Get a Straight Answer

Questions and answer--listed in the order received

Please note!

Listed below are questions submitted by users of "The Exploration of the Earth's Magnetosphere" and the answers given to them. **This is just a selection--**of the many questions that arrive, only a few are listed. The ones included below are **either** of the sort that keeps coming up again and again--the danger of solar eruptions, the reversal of the Earth's magnetic field, etc.--**or else** the answers make a special point, going into extra details which might interest other users. Because this is a long list, it is divided into segments

Click here for a listing arranged by topic.

Items covered:

1. Reversals of the Earth's field (4 queries)
2. Can the Earth's field be used for spaceflight?
3. The Sun's magnetic poles
4. Synchronous satellites
5. Magnetic field lines
6. Alternate theory of the Sun and solar wind
7. The Geiger counter (3 queries)
8. Measuring the Earth's magnetic field
9. The strength of the Earth's field
10. Solar Eclipses
11. Magnetometer for Observing Magnetic Storms
12. Cosmic Rays
13. Magnetic Shielding
14. Use of solar wind for space propulsion
15. A working model of the magnetosphere?
16. The Van Allen Belt
17. Magnets of different shapes
18. On building an electromagnet
19. Capturing the Energy of the Solar Wind
20. About the Upcoming Solar Maximum
21. Lining-up of Planets
22. Radiation Hazards to Air Crews
23. The Ozone Hole and the Magnetic Field
24. How are Ions produced?
25. About the "Starfish" artificial radiation belt
26. How do Magnetic Reversals affect Animal Migrations?
27. Which is the "True" North Magnetic Pole?

28. Electric and Magnetic Energy
29. Any connection between Solar Wind and Solar Flares?
30. Ozone and the Magnetic Field
31. What if the Radiation Belt Reached the Ground... ?
32. Free Energy from the Earth's Magnetic Field?
33. Relativity
34. What is a "REM"?
35. What exactly does "Radiation" Mean?
36. Can anything solid be carried by the solar wind?
37. Dimensions of the Magnetosphere (2 related questions)
38. Skywriting by Aurora
39. Capturing the energy of solar wind ions
40. Radio Propagation
41. Radiation Belts and Manned Space Flight
42. Magnetc shielding against neutral matter?
43. When and where can I see "Northern Lights"?
44. Universal Time and Magnetic Local Time
45. Does the magnetosphere affect weather?

46. "Importance of auroras to society"
47. Magnetic storms and headaches
48. Appolo Astronauts and radiation
49. What materials does a magnet pull?
50. Experimental simulation of the polar aurora
51. Cosmic ray research using balloons
52. Magnetic health products
53. Geiger counters for locating lost objects
54. Magnetic effects from other planets
55. Blocking of the Solar Wind by our Moon?
56. Fry or Freeze... ?
57. The Speed of the Solar Wind
58. What is "Radiation"?
59. How does one Contain a Plasma?
60. Soviet Nuclear Explosions in Space
61. Can Polar Aurora be seen in Atlanta, Georgia?

62. Why no aurora at the magnetic poles?
63. When and how were positive ions discovered?
64. Did astronauts use articifial magnetic shields"?
65. Harvesting electrons from power lines?
66. How can the intensely hot Sun be magnetic?
67. What are "geomagnetic conjugate points"?
68. What is the smallest magnet possible?
69. Can plasma physics explain ball lightning?
70. Harnessing the Energy of the Aurora?
71. Radiation Belt and Brazil
72. Risks from stormy "Space Weather"
73. Man-made triggering of radio emissions
74. Does our magnetic field stop the atmosphere from getting blown away?

75. Radius of particle gyration

76. Are electric storms an "electromagnetic" phenomenon?
77. How can steady magnetic fields induce electric currents?
78. There are electromagnetic waves all around us!
79. Best orbit for a Space Station
80. Is space debris electrically charged?
81. Magnetic induction by the Magnetosphere
82. Questions about the Solar Corona:
(1) Why don't its particles separate by weight?
(2) What accelerates the solar wind?
83. Why has the aurora been so frequent lately?
84. Was the magnetosphere involved in the hole in the ozone layer?
85. Who Discovered Sunspots?
86. "Soda-Bottle Magnetometer"
87. Magnetism and Weather
88. Is the Polar Cusp visible to the Eye?
89. Effects of Radiation beyond the Van Allen Belts
90. Deflection of a beam of Electrons in the Earth's Field

91. Space Tether
92. Does the Earth's magnetic field rotate?
93. Dynamo currents at Jupiter's moons
94. A Russian space tether experiment?
95. How come a magnetic field can block particle radiation but not light?
96. What is a "magnetic moment"?
97. Is fire a plasma?
98. Do interplanetary field lines guide the solar wind back?
99. Magnetic connections between planets and the Sun
100. The solar wind and solar escape velocity
101. Space tether to remove trapped radiation?
102. Electromagnetic Waves and Electromagnetic Induction
103. Solar wind effects on our lives
104. Weaker global magnetic field--higher cosmic ray dosage?
105. Sound waves on the Sun?
106. Mapping the magnetosphere using a surface network?
107. History of Cosmic ray Research
108. What causes sunspots
109. Why does Plasma Follow Field Lines?
110. A solar wind contribution to global warming?
111. Waves in the Magnetosphere
112. What are "frozen" magnetic field lines?
113. Why doesn't magnetism affect electro-magnetic waves?
114. Eddy Currents
115. What is the Radius of the Sun's magnetosphere?
116. Project to show that Iron rusts faster in Fresh Water
117. Fluorescent lightbulbs
118. More about the Year 2012
119. Can Space Plasma help Spacecraft Propulsion?
120. When is Earth an Insulator and when a Conductor?

121. Can upper atmosphere atoms join solar wind?

122. "Radiation Remediation"?
123. Who invented AC?
124. Geiger Counters (1)
(Followed by ***Geiger Counters (2)***)
125. Fluorescent tubes lighting up near high voltage
126. Earth's field--Magnetic or Electromagnetic?
127. How to test a Geiger counter
128. Gamma ray bursts
129. Magnetic effects of our galaxy
130. How does electromagnetic induction occur?
131. Magnetic field of the Sun
132. Flux Transfer Events (FTEs)
133. Building a Terrella experiment like Birkeland's
134. Electric field due to electromagnetic induction

If you have a relevant question of your own, you can send it to
education("at" symbol)**phy6.org**
Before you do, though, please read the instructions

91. Space Tether

The space tether seems to extract kinetic energy from the orbital motion of the shuttle.

But as the shuttle loses energy, it descends to a **lower** orbit and must **speed up**. How can the shuttle lose energy AND speed up?

Reply

You are right, the kinetic energy of the shuttle increases. But it loses potential energy, like any object which descends from a high location to a lower one. In the final balance, the sum of potential+kinetic energy gets smaller.

92. Does the Earth's magnetic field rotate?

Hello David,

My 8 year old son and I are conducting simple experiments involving electricity and, particularly, magnetism.

We noticed that iron filings sprinkled upon a horizontal plane suspended above a pole of a dipole magnet do not appear to move when the magnet is rotated about the line extending between its two poles.

Yet, we understand that the accepted scientific view is that the Earth's magnetic field rotates (nearly) synchronously with the Earth.

So, our question is: **Does the Earth's magnetic field rotate?** If so, how do we know this?

