[an error occurred while processing this directive]

Site Map	Quest. & Ans.	Glossary	Timeline	For Teachers	Review (1)	Review (2)	Central link

[an error occurred while processing this directive]

#10a. Particle Drifts in Space (Optional)

(Files in red–history)

- **Index**
- 9. Magnetic trapping
  - 9H. Poincaré, 1896
- 10. Trapped Motion
  - 10H. Einstein, 1910
- 10a. Particle Drift
- 11. Explorers 1/3
  - 11a. Geiger Counter
- 12. Rad. Belts

Space physics can be weird. In regions of magnetic fields, the relation between electric fields and currents is very different from its form in everyday technology.

Ohm's law tells that electric fields drive electric currents, from high voltage to low voltage. In a conductor such as a wire, **electrons move from (-) to (+)**, while ions (if they are free to move), are pushed in the opposite direction, (+) to (-). In space, on the other hand, the **the entire plasma is moved sideways,** perpendicular to both magnetic and electric field lines. No steady electric current results from the electric field, and **both** ions and electrons advance in the same direction.

On the other hand, electric currents often flow in space **without any voltage driving them**. No electric field is involved--the magnetic field is doing it all, when it has the appropriate structure.

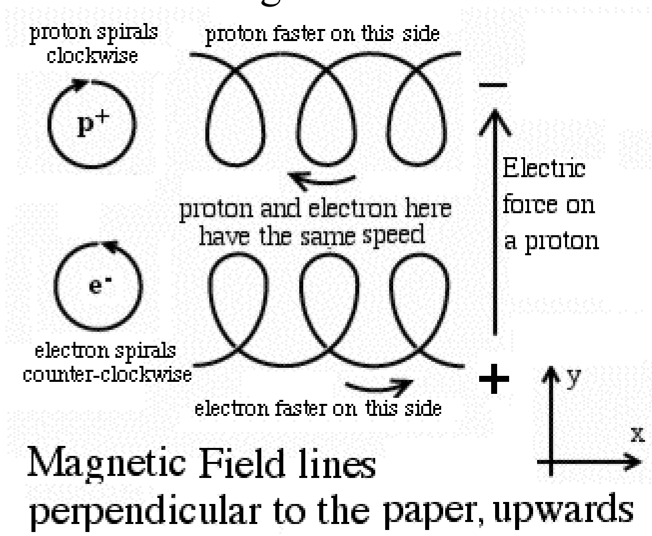
This strange behavior is explained below. No math is used, but the arguments are a bit complex--skip this part, if you want. If you decide to continue, **go slow**: it only takes a short time to **read** this web page, but much longer to **understand** it. Make sure to assimilate each part of the argument before going to the next one.

Electric Drift

The drawing shown here explains what happens when electric and magnetic fields act together on ions and electrons. Consult it in each stage of the discussion.

1. *Why electric fields* ***parallel*** *to magnetic field lines are rare in space*

It will be assumed in what follows that the direction of the electric force ("direction of the electric field") is always **perpendicular** to the local direction of magnetic field lines.

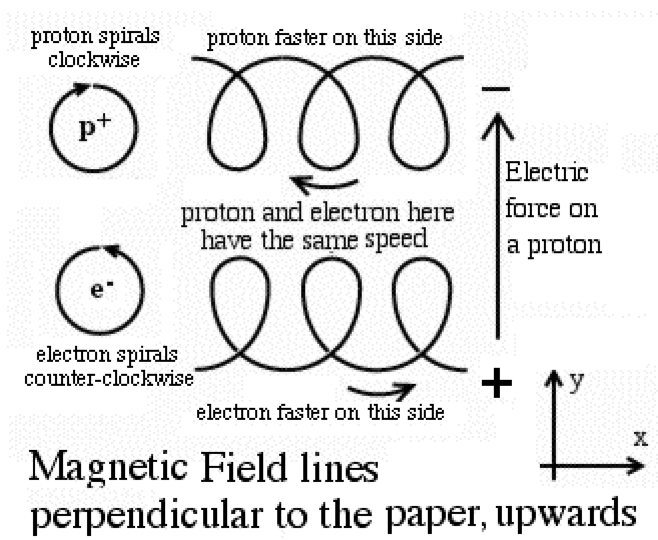


There exists a reason. In space, ions and electrons spiral around their guiding magnetic field lines, but at the same time they can also **slide** along those lines, like beads threaded on a wire.

