the integrated Pedersen conductivity in the conducting region of the simulation experiment.

where the plasmoid is formed, is neither parallel nor antiparallel to the B-field inside the conducting section of the tank.

The incident plasma flow in fig. 4c is supposed to simulate a high-β solar wind drifting across geomagnetic field lines linked to the Earth's ionosphere where Σ_P is of the order of 1 Siemens and is quite different from that in the interplanetary medium. When the value of β in the streaming plasma is of the order of unity, we will see below that diamagnetic effects are important.

Chapman-Ferraro currents circulate parallel to the average magnetopause and plasmoids surface where they are driven by kinetic plasma pressure gradients and magnetic field gradients. These magnetization, grad-B and curvature plasma currents change the magnetic field intensity in the region of plasma deflection; they enhances the strength of B outside the plasmoid such that the total plasma pressure (kinetic + magnetic) is conserved across the surface of a plasmoid or of the magnetopause (Burlaga and Lemaire, 1978). In the case of Baker and Hamel's non-diamagnetic plasma beams, Chapman-Ferraro current intensities are small (fig. 4b); however in the case of solar wind, diamagnetic plasma streams, these current intensities are large (Roth 1978, 1979) and their distribution can be rather complex.

It is clear that when the incident velocity of the plasma is supersonic a shock wave must form in front of the obstacle.

VISCOUS LIKE INTERACTION .

At the magnetopause there is often a plasma density gradient. Because of the very small Coulomb collision frequency the cross-B diffusion coefficient is almost equal to zero. Strong wave-particle interactions have been invoked as being responsible for solar wind plasma diffusion into the magnetosphere. Impulsive Penetration is a third entry mechanism which is probably the most efficient of all (Lemaire and Roth 1978; Lemaire 1979b). Impulsive Penetration is a time-dependent process based on the existence of momentum density inhomogenities in the impinging plasma stream.

These plasma irregularities are plasmoids according to Bostik's definition. They can be formed in the solar wind or in the solar corona by unstable flow regimes. Kelvin-Helmholz instability at the magnetopause or in the interplanetary medium can perhaps also produce such plasma inhomogeneities in the impinging solar wind flow. But whatever their origin may have been, once such plasmoids are present in the solar wind they penetrate deeper into the geomagnetic field when they have larger momentum density. Indeed the critical magnetic field strength $B(x_1)$ for which such more impulsive plasmoids are stopped by adiabatic heating is larger than for the average background solar wind plasma; their bulk velocity given by eq. (8) goes to zero deeper into the geomagnetic field than average solar wind plasma elements which are stopped at the average magnetopause surface.Their penetration depth, d, has also been shown to be larger when the integrated Pedersen conductivity of polar cusp geomagnetic field lines is smaller (Lemaire 1977, 1979a).

Considering a distribution of plasmoids with a broad range of momentum densities, geometrical shapes and dimensions, one can account the existence of a rather wide Plasma Boundary Layer at the outer edge of magnetosphere. Magnetospheric plasma and solar wind plasma are intermixed in this transition layer (Roth 1978, 1979; Lee and Kan 1982; Lemaire 1979b; Eastman and Hones 1979).

It has been suggested by Heikkila (1982) that the hypothetical 'viscous-like' interaction mechanism introduced to drive magnetospheric convection is a consequence of the impulsive penetration of plasmoids into the magnetospheric Plasma Boundary Layer; the solar wind momentum of the penetrating plasmoids is deflected eastwardly (Lemaire, 1984), and can indeed be transfered, via electromagnetic coupling, to both the magnetospheric and the ionospheric plasma in the dayside cusp region (Lemaire 1979a).

It can be concluded, therefore that Impulsive Penetration theory fits well in the context of "closed" magnetospheric models where viscous-like interactions play an important role (Piddington 1960a,b; 1979; Johnson 1960; Axford and Hines 1961).

DIAMAGNETIC EFFECTS.

In Baker and Hamel's and Demidenko et al's experiments as well as in the solar wind, the plasma density, n, is large enough for collective dielectric effects to be important (i.e. $K \gg 1$) :

$$K = 1 - \varepsilon = \frac{nm^+}{\varepsilon_o B} = \frac{nm^+ c^2}{B^2/\mu_o} = \left(\frac{c}{v_A}\right)^2 = \left(\frac{\omega_p^+}{\Omega^+}\right)^2$$

where ε is the plasma dielectric constant; v_A its Alfvèn speed; ω_p^+ the ion plasma frequency and Ω^+ the ion Larmor frequency. But in these laboratory experiments, n is not large enough for diamagnetic effects to be as important as in the solar wind. Indeed, Baker and Hamel's plasma streams have a low β-value; β is much smaller than in interplanetary space plasmas where β = .1-10.

When the condition

$$\beta \ll 1 \tag{9}$$

is not satisfied, the magnetic fields generated by plasmoids are appreciable as compared with the external B-field; the plasma then exhibits "diamagnetic" properties (Schmidt 1960). As a consequence of plasma pressure gradient drifts, magnetic gradient drifts, and curvature drifts, collective currents $j_p(x,y,z,t)$ are driven within the plasmoid and at its surface. They determine an additional magnetic (induction) field $\underline{B}_p$ such that

$$\underline{\nabla} \times \underline{B}_p = \underline{j}_p \tag{10}$$

The fields $\underline{B}_p(x,y,z,t)$ that are generated by these local plasma currents can be rather complex, but have to be added (vectorially) to the external magnetic fields $\underline{B}_e(x,y,z,t)$ produced by distant (exterior) currents or magnetized bodies; the external field satisfies the equation

$$\underline{\nabla} \times \underline{B}_e = 0 \tag{11}$$

and the total field $\underline{B} = \underline{B}_p + \underline{B}_e$ verifies also eq. (10) with $\underline{B}_p$ replaced by $\underline{B}$.