Reply

Your question is not a simple one, and has in the past confused quite a few people. A rough outline of the answer follows below; it is not exactly simple, and I can only hope that you and your son will have the patience to follow it to the end.

I take it you refer to the axially symmetric parts of the field. The observed field also has many irregularities, and these certainly rotate with the Earth. For instance, the north magnetic pole (and the south one, too) is separated by something like 1000 kilometers from the geographic pole, the pole around which the Earth rotates. And indeed, the magnetic pole rotates every day a full 360° around the geographic one. What you have in mind--what your experiment involves--is something else: a symmetric field rotating around it s axis of symmetry.

If you have a source of magnetic field in empty space--iron magnet, coil--and you rotate it around an axis of symmetry, **there is no extra effect**, and therefore, nearby objects will not feel any force to make them share the rotation.

For instance, if you have **a bar magnet** and twirl it around its length, around the line connecting the poles, you get no observable change. At any point in the surrounding space, the magnetic force sensed (say, by a compass needle) is not changed by the rotation.

All that is true **in empty space**. And to a very good approximation, it also holds if the space contains substances which do not conduct electric currents--air, wood, paper, glass etc. In all these cases, just having the source of magnetism rotate has no measurable effect.

But if space is filled with a substance which **can conduct electricity**, and the rotating magnet also conducts electricity, the situation is different. Under certain conditions, **electric currents may then be produced**, and in that case, two effects are added:

- **First** electric currents are SOURCES of magnetic fields, and therefore the magnetic field may be modified.
- **Secondly**--more important here--magnetic fields exert a FORCE on the carrier of electric current, and in this case, in general, that force tends to make it share the rotation.

Space around Earth--except for the lower atmosphere--**does** conduct electricity. In the ionosphere--say 120 kilometers up (70 miles) and higher, sunlight rips off electrons from atoms, creating a "plasma," a mixture of free floating electrons and positive ions (left-over atoms, which miss an electron or more), and **a plasma conducts electricity**. If a free electron collides with an ion, the two may recombine again--but densities are so low that in most regions recombination does not catch up with "ionization" (the break up of atoms), even during the night, when the ripping-off of electrons stops. Also, higher up in space additional sources of plasma exist, e.g the "solar wind" blowing from the Sun.

Such magnetic forces try to make the plasma "co-rotate" with the Earth. Their effect turns out to be the same as would occur, **if magnetic field lines** which thread the plasma are **viewed as attached to it**. Then everything--Earth, plasma and field lines attached to it--rotate together. Once more--be aware that this only happens when space is **filled with a good conductor of electricity**. Without electric conductivity, the magnetic field **does not** transmit rotation. Iron does conduct electricity, but iron filings scattered on paper are not enough, they do not provide a good enough path for electric currents.

I guess this is about as far as one can go with an 8-year old. As for the "simple experiments on magnetism" you conduct with him, I would recommend three more, described in

http://www.phy6.org/earthmag/MagTeach.htm

For your own interest--if you want to know more about the way rotation CAN produce electric currents--look up the sections on dynamos in "The Great Magnet, the Earth", home page

http://www.phy6.org/earthmag/demagint.htm

If you want to more about the way plasma moves together with magnetic field lines, look at the section on the magnetic field of the Sun, which is deformed by the Sun's uneven rotation.

http://www.phy6.org/earthmag/mill_5.htm

A more elaborate example is found in

http://www.phy6.org/Education/wimproj.html

All that, however, is already quite a bit advanced.

93. Dynamo currents at Jupiter's moons

Are phenomena similar to the Io Dynamo also happening on Europa and Ganymede - the other big moons of Jupiter? Do they have footprint aurorae on Jupiter?

Reply

In principle, the same electric current generation which exists between Io and Jupiter can also exist with other moons, but if it does, it must be very weak.

Observationally, the finger was first pointed at Io because the radio emissions from Jupiter (even before space probes were sent to Jupiter) were known to be strongly dependent on the position of Io, not of any other moons.

Theoretically, we know Io has volcanoes and therefore an atmosphere and an ionosphere, and is the source of gas and ions around its orbit. I think these help conduct the electric current. Other moons do not have those features. **<h394. A**

Russian space tether experiment? </h3

Perhaps you would be so kind as to help me. I can find no trace of a Soviet space probe which, maybe ten years ago or more, attempted to collect and measure spatial electricity by means of a long trailing conductor. As I recall it failed because of a burn-out.

Reply

There was in 1989 a Russian AKTIV satellite with a wire loop. See: **cfa-www.harvard.edu/spgroup/TetherHBK_file4.pdf** pages 190-191

95. How come a magnetic field can block particle radiation but not light?

I know the earth's magnetic field blocks high energy radiation/protons from the sun, but why does it not block all radiation i.e.: visible light, UV light, infrared? also, does the ability to block different wavelengths/energy levels depend on the strength of the field?

Reply

The best way to reply to your question is through an analogy. Imagine you sit in an armored vehicle, and an enemy machine gun is firing at you. The bullets never reach you, they are stopped by the armor, but you can clearly hear the sound of their impact. How come the sound gets through and the bullets don't?

The reason, of course, is that the two are quite different. The bullets are chunks of matter, and to let them through, the matter of the armor has to give way, something it strenuously resists. The sound is a wave: the bullets make the armor oscillate and propagate the wave through it, without breaking its integrity.

Similarly with **particles** and **electromagnetic radiation** from the Sun (or from any source): they are completely different. The issue is confused by the fact that streams of high-energy particles are also popularly called "radiation," as in "radiation belts" and "alpha-radiation" (or "beta radiation") from radioactive substances. There are historical reasons for this usage, but unfortunately, it is now too deeply rooted to be easily changed.

Particles found in space carry an electric charge, and a moving electric charge can be viewed as equivalent to an electric current. Electric currents react to magnetic forces--in fact, magnetism may be viewed as interactions between electric currents--so it's no wonder charged particles get deflected, sometimes even trapped.

Light, X-rays, radio etc. are electromagnetic waves, wave-like disturbances propagating in space. They carry **no** electric charge, and in empty space they are **not** affected by magnetism. (When passing through matter they can be modified--e.g. light is refracted by glass--and that modification may strongly on magnetic fields, but that's a different case). What absorbs those waves is matter, e.g. atoms and molecules: when a wave encounters those, it may suddenly materialize as a compact "photon" and deposit its energy.

96. What is a "magnetic moment"?

Another user asked you "what is the smallest possible magnet" and you wrote

> "Maybe the electron. Imagine it (as people around 1900 imagined it) as a tiny sphere loaded with negative electric charge. If you make that charge rotate around some axis, its different parts will move in circles, each acting like a small current, and the result would be that the electron is magnetized along its rotation axis--"has a **magnetic moment**" in sciencespeak."

I am a journalist, explaining science to the public (for a university research team). Could you define the term "magnetic moment" for me? I'm a bit baffled...

Reply

"Magnetic moment" is a measure of the strength of a magnetic source. A good comparison is provided by the electric force, whose source is **electric charge**." Given two electric charges, one 100 times larger than the other, the **electric force** produced by the bigger one, at any distance, is 100 times larger than what the other charge produces at the same distance.