If the **electric force** had some part in that direction (a "vector component"), those ions and electrons, as they advance along their guiding field lines, would also be accelerated by it, and gain speed. However... gaining speed also means **gaining energy**. Because energy in nature is conserved, whatever the particle gains, **weakens** the accelerating part of the electric field, and unless fresh energy is constantly supplied, that part does not last long.

Without such fresh energy (the usual case), the electric force along the field line quickly drops to zero. When that happens, the **same voltage** exists at all points along a magnetic field line, leaving no voltage differences that might drive currents in that direction. The remaining electric field is then **perpendicular** to the magnetic field lines, as in the drawing here.

An exception to this rule is discussed in section #28, dealing with the origin of the aurora. There energy **is** being supplied and the electric force **does** have a component in the same direction as the magnetic field line.



2. *The Electric Force*

For the above reason, the local magnetic field lines in the **drawing (repeated here for convenience)** are assumed to be **perpendicular** to the paper, **coming out towards you.** Suppose also the electric field--representing the electric force--is **in the plane of the drawing, towards the top of the figure.** A straight arrow was drawn giving that direction, which we choose to be the y direction in a system of (x, y) axes, drawn in the bottom right corner.

A positive particle--such as a proton, marked here **p+** --is pushed by the electric force towards the **top** of the drawing, in the +y direction.

A negative electron, marked **e-**, is pushed towards the **bottom,** in the -y direction You can imagine (if you wish) a positive charge somewhere below the drawing, and a negative charge somewhere above it, creating that force--repelling or attracting the proton or electron.

3. The Magnetic Force Alone

If the electron and the proton (or other positive ion) were free, they would simply move in those directions. But they are not free, because of the **magnetic force**.

If only magnetic forces were present (no electric field), the **proton** would circle around a magnetic field line in the **clockwise** direction (from where we are looking) and the **electron** in the **counter-clockwise** direction. These directions are given near the left edge of the drawing.

4. Electric and Magnetic Forces together

The electric force modifies the motion. **Protons** are accelerated in the +y direction, so they move a bit **faster** on the part of their circle **closer to the top** of the page (see drawing above!).

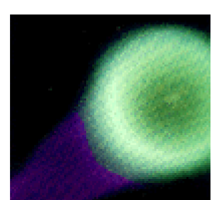
Electrons are accelerated in the -y direction, so their speed is a bit greater on the part of their circle **closer to the bottom**.

Faster ions or electrons **circle with a bigger radius.** They behave a bit like a racing car: the greater its speed, the wider is the circle it follows when going around a curve.

Therefore **protons make wider circles at the top** of their circles, and **electrons make wider circles at the bottom** of their circles. This is shown in the drawing, and the result is a slow crablike sideways motion (**"drift"**) in the (-y) direction, by **both ions and electrons.** Even though they circle their field lines in opposite directions, the electric field moves them **both in the same direction**, to the right.

It can also be shown that the velocity of both motions is always the same--even though protons are nearly 2000 times heavier, and even though the initial energies of the particles can be very different. (To those familiar with mathematics and physics, this process can be explained much more concisely and transparently.) The result is always a **sideways flow of the plasma**, a migration of the entire plasma, a **bulk motion of the gas** rather than a flow of electric current.

Barium Clouds and Solar Wind



Such an "electric drift" takes place in the barium cloud (section #8 whose figure is repeated here). The green cloud of neutral barium **stays still**, while any electric field present makes the purple cloud, consisting of ions and electrons, **drift away** from it (see illustration).

Of course, since ions and electrons remain free to slide along magnetic field lines, the ion cloud also expands slowly in that direction (or rather, in two opposite directions--up **and** down the field lines).

Where can such electric fields come from? Probably from far out in space. As noted earlier on this web page, a magnetic field line tends to have the same voltage everywhere along its length. If an electric field is created anywhere on that line, its voltage will be transmitted to the rest of it, and with it, the electric field is also transmitted. Thus an electric field created far in space can spread to the end region of the line, where the line comes down into the atmosphere, and where the transmitted field causes barium clouds to drift.

