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ACCELERATION OF A CLOUD OF IONIZED GAS WHOSE OWN MAGNETIC FIELD SCATTERS AN ELECTRON BEAM

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We consider acceleration of a plasma with its own magnetic field in the scattering of an incident electron beam. Two ways of increasing the amount of energy extracted from the electrons are indicated: multiple scattering of the electron beam by the magnetized plasma, and application of induction inertia ("increasing the weight") of electrons in a powerful current. It is noted that the effect can be employed in plasma accelerators and that it may occur in astronomical processes.

WE consider the mechanism whereby a cloud of ionized gas with its own magnetic field is accelerated when an electron beam is incident on the cloud. Its own magnetic field makes the plasma opaque to the electrons, and the strong scattering of the electrons is accompanied by an effective transfer of momentum to the plasma, in view of its connection between the plasma and the force lines of the frozen-in field which produces the scattering. This acceleration mechanism is the opposite of the Fermi mechanism for the acceleration of particles (by reflection from moving cosmic plasma clouds with 'frozen-in' magnetic fields), since it uses the reaction of the cloud.

An incident nonrelativistic electron current J acts on a magneto-plasma cloud from which the electrons are strongly scattered or reflected, with an effective force $F \approx m_0 v_e J/e$. For example, if $J = 10$ amp and the electron velocity is $v \approx 0.3c$ we obtain $F \approx 10^3$ dynes, which accelerate a plasma with mass $M \approx m_i N \approx 10^{-12}$ g (the total number of particles is $N \approx 10^{12}$) to a velocity $u \approx Ft/M \approx 10^6$ cm/sec within $t \approx 10$ μsec.

To increase the acceleration force and to improve the utilization of the beam energy, the electrons can be multiply reflected from two magnetized clouds or from a cloud and a magnetic mirror (concentration of force lines of an external magnetic field), with the electron beam injected along the mirror axis. In scattering and reflection from a magnetized plasma, the electron velocity direction changes or a shift from the axis takes place, and the electrons remain locked for a long time between the mirror and the magnetized cloud.

Another possible method of intensifying the action of the electrons on the plasma is based on an inductive increase of the electron mass. If the incoming beam has a noticeable inductance (i.e., $N_1 r_0 L_1 \gg 1$, where N_1 is the running number of charges, r_0 their classical radius, and L_1 the running induct), then the momentum transferred by the beam can exceed the mechanical momentum of the beam particles in view of the inductive increase in the particle mass $m' = m_0 (1 + N_1 r_0 L_1) \gg m_0$. In this case the effective force is

$$F = m_0 \{1 + N_1 r_0 L_1\} v_e J/e \approx L_1 J^2/c^2.$$

For example, even when $J \approx 10$ kiloamp and $L_1 \approx 10$ we obtain $F \approx 10^6$ dynes, i.e., high acceleration of the cloud is expected when a plasma cloud with frozen-in magnetic field is injected in a gas-discharge current.

The limiting velocity u_{max} which a magnetized cloud opaque to electrons and ions can acquire in a gas discharge can be readily determined by equating the pressures of the electron and ion beams in the coordinate system of the moving cloud:

$$(v_i + u_{max})^2 \approx (v_e - u_{max})^2 \, m'/m_i,$$

where v_e and v_i are the ordered velocities of the electrons and ions. When $v_i \ll u_{max} \ll v_e$ we obtain $u_{max}^2 \approx m' v_e^2/m_i \approx c^{-2} J^2 L_1/m_i N_1$.

We note that the process need not necessarily be nonstationary for an inductive mass increase to occur. Even in stationary scattering of the current by an obstacle or in stationary flow of current over the obstacle, the obstacle will be acted upon by a force determined by the value of the current and by the running inductance, in accordance with the formula given above (this can be readily verified by calculating directly the forces of interaction between the unperturbed and perturbed portions of the current).

It is not difficult to produce special plasma-magnetic inhomogeneities: when a plasma is produced in a magnetic field, partial capture of the field by the produced plasma takes place spontaneously. If the plasma is produced in a gas discharge, the residual currents and fields are also retained in the plasma.

The momentum can be transferred to the plasma not only by scattering of the electron beam on the plasma's own field, but by scattering of the beam on the inhomogeneities that the plasma produces in the external magnetic field (on the bends of the force line and on the strengthened edge field crowded out by the plasma).

In cosmic space this process can occur near stars, in the regions where currents circulate and plasma-magnetic inhomogeneities—turbulences—exist. The large scales of the processes (large N_1 and long acceleration paths, the long times of confinement of the self-magnetic fields and of equalization of the inhomogeneities) may cause these processes to produce bursts of accelerated cosmic particles.

The reduction in the penetrating ability of a plasma with internal magnetic field can manifest itself also in the transfer of momentum of a magnetized plasma stream incident on a layer of another plasma. Such a process is the apparent cause of the pressure that the solar plasma stream, which carries an internal magnetic field, exerts on the plasma of the tails of comets.

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