Magnetic forces are more complicated. Imagine you have a bar magnet. A good approximation to its behavior is obtained by regarding it as a pair of "magnetic poles", an "N-pole" and an "S-pole." I won't use the words "north" and "south," because they confuse people--see

http://www.phy6.org/earthmag/magnQ&A1.htm#q14

Each pole is the source of magnetic force, which like the electric force from an electric charge (and like the force of gravity produced by some mass), weakens with distance R like $1/R^2$.

However, poles ALWAYS come **in pairs**, equal in strength but opposite in type. Their forces therefore interfere with each other--while one pole pulls, the other repels. For that reason, at a great distance R, the magnetic field decreases with R at a faster rate, like $1/R^3$.

Intuition will tell you (and math confirms) that this interference--the mutual near-cancellation of push and pull--is greatest when the poles are close to each other, i.e. when the bar magnet is SHORT. The magnetic force produced by a bar magnet, at a given point in space, therefore **depends on two factors**--on both the **strength Q** of its poles, and on the **distance D** separating them. The force is in fact proportional to the product M = QD ; of course it also depends on the distance R, and its direction depends on the angle between R and the axis of the bar magnet.

M is known as the "magnetic moment" or "dipole moment" of the magnet. Sorry it took so long to get so far, but I know of no simpler way.

--- --- --- --- ---

...and in case you wondered

Loops or coils carrying an electric current are also sources of magnetism, and such a loop or coil behaves (at a distance) like a small bar magnet (see wmfield.html). It turns out that the magnetic moment of a loop--i.e. of the bar magnet whose action it mimics--is proportional to the strength of the **current** flowing in it, times the **area** of the loop. A coil of (say) 20 turns multiplies that area 20-fold. (All that, without adding any iron, which magnifies the effect).

97. Is fire a plasma?

The fire given off when burning for example, paper, wood, gasoline--is that another of the manifestations of a plasma? If it isn't plasma that makes the fire shine--what is it?

Reply

You asked a good question, but the answer is--no, fire is not hot enough to create a plasma.

Most flames are yellow. The main reason is that flames contain little bits of burned material--bits which later form its smoke--and they get hot enough to glow. Hot solid materials always glow--for instance, the filament in a lightbulb. However ,glowing in yellow light does not require a very hot temperature.

To create a plasma takes more energy, and requires a higher temperature than the flame provides. The collisions between atoms need to be energetic enough to kick an electron completely out of the atom.

An electric arc welder drives a huge current across a narrow juncture where two pieces of metal touch, and that creates a temperature high enough to create a plasma. The surrounding air is also hot enough. After touching the two pieces can be separated, and the air continues to carry the electric current, and to heat enough to create the plasma. The metal tip glow so brightly (white light, with a lot of eye-damaging ultra-violet) that the welder can only view the work through a thick dark screen.

Before writing to you, just to make sure, I took an electric meter and measured the resistance between two metal contacts separated by a small distance, putting both in the flame of a gas oven, which gets pretty hot. No electric current could be detected, both inside the flame and away from it, meaning the flame did not conduct any observable electric current.

98. Do interplanetary field lines guide the solar wind back?

Don't the magnetic field lines from the Sun need to close somewhere in space? Would such closing of field lines bring back the gyrating particles back to the Sun and give rise to a "reverse solar wind"?

Reply

Magnetic field lines do not always tell charged particles where to go! Sometimes, when the particles are numerous and have a greater energy density than the magnetic field, **they** are in charge and flow unimpeded. The magnetic field may then be deformed, and an electric field may also arise, effects that allow the particle flow to proceed undisturbed.

For more about this, look up one of two files (they are identical)

- **http://www.phy6.org/Education/wimfproj.htm**
- **http://www.phy6.org/stargaze/Simfproj.htm**

Whether the magnetic field dominates the flow of a plasma, or the flow dominates the magnetic field, always depends on one question--what dominates the energy density, the plasma or the magnetic field?

If the field does, its structure is relatively rigid and it determines where particles can and cannot go. The inner radiation belt of Earth is a good example--dominated by the dipole structure of the Earth's field.

If the plasma has a higher energy density than the magnetic field, its flow is relatively undisturbed, and instead, it deforms the magnetic field to suit its motion. **This is the case in the solar wind**.

> (What if the two are comparable? We then may get complex physics, as in the Earth's outer magnetosphere!)

Because the solar wind dominates, it drags out solar magnetic field lines (as the above web site shows), in a spiral due to the Sun's rotation, which gets more and more circular. The wind itself does not follow field lines but continues to move radially. (At the end of the above web page, however, is a story of a different population of particles, high energy particles from an eruption on the Sun, which--because their number is few--do follow the field lines.)

Ultimately the solar wind encounters interstellar plasma and magnetic fields, and undergoes a shock transition, where its density increases and its velocity drops, to less than the "Alfvén velocity", a rarefied plasma's equivalent (in some ways) to the speed of sound. That transition was crossed by Voyager 1 last December (see section #18B). Ultimately there exists another boundary, due to the interstellar magnetic field, and I am not sure what happens there, whether field lines temporarily interconnect with the outer field or get tangled up. In either case, the solar wind does not come back, though it may end up deflected to move along the interface

99. Magnetic connections between planets and the Sun

Where would I find a drawing of magnetic lines of force of the whole solar system showing which go in to which planets and out to which other planets, or where they go, if nowhere then to other dimension?

Reply

There can exist no "drawing of magnetic lines of force of the whole solar system" because the pattern constantly changes. The field of the Sun changes as its sources change--sunspots, etc.-- and also, it rotates past planets. Therefore planets face different fields all the time, and depending on circumstances, may or may not at any position "reconnect" their magnetic fields with the Sun's. See more on reconnection in "Exploration of the Earth's Magnetosphere," section #23 The Tail of the Magnetosphere.

100. The solar wind and solar escape velocity

Acording to your web site, the particles in the solar wind are leaving the Sun at about 400 km/s. That is **less than the escape velocity** from the surface of the Sun, which is about 600 km/s. Does it mean many of these particles will eventually fall back to the Sun? Is there any evidence of such as behaviour?

Reply

The solar wind does not start from the Sun's surface, but from the corona, and is accelerated somewhat gradually. Obviously, it has to overcome solar gravity, which I suspect is one of the conditions needed for accelerating the solar wind--maybe like a lid on a pressure cooker, holding down the hot corona until it can just barely escape.

You might want to look up
http://www.phy6/org/ Education/FAQs6.html#q82

Incidentally. NASA has been toying for years with the idea of a solar probe, approaching the Sun within 4 solar radii--following boost from a "hairpin" orbit around Jupiter (mentioned briefly in
http://www.phy6.org/stargaze/Stostars.htm

and in the page following it). It would be shielded from the Sun's intense heat by an "umbrella" of tungsten or similar material, and would study the solar wind in its source region. How can it do so with a metal barrier between it and the Sun? Simple: at closest approach is moves at about 300 km/s, so in its own frame of reference, solar wind particles (unlike sunlight) would seem to come in from the side, at an angle. They would seem to have the vector sum of their own velocity and that of the corona relative to the fast-moving probe.

101. Tethers to remove radiation belt?

I read about the HiVolt proposal by the late Robert L. Forward to drain the inner Van Allen belt to 1% of its natural level using highly electrically charge tethers in orbit. The idea is that electrons would be deflected by the large electrostatic fields and intersect the atmosphere and harmlessly dissipate.