When $\beta \sim 1$, $\underline{B}_p$ is of the order of $\underline{B}_e$ and the field line distribution of the external magnetic field ($\underline{H} = \underline{B}_e/\mu_o$) is drastically perturbed. This is illustrated in fig. 5a and 5b showing the magnetic field line distribution obtained when a cylindrical current density system (axial and toroïdal) is superimposed on an external dipole which simulates the Earth's magnetic field; the filamentary current system simulates that created by an ideal cylindrical solar wind plasmoid penetrating into the magnetosphere. Magnetopause and tail currents have been ignored for the sake of simplicity. These simplifications, however, are not essential for the aims of this demonstration.

In fig. 5a the filament is located at 10 Earth radii. One can see

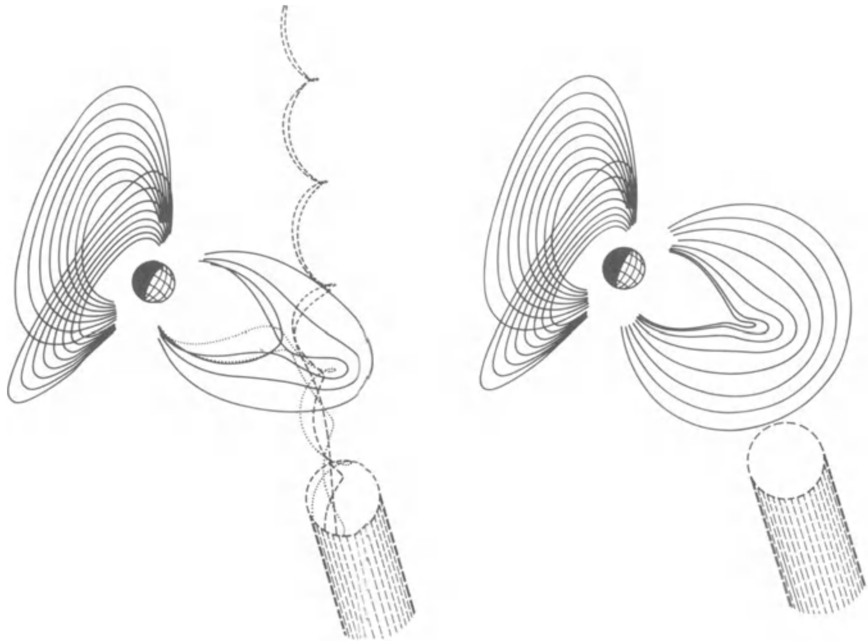


Figure 5. The magnetic field line distribution resulting from superposition of a dipole field and the perturbation fields generated by a cylindrical system of given axial and toroidal current density distributions. The currents simulate those of filamentary solar wind plasmoids penetrating into the geomagnetic field; they produce helicoidal diamagnetic fields of which bundles of field lines interconnect with those of the dipole; a) on the right panel the axis of the current system is located at 10 Earth's radii, b) on the left panel it is closer to Earth at 8 R_E where the local dipole field intensity is significantly larger than the diamagnetic field perturbation.

that, in addition to "closed" geomagnetic field lines and interplanetary magnetic field lines, there are bundles of field lines, originating in the polar cusp regions, which are interconnected to those of the solar wind. These interconnected field lines ressemble those often drawn to represent approximatively the magnetic field topology in 'flux transfer events'. It should be pointed out that the calculated field topologies represented in fig. 5a and b, satisfy precisely Maxwell's equation

$$\underline{\nabla}.\underline{B} = 0 \ , \qquad (12)$$

and that there exists at least a current system producing them.

The figs. 5a and 5b have been reproduced from a video-montage illustrating the time-dependent interconnection of geomagnetic field lines and interplanetary magnetic field lines induced by diamagnetic solar wind plasmoids (Lemaire 1982b). Such motion pictures show more clearly and convincingly than a two-dimensional diagram how these interconnections proceed from one latitude to another, and from one polar cusp longitude to another as a plasmoid penetrates deeper into the geomagnetic field. They indicate that the Impulsive Penetration theory, when properly understood, does predict the existence of interconnected (some would probably prefer to say 'reconnected' or 'merged') magnetic field lines inherent in earlier steady state 'open' magnetospheric models.

CONCLUSIONS.

The theory of Impulsive Penetration of Solar Wind plasmoids into the geomagnetic field contains aspects of both the "open" and "closed" magnetospheric models. Indeed, it incorporates the existence of open (interconnected) magnetic field lines, as well as the notion of 'viscous-like' interaction as discussed above.

Baker and Hamel's experiments have been used here as a basis for discussion. Several possible modifications and qualifications of these experiments have been suggested in order to simulate more accurately the interaction of an inhomogenous 'gusty' solar wind plasma with the Earth's magnetosphere.

It has also been shown that it is not only the topology of magnetic field lines which determines the position of a magnetopause and thickness of the Plasma Boundary layer, but also the value of their integrated Pedersen conductivity. Consequently, even in 'Terrella' simulation experiments like those of Baum and Bratenahl (1982) or Podgorny _et al_. (1978) it appears to be essential to scale properly the values of the integrated Pedersen ionospheric conductivity by making appropriate adjustments to the thickness of the insulating wall coatings that are supposed to carry the depolarization Pedersen currents. To imitate correctly the solar wind magnetosphere interaction, it is important to scale carefully the different boundary conditions, not only in the interplanetary medium but also in the ionosphere of a planet.

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