

Frozen-in field lines

In my monograph Cosmic Electrodynamics(1950) I devoted much space to clarifying the advantage of the concept "frozen-in magnetic field lines", which made it possible to treat a number of plasma phenomena in a simple way. However, the same monograph also contained a chapter on "Magnetic storms and aurorae" in which this concept was not mentioned. The reason was that it was obvious that in the magnetosphere the lines of force are not frozen-in. If they were the equatorial region must corotate with the ionosphere, and it was obvious that it did not. However, I could not understand why.

Some years later this was clarified. In a paper 1958 I pointed out that the reason must be that there were "parallel electric fields (= electric fields parallel to the magnetic field lines)". Independently, McIlwain 1960 made the same conclusion from his measurements in the magnetosphere at about the same time.

In our monograph "Cosmical Electrodynamics, Fundamental Principles" Fälthammar and I (1965) pointed out that the frozen-in concept must be used with care, because [in] it can sometimes be misleading. We discuss the motion of electrons in the magnetosphere and demonstrate that the magnetic mirror effect may produce large parallel electric fields (p 162-167). Further we discuss the limitations of the frozen-in concept (p 189-191). We point out that [with] a parallel electric field in a low density plasma the magnetic lines of force need not be frozen in. We conclude that "in low-density plasmas the concept of frozen-in field lines is questionable". Indeed, this picture has become very popular because it is thought to be of great pedagogical value. This is not correct. It is a pseudo-pedagogical concept. It makes you believe that you understand a situation, when in reality you have completely misunderstood it.

In a large number of later papers and especially in my monograph Cosmic Plasma I have given increasingly strong arguments for the view that the frozen-in concept often is terribly misleading when applied to magnetospheric problems. This applies also to "magnetic merging" ("magnetic reconnection") concepts. There is no objection to magnetic merging as a purely geometric description of what happens when the geometry of electric currents changes, but it is very often -- if not always -- wrong to calculate the transfer of energy by the magnetic merging formalism. The reason is that the magnetic merging theories are basically local theories. But as soon as "the magnetic field has a non-zero curl", i. e. an electric current flows the whole region where this current flows must be taken into account. In other words we need a global theory. To treat the problem with a local theory is wrong.

Frozen-in field lines.

~~Carl-Gunnar Fälthammar~~
~~FROZEN-IN~~
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Some years later this was clarified. In a paper ¹⁹⁵⁸ ~~1958~~ I pointed out that the ~~only~~ reason must be that there were "parallel electric field" (= electric fields parallel to the magnetic field lines). ~~Independently, McIlwain made the same conclusions~~ ¹⁹⁶⁰ ~~Independently, McIlwain 1960~~ ~~From his measurements~~ ~~in the magnetosphere. McIlwain reached the same~~ ^{at about the same time.}

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that the frozen-in concept ⁴ must be used with care, because in ~~certain situations~~ it can sometimes be misleading ~~(p. 167)~~ ~~and~~ ~~deserve a paragraph~~. We discuss the motion of electrons in the magnetosphere and demonstrate that the magnetic mirror effect may produce large parallel electric fields (p. ~~166~~¹⁶² = 167). Further ~~we~~ we discuss the limitation of the frozen-in field concept (p. 189-19). We ~~and~~ point out that a parallel electric field in a low density plasma the magnetic lines of force ~~and~~ need not be frozen-in. We conclude that "in low-density plasmas the concept of frozen-in field lines is questionable." Indeed, the ~~popularity~~ ~~of this picture~~

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The reason is that the magnetic mapping theories are basically ~~local~~ ^{local} theories. But as soon as ^{i.e. electric} an ~~even~~ current flows (the magnetic field has a non-zero curl) the whole region where this current flows must be taken into account. In other words we need a global theory. To treat the problem with a local theory is wrong.

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