The reason for this proposal was the hazard the belts pose to artificial satellites and (moderately) to human astronauts.

Is the HiVolt proposal plausible, and would dissipating the belts carry some other consequences?

Reply

Until your message I had not heard of "HiVolt." I do not think it would work, especially for the inner Van Allen Belt. That belt has protons of typically 10-50 million electron volts, and any voltage imposed on space would be much too small to affect it.

Also, the plasma surrounding any charged object in space limits the distance to which its electric field extends--to meters in the inner magnetosphere, tens of meters further out, a distance known as the Debye distance. Suppose you charge a wire to +1000 volt, positive, by shooting a beam of 1000-electron-volt electrons into space from the satellite to which it is attached. Electrons will be attracted to it, and will create a layer of negative charge around it, extending to about that distance. Further away, positive and negative charges associated with the wire balance out, and you get no electric field.

As for additional consequences--trapped particle have a minor effect on the Earth's global field--and the inner belt contributes just a tiny part of this.

To be sure, you could perhaps precipitate ions and electrons (especially electrons) by injecting modified electromagnetic waves into space. Dr. Robert Helliwell did so many years ago by sending low frequency radio signals from an antenna in the Antarctic, and getting signals due to electron precipitation at the other end of the field line, in Roberval, Quebec. But only some electrons were affected. Some such waves anyway arise spontaneously all the time, limiting the particle density naturally.

102. Electromagnetic Waves and Electromagnetic Induction

Your page on electromagnetic waves was insightful, pointing out the connection with the discoveries of Hertz, Einstein etc.

However I do not understand how an EM wave exactly moves across empty space--as shown by the moving diagram on your web page.

When you use the term "oscillation," do you imply that the magnetism of a source induces an electric current, which induces a magnetic field and so on ? If my rambling sentence is correct, then what exactly does the magnetism induce into, to produce that current? This is particularly unclear if the EM wave spreads in empty space, where there is no material to induce currents into! I would greatly appreciate it if you could help clarify to me, how exactly an EM wave would move through empty space.

Reply

I guess the web site **did not say enough about electromagnetic induction**, an omission which needs to be remedied.

Electric currents do create magnetic forces, which you can observe (say) using a compass needle. This was found by Oersted and Ampére, and later Faraday (perhaps) and Maxwell (certainly) called the region of magnetic forces a "**magnetic field**."

Many people also **tried the opposite**: if an electric current flowing in a coil around a bar of iron turns it into an electromagnet (a similar effect, but less strong, also exists without the iron)--perhaps if we put a bar magnet inside a coil of wire, it will create an "induced" electric current in that wire.

It did not work that way, and today, knowing about energy, we can guess why: an electric current in a wire needs a constant supply of energy, and where would that come from?

However, Faraday found a **somewhat** similar result, if the magnetic field in the coil was **undergoing change**, as happens (for instance) as the bar magnet is **being pushed into the coil**, or being pulled out. During those changes, a momentary current **did** flow. Faraday called this electromagnetic induction, creating an "**induced current**." See for instance

http://www.phy6.org/earthmag/dynamos.htm

> (By the way, if the coil is made of a **superconducting** material, the current produced by thrusting a bar magnet through it will persist, because it requires no additional energy. Of course, once you pull the magnet out, a reversed induced current will cancel the one originally created.)

That led to Faraday's law of induction, by which a **changing magnetic field** can generate a **changing electric field** during its change (there exist formulas, too). If a closed conducting wire occupies the space where the change occurs, the changing electric field may cause a **changing electric current** to flow. That of course is how we generate AC electricity, and also how transformers work--a high voltage current flows in a coil around an iron core, causing a changing magnetic field, and a "secondary" coil wrapped around the same core senses the changing magnetism and an induced electric current flows in it, perhaps with a different voltage.

In that case we have the chain

Changing magnetic field -- > changing electric current -- >
changing magnetic field caused by that current -- > and so on

That is also described in
http://www.phy6.org/stargaze/Sun5wave.htm

Up to here, the cause-effect chain involves magnetic **fields** and electric **currents**. However, in empty space (as you noted) there exist **no** electric currents--only "electric fields," regions where a current **might** flow if (say) a closed copper wire passes the location, but otherwise nothing remarkable seems to happen there.

James Clerk **Maxwell** however guessed, that maybe this became a **modified** type of space--an "electric field." Under certain conditions, a varying electric field can **also** carry an electric current, through empty space. For instance, an electric current can flow through **empty space between the plates of a capacitor**. That is a device for storing electric charge, and in the simplest case, consists of two parallel metal plates, with empty space between them. Ignore for now the details and theory, let it just be said that if the voltage of one plate (that is, the level of its electric field) rises or falls rapidly, the voltage of the other plate is "dragged" up or down to match the changing values. It can be shown that a variable electric current then flows between the plates, through the empty space. The faster the change, the more efficient is the generation of such a current.

Maxwell guessed that this unusual electric current, flowing through "empty space," can also generate magnetic field, just like the flow of a current in a wire. He called it a "**displacement current**" and included it in his formulation of the fundamental equations of electricity.

He then modified the above chain of cause-and-effect, to

Changing magnetic field -- > changing electric field -- >
changing magnetic field -- > changing electric field -- > and so on

With the displacement current replacing the ordinary electrical current, theory predicted that **electromagnetic waves** could exist in empty space. Those waves spread in 3 dimensions like sound--except that where sound contains pressure variations **along** the direction of propagation, the electromagnetic wave contained variable electric and magnetic fields **perpendicular** to the direction of propagation, a bit like the jiggling of Jello.

Unlike sound, it was sensitive to electrical properties--for instance, a good conductor of electricity tended to reflect the wave rather than let it pass (hence mirrors). The wave spread with the velocity of light (which turned out to be related to measured properties of electricity and magnetism) and Maxwell guessed it **was** light. From that he deduced some laws of reflection, and also explained the polarization of light. Then came Hertz, and radio, and the rest as they say is history.

I hope this short description makes sense

103. Solar wind effects on our lives

I am a scientist in biology and also have had interest (amateur) in Astronomy. I have been curious about the solar wind and **its effect on biological processes and on life**.

I would appreciate if you would kindly suggest some references on this topic. Also, is there any information or observations of influences of sunspots and solar wind? For instance, can or does the solar wind influence infrared activity of sunspots and resultant effects on earth?

Reply

The solar wind blows irregularly, but does not follow the sunspot cycle. Its particles are very rarefied and of relatively low energy, and its effects on the Earth's magnetic environment depend mostly on the **direction of its magnetic field**, which also varies irregularly (see drawing at the end of section #26 in "Exploration of the Earth's Magnetosphere.") I doubt the quiet-time solar wind has much effect on life on Earth. By the way, the solar wind tends to originate not in sunspots but in "coronal holes" **between** them, regions where magnetic field lines **stick out** into distant space. Above the sunspots themselves, field lines form "arches" which seem to hold back the corona and interfere with any outward flow.