> **Electric fields in space also arise in other ways**. When some powerful cause "pushes" plasma to move in some direction, an electric fields helps achieve this. The positive and negative charges creating such a field need only a relatively small number of electrons to be moved to new positions, and where the impulse for moving the plasma is strong enough, nature obliges and shifts them. The motion of plasma--changing the magnetic field line structure--is also associated with an electric field, of a type which **cannot** be conveniently described by simple voltage distributions.

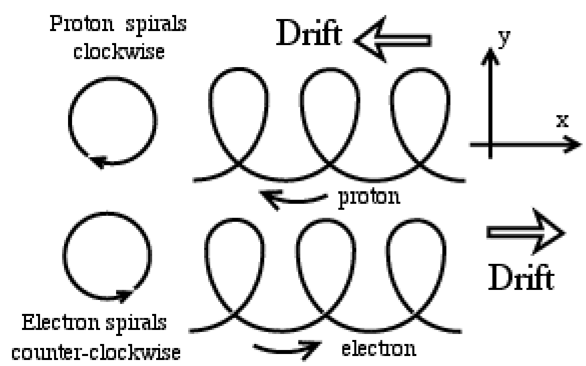
One example is **the solar wind**, a steady flow of plasma spreading out from the solar corona, the hot upper atmosphere of the Sun, which is too hot for the Sun's gravity to retain it (see section #18). The solar wind spreads **radially outwards**, while the interplanetary magnetic field lines which accompany it are **expanding spirals** around the Sun (section #18a).

The radial motion of solar wind ions and electrons must cut across those spirals. How do those particles **avoid being forced into tiny spirals** around those lines? By an electric field! The flow of the solar wind is driven by powerful energy sources, which make its motion take precedence, which it does by creating the appropriate electric field.

(On the other hand, high energy particles from solar outbursts are too few in number to force their way through, and are forced into the spiral route. See note at the end of section #18a.)

Magnetic Drifts

Now to the other oddity--**electric currents without any voltage**.



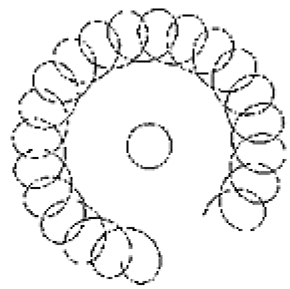
Suppose as before that magnetic field lines are perpendicular to the drawing, and that the same (x, y) axes are used as before. Only now **(drawing on the left)** no electric field exists, and instead the **strength of the magnetic force** changes with distance in the y direction--it **is much greater at the top** of the drawing than at the bottom.

As before both ions and electrons circle around magnetic field lines, as drawn (we ignore the sliding motion). However, the **size** of the circle also depends on the strength of the magnetic force--the stronger the force, the smaller the radius of the circle. (In the limit where the magnetic force drops to zero, the particles move in straight lines--same as circles of infinite radius!)

Because the way the strength of the force changes, the orbits, again, are no longer circles but flat spirals (**see drawing**), curving more sharply at the top of their motion.

The result as before, is again a crablike sideways "drift." This time, however, protons and electrons drift in **opposite** directions. Protons move to the left, electrons to the right, and **both** motions contribute a **right-to-left electric current**.

The **ring current** described in section #9 is of this type. The figure from that section, reproduced here, looks down on the equatorial plane of the Earth, from the north. All field lines point **upwards**, as in the previous drawing, and the strength of the magnetic field increases inwards, towards the Earth. The drift is therefore in the 3rd perpendicular direction, which carries the particles around Earth--electrons counterclockwise, protons clockwise, and the current flows clockwise too. The earlier drawing illustrating magnetic drifts may be viewed (qualitatively) as a magnified blow-up of the situation at the bottom of the ring current drawing.



Questions from Users:

*** Why does Plasma Follow Field Lines?

Next Stop: "#11 Explorers 1 and 3 Discover the Radiation Belt"

Back to the Index Page

Timeline **Expanded timeline** **Glossary**

Author and Curator: ***Dr. David P. Stern***
Mail to Dr.Stern: **education**("at" symbol)**phy6.org**

Co-author: ***Dr. Mauricio Peredo***

Last updated 8 August 2007
Re-formatted 3-11-06