Of course, sunspots can have eruptions, which push fast clouds through the solar wind, creating shock fronts in interplanetary space and sometimes causing magnetic storms

Infra-red emissions by the Sun are also not significantly affected. On the other hand, **soft X-ray emissions** by the Sun seem to have a significant 11-year cycle. But they do not influence the surface of Earth, because they are already absorbed at high altitudes, although they are important for the ionosphere. They also heat up the outer atmosphere and make it swell up during years of maximum sunspot activity, and this shortens the orbital lifetime of satellites orbiting close to Earth. The space station "Skylab" came down a bit earlier than expected (in 1977?) because sunspots became active.

104. Weaker global magnetic field--higher cosmic ray dosage?

The Earth's magnetic field had diminished by some 10% since the mid 1800's. Isn't there a possibility that this has caused the magnetosphere's shielding effect to become diminished as well, thereby allowing **more high speed radiation** to penetrate our atmosphere. When, and if you find the time, I would appreciate your perspective on this possibility.

Reply

A weaker magnetic field is slightly less effective in shielding out cosmic rays, but not of the solar wind.

The contribution of cosmic rays to global warming is negligible: the rate they add energy to Earth is comparable to the one due to starlight. For more about them

http://www.phy6.org/Education/wcosray.html

The increase in our exposure to cosmic rays due to weakening of the Earth magnetic field, is **much smaller** than the one due to a moderate rise in altitude--say, from sea level to that of Denver. About 30 years ago I listened to Marvin Schneiderman of the National Institutes of Health (NIH) lecture about the statistics of cancer, and asked him whether Denver experienced higher cancer rates, due to its increased radiation level. He said, "Actually, it is one of the healthiest places."

The solar wind is shielded out by the boundary of the magnetic field. If the field weakens, the boundary shrinks, but there is very little change on the Earth surface. (The boundary distance oscillates anyway, as the intensity of the solar wind varies.)

Overall, I don't think the 10% change has much effect.

105. Sound waves on the Sun?

I have a question about our sun. The sun has an atmosphere, which ought to transmit sound. **What would it sound like** to be on the sun? Have there been any probes to the surface to listen to the sun?

Reply

Your simple question leads to many complications, most of them going far beyond my limited knowledge, or even that of experts.

Sound waves certainly exist on the Sun, and are likely to be exceedingly **LOUD**. No instruments have ever landed on the Sun, nor are any likely to do so (they would boil away instantly) but all we can observe, especially the constant churning of the solar surface, suggests a high density of sound-like waves.

Furthermore, the visible "surface" of the Sun, at about 6000 degrees K, has above it a rarefied corona of about 1,000,000 deg. K. Assuming the required energy comes **from the Sun below**, how does it reach the corona, without heating the surface layers? Sound waves have been suggested--and to create a million degrees, they need to be pretty intense.

However... sound is not the only wave mode. Sound in our atmosphere (or in solids) is the periodic interchange of motion (kinetic energy) and compression (one form of potential energy). The surface of the Sun his hot enough to conduct electricity, and that allows **modes where magnetic fields get periodically compressed** (Alfvén waves), also electric oscillations, and to make things really complex, all sorts of hybrid modes between various forms of energy (including ordinary sound). Your "sound" turns into something very complicated. Many modes get reflected back from the low densities of the corona, which is why to the best of my knowledge, the heating of the corona is still unsolved.

If you want to get a taste of what's involved, ask Google about (say) "photospheric sonic waves."

106. Mapping the magnetosphere using a surface network?

I am on staff at a university and I have an idea for what could be an interesting and useful university **student R & D project**. It's related to mapping the earth's magnetosphere, so I believe you would be a good person to ask for advice. Here is the idea...

As I see as the problem, Earth's magnetosphere is not mapped in as much detail as scientists would like it to be, due to the vastness of the earth and the relatively small number of magnetosphere measuring instruments. One Possible Solution is as follows:

5. Distribute a very large number (perhaps thousands) of fairly simple, relatively low cost **magnetic field sensors** at various locations around the globe. They may just give the horizontal field, or observe it 3 dimensions, even measure its strength. Cost could be a major design constraint.
6. Connect the sensors to **volunteers' PCs**, either of private citizens or else at "controlled" locations, e.g. government and research facilities. The CPU load on the PCs would be very small.
7. **Network these PCs** together via the Internet using existing PC "grid networking" technology. Similar projects are already operating.
8. **Gather the data** at a central server, and **analyze it**, to better understand Earth's magnetic field and help us to predict things like reversal trends.

My university would like to be active in such a project. Can you please advise us, if this seems like a good project and one that would benefit the scientific community?

Reply

Unfortunately, your idea will not work, for several reasons:

9. The magnetosphere is **constantly varying**, due to changes in the solar wind (the cause of the magnetosphere!), changes in the "tilt angle" between the Earth axis and the direction perpendicular to the solar wind (due to the Earth's rotation, since the magnetic pole is distinct from the rotation pole), and variations in the currents flowing in the magnetosphere, due to various internal sources.
10. Because of the basic nature of the magnetic field, observing it just on the surface of the Earth **is not enough** for reconstructing the electrical currents which create it in space or in the Earth's core. We need detailed observations **in the regions where those currents flow**, too. We therefore cannot fully reconstruct the field in the regions of currents.

    Satellites allow us observe the field in current regions in space (though we have too few of those to get more than an average structure). As for the currents in the Earth's core, which give Earth its "main" field, we would love to know their structure, too, but no way exists to make observations within the core.

    Surface observations such as the ones you propose **can predict** the extension further out in space of the field which the core produces. However such information **cannot** determine the currents flowing out in space, or their contributions to the field. Even to estimate the outward extension of the core field, we need first estimate how much of the surface field originates out in space, and subtract that part from the surface data.

For more, see

http://modelweb.gsfc.nasa.gov/magnetos/data-based/modeling.html

107. History of Cosmic ray Research

Perhaps you can help me. I'm working on a history of science story on cosmic rays and I'm confused about their nature and how scientists know what they know. Historically I understand that **cosmic rays were first thought to be photons** and part of the electromagnetic spectrum. Then it was discovered that they carried electric charges and were deflected by Earth's magnetic field. This put them in the camp of particles. (As an aside it is mind blowing to think that a photon with an electric and magnetic field but no charge is not effected by Earth's magnetic field.)

Now historically this is where I get lost. What did **Patrick Blackett's discovery** do? The Nobel prize website below has a lovely description of him finding both a positive and negative electron -- confirming Anderson's discovery of the positron and Dirac's theory on antimatter. But the description goes on to talk about "transmutation of light into matter." **Which are cosmic rays?** The light or the matter?

http://nobelprize.org/nobel_prizes/physics/laureates/1948/press.html

Thanks so much for you help,

Reply

Here is the history, as far as I remember (you may check it, at 75 my memory may have gaps).

A long period of uncertainty about the property of atoms (especially their emitted characteristic "spectral lines" of very sharply defined color) reached a breakthrough with Schr�dinger's equation and his quantum theory in 1925-6 (see here and in sections that follow for some f the history behind it), followed in 1928 by Dirac's generalization, in which he tried to reconcile Schr�dinger's work with special relativity.

One result of Dirac's generalization was **the prediction** that every elementary particle has an "**antiparticle**" of opposite charge but the same mass. This was confirmed by Anderson in 1932, who saw in a cloud chamber the track of a particle--a fragment from an interaction of cosmic rays--which behaved like an electron but whose motion in a magnetic field curved in the opposite direction from that of electrons, suggesting it had a positive electric charge. He named it **the positron.**

What Blackett observed was the way positrons were produced--by simultaneous "pair production" of a positron and an electron by a gamma ray photon of sufficient energy, interacting with matter.

Any such process (and any other in nature!) must **conserve energy, electric charge and momentum**. The energy is provided by the photon: part of it goes to create the masses of the new electron and positron, at the exchange rate dictated by Einstein's famous $E=mc^2$, and the rest is given as kinetic energy to the newly created particles. The net electric charge remains zero, like that of the photon (the positron has a charge equal to that of an electron but of opposite sign), and to conserve momentum some massive particle must also be present to absorb the recoil, which is why pair production usually happens in the strong electric field near an atomic nucleus.

The process is reversible--once a positron is slowed down by matter, it can interact with an atomic electron and "**annihilate**," a process where the particles convert to gamma rays. (Antiprotons also exist and can annihilate, and there exists a funny poem--see **http://dnp.nscl.msu.edu/nplinks/history.html**--in which Dr. Teller meets Dr. Anti-Teller, they shake hands "and the rest was gamma rays.")

As for cosmic rays, they were **discovered by Victor Hess in 1912**. By that time it was known that air had a slight electric conductivity, ascribed to radioactivity in soil minerals. Hess took sensitive instruments **on a balloon flight** and found that the effect, instead of decreasing as he rose (radiation from the soil being absorbed by the atmosphere below him), actually increased dramatically. That meant some ionizing radiation was **arriving from space**, and it could consist of either particles or gamma rays, he had no way of telling.

Hess had ascended only part-way across the atmosphere, and whatever was arriving from space still had to cross a fair thickness of air. **Robert Millikan** of Caltech, famous for measuring the electric charge of the electron, guessed they were gamma rays, since that was the most penetrating radiation he knew. He thought that gamma rays of higher energy than known at his time could have crossed that thickness.

In fact, **they would not**, because of pair production. We know now that the primaries actually are charged nuclei--mostly protons--and as they interact with the upper atmosphere, they produce secondaries, mainly **pions** (pi-mesons). Some of those are neutral and decay almost immediately to gamma rays, which produce electro-positron pairs, and these create gamma rays of lower energy by "braking radiation" (bremsstrahlung, a German word), which again produce pairs, which again... until at ground level (if energy does not run out) there arrives a mixed shower of electrons, positrons and gamma rays, sometimes covering many acres. This is how some (relatively rare) cosmic ray primaries were found to have enormous energies.

But Millikan was both famous and stubborn, so his theory of cosmic gamma rays was widely circulated. Some cosmic photons do exist, and have recently yielded important information--see

http://www.phy6.org/Education/wcosray.html

But they are a very small minority.

The realization that cosmic rays were charged came when **detectors were placed on a ship**--I think it was in 1927, the ship sailed from Holland to Java and back, and the cosmic ray intensity declined as the magnetic equator was approached. Charged particles are affected by magnetism, gamma rays are not. It was a small effect, because only cosmic rays with enough energy to send secondary fragments through the entire atmosphere would contribute, and those energies are not too affected by the Earth's magnetism. Lower energies, whose effects can be observed on high mountaintops, vary much more with distance from the magnetic poles.

In 1930 Bruno Rossi predicted that if the particles were positive, more would come from the west than from the east, and that was confirmed by Alvarez and Compton, and others, (including Rossi himself), using Geiger counters in directional arrays, linked by early primitive logic circuits ("coincidence circuits", now called 'and' circuits). See for instance Rossi's autobiography "**Moments in the life of a Scientist**." After World War II, unmanned high altitude balloons listed stacks of photographic emulsion to the top layer of the atmosphere, actually capturing the tracks of those "**primary cosmic rays**."

That is it, in a nutshell.

Response

Thank you for taking the time to explain the cascade of particles through the sky. This is very helpful. The science is fascinating. I'm having fun researching the history. Thanks for filling in gaps in my story.

108. What Causes Sunspots?

I am taking a class called Science Research and Technology (SRT) in which I am doing a project on the cause of sunspots. Scientists say that sunspots are caused by disturbances in the sun's magnetic field, but what disturbance and the exact cause isn't clear. Could you please tell me what you think on this topic

Reply

Before telling you anything about sunspots, I should say that scientists do not understand them well enough. How deep do they go? Once they were thought to be associated with magnetic fields near the surface, now astronomers believe they go quite deep. We cannot study very well what goes on inside the Sun.

Anyway, I once wrote a fairly thorough review of sunspots at
http://www.phy6.org/earthmag/mill_5.htm

What is stated there is still believed: sunspots are caused by the uneven rotation of the Sun (see image there), the equator rotating faster than the polar regions. That stretches out magnetic field lines, crowding them together and making their magnetic field stronger. Strong magnetic field (under the surface) pushes away the solar gas, which therefore gets less dense, so that regions of strong field tend to float up to the top, the way oil floats to the surface of water. Where it breaks the surface, sunspots occur.

But we still do not understand a lot--why exactly the Sun rotates unevenly, why the north-south magnetic polarity reverses every 11-year cycle, how sunspots slow down the flow of solar heat (which makes them dark).

To learn more, you will have to read more of my web pages, and look at other resources.

109. Why does Plasma Follow Field Lines?

These days I have been reading your info about geomagnetism and its relations with the solar wind, CMEs, etc.

I know you're an expert in the subject. But it's quite complicated for me and now I feel a bit messy and lost about it. There are many interacting processes. For instance, I still can't understand why plasmas follow magnetic field lines. I thought that their movement should be perpendicular to the magnetic lines due to its electrical charge, like the movement of those electrons trapped in the Ring Current zone, that swirl around Earth. *(Abbreviated from a longer message)*

Reply

Why do plasmas follow magnetic field lines... ? Presumably you refer to the bulk flow of plasma, not to individual electrons and ions, which do follow field lines while spiraling around them... but also drift at right angles due to other processes, discussed in section 10a.

Well, such drifts **may or may not** determine the bulk motion. It all depends on the **electric field E** (a vector like the magnetic field **B**) created (as you noted) by electric charges in the plasma itself. The plasma also tries to obey **Newton's laws**, e.g. its momentum tries to keep it going in its original direction, and if it has enough momentum, its charged particles re-arrange themselves to create **E** to enable it to do so.

If the plasma is **rarefied**, it does not have much momentum (per unit volume, to be accurate), and this process may be too weak. The plasma's particles will individually spiral around magnetic field lines, as you noted, and slide along them, but while electric fields may also be present, any **E** produced to preserve their original bulk motion will not have much effect. Motion around guiding field lines will be persist, as will motion **along these lines**, also magnetic drifts and mirroring, but all these are **all purely magnetic effects.**

If on the other hand the plasma is **dense**--if it has considerably higher energy per cubic centimeter than the magnetic field has (not asking now how that is calculated, though some hints are given **here**)--then it "goes wherever it wants" and behaves more like a regular gas. It does so by moving the average density of electric charges to create an electric field **E**, which allows the motion "sideways" across the magnetic field. See "Exploration of the Earth's Magnetosphere" section #10a, about the effect of "electric and magnetic forces together."

In that second case, instead of the magnetic field deforming the motion of the plasma, **the plasma deforms the magnetic field**, as discussed for the solar wind in section #18b. In that case, the solar wind expands radially, deforming the magnetic field into a spiral.

An example where part of the plasma is deforming the field and another (a burst of high energy protons) has its motion deformed by magnetic field lines is described there at the end, for the event of 17 November 1999. This sort of motion is described in "http://www.phy6.org/Education/wimfproj.html" , where **some** of the particles (rarefied ones at high energy) illustrate the first case and **others** (dense ones at low energy) illustrate the second.

110. A solar wind contribution to global warming?

My question to you is whether anyone has ever attempted to **correlate the Earth's magnetic field strength with climate changes**. My layman's logic wonders whether a reduction in field strength of 10% would result in some additional solar energy reaching the atmosphere, and hence cause an increase in overall global temperatures. I understand that the geologic record of magnetic field strength may span far more time than the records of global temperature in the polar ice core samples (or however those estimates are made), but has any attempt at correlation of the data been made?

Reply

The "solar energy" received by Earth presumably includes **sunlight** and the **solar wind** (with the magnetic effects it brings with it). Let us compare.

Suppose the Earth had NO magnetism at all, so that the solar wind would hit its surface directly--as it hits the Moon, most of the time. The solar wind has a density of about 6 protons per cc, and velocity about 400 km/sec, so each square centimeter facing it is hit each second by as many protons as are in a column about 400 kilometers high and of 1 square centimeter cross section:

400,000 x 100 x 6 = 2.4 x 100,000,000 protons and each square meter (10,000 times larger) about 2.4 10^{12} protons

Each proton carries about 1000 electron volts, each of which is abut 1.6 10^{-19} joule So that each square meter gets about 4 10^{-4}joules per second, that is, 0.0004 watt.

The **"solar constant" of sunlight energy** received by a square meter on the Earth perpendicular to sunlight is about 1300 watt. It's more than a million times larger.

The changing strength of the Earth's magnetic field may have less effect than its magnitude suggests. That field **diverts** the solar wind around the Earth, though some energy is transmitted in other ways, through reconnected field lines. If the field were only half as strong, the obstacle would be smaller, but still, most of the solar wind would flow around. The total effect remains roughly the same as before--that sunlight is more than a million times more effective as carrier of energy.

111. Waves in the Magnetosphere

I have not fully read your article at **http://www.phy6.org/Education/Intro.html** yet but I am looking for an answer to whether or not there are any identifying characteristics of the earth's magnetosphere along the lines of specific frequency, with certain frequencies in Mhz, much the same way as electricity or radio waves?

If so, where would I find this information?

I am not a physics student but am just trying to learn a little about magnetism. I will continue to finish reading your article though.

Reply

The ocean has waves, of various size and frequency. But the bulk of its energy, activity etc. is in the water itself.

The magnetosphere, similarly, supports all sorts of waves--**whistlers, Alfvén waves, micropulsations, hybrid wave modes, auroral kilometric radiation etc.**, waves whose frequency is tied to the density of the plasma and to its magnetic field. Many of them may be viewed as electromagnetic waves modified by the presence of plasma and magnetic fields.

This is a huge field of research and to understand it takes a lot of data and math, combined. But as in the ocean, these are mostly secondary phenomena. My web pages mostly describe that "ocean." Read them!

112. What are "frozen" magnetic field lines?

Firstly, I must thank you for taking so much of your precious time in creating a superb site covering the Magnetosphere. I have enjoyed reading the entire section with great enthusiasm.

I am a 38 year old electrician from the UK with some college physics education and I have a question that I could not find an answer to in your site:

I have been taught that all magnetic fields are maintained by electrical currents due to the movement of charged particles, including the orbit and spin of electrons in atoms and molecules, but I keep finding the phrase **'frozen magnetic field'** in all sorts of literature covering astrophysics. Can you explain to me what these are?

I have searched for answers on the web but I just find explanations of 'perpetual' currents maintaining 'frozen' magnetic fields in superconductors. Is this the same phenomenon?

Reply

Indeed, there exists a sort of connection between "frozen" magnetic fields in superconductors and in space plasmas. Both media can be considered as **perfect conductors** of electricity, having **zero resistivity and infinite conductivity**, and for that reason, they **cannot tolerate any electric field E**. The symbols for electric field **E**, magnetic field **B** and velocity **v**, really need to be marked in bold face letters, since they are all vector quantity, with direction in space as well as magnitude..

If you plan to read further, better **tighten your seat belt**.

In an ordinary conductor at rest, **E** causes electric currents to flow in the direction of **E**, trying to short it out, and if the conductor is perfect, always E=0 because no generator can supply the infinite current that is called for.

If in addition the material is MOVING through a magnetic field **B**, however, the motion adds in the moving material a "dynamo" electric field **v** x **B** --where "x" will be the vector notation for the "cross product," proportional to **B** and to the component of v perpendicular to **B**. That electric field is directed PERPENDICULAR to the plane defined by **v** and **B** --and of the two possible two perpendicular directions, it is the one of the middle finger of the RIGHT hand, if **v** is along the thumb and **B** along the index (that is the definition of the cross product).

The total electric field **sensed in any moving material** is thus influenced by its motion (making dynamos possible, etc.), and equals **E** + **v** x **B**. If that material is a perfect conductor, THAT must be zero, so in such materials, the locally sensed value of **E** is zero, and

$$\mathbf{E} = -\,\mathbf{v} \times \mathbf{B}$$

Since **v** x **B** has (by its definition) no component **along** magnetic field lines (that is, in the direction of **B**), **E** cannot have one either. In a perfect conductor, any electric field parallel to field lines is shorted out.

Plasma contains free charged particles, and if a magnetic field exists, those spiral around the magnetic field lines. To a very good approximation, in a plasma **rarefied** enough for collisions to be extremely rare (as is the case in interplanetary space), there too

$$\mathbf{E} = -\,\mathbf{v} \times \mathbf{B}$$

To repeat what was noted before: any part of the electric field **E along** a field line will cause ions and electrons to spiral up or down the field line, and **cancel** that part. However, an electric field PERPENDICULAR to B can exist, as long as it is associated with a bulk velocity **v** to make the above equation hold.

This can happen in different ways, but with two extremes. Either the plasma is very RAREFIED (its energy density is small compared to that of the magnetic field): the electric field imposes a flow **v** and moves the plasma until the equation is satisfied. Or else, the plasma is DENSE and has a lot of momentum: then nature lets it move where it wants, which may require shifting electric charges so that **E** of the right value is created, and also perhaps modifying the magnetic field. In either case, however, **the above equation** is always (to a large degree) satisfied.

This is how **the solar wind** (outside about 10 solar radii) overpowers the Sun's magnetic field and manages to move radially outwards, no matter what the sources of magnetic field are. In the first case magnetic field lines stay fixed and constrain the motion of particles, in the second case the velocity **v** is more or less unchanged, and field lines bend and twist to preserve the above "MHD condition" (MHD = magneto-hydrodynamics).

Now mathematicians have analyzed this equation, and applied to is an operation known as "**curl**", involving vectors and partial derivatives--if you have not studied it, it will take you too long. Let me just saw that the curl of a velocity vector **v** (say in water, where this was first studied) is the local "**vorticity**," measuring the tendency to spin tornado-like, and the direction of the curl (it's a vector, remember) is **the axis** of that tornado. We then get, in a perfect, conductor

$$\text{curl}\,\mathbf{E} = -\,\text{curl}\,(\mathbf{v} \times \mathbf{B})$$

(there is a mathematical symbol for the curl, too, $\nabla\times$) Now the magnetic induction law of Faraday, the principle behind transformers etc., says that a changing magnetic field creates an induced electric field. Actually, it only promises a total e.m.f.--a voltage in a closed circuit, which distributes itself according to local resistivity and motion. This e.m.f. is expressed by the curl of **E**

$$\partial\mathbf{B}/\partial t = -\,\text{curl}\,\mathbf{E}$$

which is one of Maxwell's famous equations summing up the properties of electromagnetic fields (the "∂" here is a partial derivative--only with respect to time, and not other variables, such as (x,y,z)) . Put it together

$$\partial\mathbf{B}/\partial t = \text{curl}\,(\mathbf{v} \times \mathbf{B})$$

This equation has the advantage that it deals **only with the magnetic field and bulk flow**; the electric field (troublesome to calculate and often to observe as well) has dropped out. And mathematicians have interpreted this equation; in terms they use:

"**The magnetic field is frozen to the flow velocity distribution**."

In more intuitive terms:

"**If two charged particles of matter participating in the flow pattern of v are initially on the same field line, they will always be on the same field line. If they are on different field lines, they will never be on the same line**."

An escape clause exists with flow involving points where **B** =0 ("neutral points"), where field lines can "reconnect." This however happens only at isolated points (though it may be important in nature). Overall, this is a very helpful property--incidentally, first discovered in the flow of ordinary fluids, with B replaced by the vorticity "curl **v**," giving a theorem about "preservation of vortex lines."

For more, see

> http://www.phy6.org/Education/wimfproj.html or an identical file
>
> http://www.phy6.org/stargaze/Simfproj.htm

Sorry if I gave you more than you expected!

David P. Stern
Greenbelt, Maryland (where your queen visited today!)

113. Why doesn't magnetism affect electro-magnetic waves?

I'm a 6th form student in the UK and it suddenly occurred to me while I was revising what we had learnt on waves and magnetic fields that, if EM waves are indeed electro-magnetic waves, why is it that they are not affected by magnetic fields? And why do such waves not display the properties of magnetic fields in the fact that they loop from pole to pole?

Forgive me if this is a rather naive question, I do understand the principles behind EM radiation and waves quite well, its wave-particle nature, thus allowing superposition etc., but I'm just curious as to how there is such a distinction between an electromagnetic wave and a magnetic field. If one consists of the other then how is it not affected by the other, and how is it EM radiation can travel in a straight line for nearly infinite distances (gravity aside)?

Reply

Electromagnetic waves are linear--when several are added together, each preserves its identity and can be separated again. On the radio, or on TV, many stations can send their signals through the same region of space, and yet your receiver can pick out any of them and amplify it alone.

You could regard a steady magnetic field as a signal of zero frequency (taking forever to switch to its electric signature). It does not interact with any electromagnetic waves of non-zero frequency, at least in vacuum.

In a material medium the magnetic field may modify the electromagnetic properties of the medium, affecting the propagation of waves. For instance, the Faraday effect in transparent media may rotate the plane of polarization of an electromagnetic wave.

In a plasma (gas containing freely floating ions and electrons) many different kinds of modified electromagnetic waves are possible--depending on the frequency of the wave and how far it is from some characteristic resonances, which depend on density and magnetic field in the plasma. In particular, "Whistler Waves" (in space near Earth they are produced by lightning at frequencies like 3000 Hz) are indeed guided by field lines, sometimes bouncing back and forth from one hemisphere to the other.

114. Eddy Currents

A question has been nagging me about eddy currents. They are never visualized the same way. Sometimes they are circling **this** direction, sometimes **that**, and sometimes there's **just one big circle** in the conductor they are being induced in.

I'm slowly beginning to suspect that they are not circling at all, or at least that they are not aligned in any way. Is it because the visualizations are just some hand-waving argument, to help people imagine what really must be expressed by equations? Or am I browsing too many scripts meant to be read by electrical engineers?

Reply

Eddy currents are indeed best visualized with the help of mathematics.

Imagine first at the flow of air in the atmosphere (or of water in a large volume, say in the ocean). There exist **two basic patterns of flow**: "**irrotational**" flow in which air or water flow from high pressure to low, and "**swirling**" (or "rotational," also called "solenoidal") where it just goes around in circles. You have to take my word for it that in any description of the distribution of velocities **v** in such a fluid (and **v** is a vector, with direction as well as strength), the flow can always be viewed as a combination of these two types, and these types only--some of the flow is irrotational, some rotational (and to be sure, there also exists a small range of motions which can be placed in either camp). That is known, by the way, as **Helmholtz'es theorem**.

Now the same holds for **flows of electric currents** (which you can visualize as the motion of electrons in matter--say, in a metal). "Irrotational" motions are the kind you get from **batteries**, where electricity flows from plus to minus (more accurately, electrons from minus to plus, a historical error in naming electric charge signs), or where it flows from some place where electrons have been separated by friction, back to where they came from.

"Rotational" flow of electricity has a different source, a **changing magnetic field**--say, in the secondary coil of a transformer, inside which the magnetic field changes because it is produced by an alternating current in the primary coil. The primary coil is attached to the AC power and its alternating current creates an alternating magnetic field in its iron core. This then **induces a rotational electric field** in the "secondary" coil wrapped around the same core--perhaps producing there a different voltage, and driving there an alternating current which can then be put to practical use.

However, **the magnetic core is iron, which is also an electric conductor**. What would prevent a voltage from being induced, not just in the secondary coil but also in the iron core? If a solid iron core is used, that indeed is likely to happen. **Those would be eddy currents**, absorbing energy and wasting it by turning it to heat, which can also damage the transformer.

If you have ever looked closely at a transformer, you know how this is avoided. The magnetic core is **not** solid iron, but consists of a stack of thin iron plates, glued together by some insulating gunk. The gunk breaks up any large-scale circuit in which eddy currents can flow, and as a result, only tiny harmless eddy current loops can flow. The iron in practically any AC machinery is made up of thin plates, for the same reason.

The magnetic field in a region changes if it is generated by AC, but another kind of change is also possible: the magnetic field sensed by a piece of metal also changes when it **moves through a magnetic field**--say, enters it or leaves it. **There too** eddy currents are produced, circulating in the metal itself.

In a battery ("irrotational" electric flow) you can talk about a **voltage**--the poles are separated by a voltage difference of, say, 1.5 volt. In a rotational electric source, all you can say is that an "**electromotive force**" (e.m.f.) of, say, 1.5 volts exists. The e.m.f is like a voltage distributed around the circular path, but how exactly its parts are distributed depends on the distribution of changing magnetic fields and of electric conductivity, along the path in which the induced current flows.

It is not an easy concept! Please look up for more at
http://www.phy6.org/earthmag/magnQ&A5.htm#q75

115. What is the Radius of the Sun's magnetosphere?

What is the radius of the sun's magnetosphere?? I can't seem to find any sources that have said number, or any other planets' except Earth for that matter. Thank you very much.

Reply

Before trying to answer your question one must first decide what is meant by "sun's magnetosphere"--and also, it is better to ask about **"size,"** not **"radius"** because whatever the size is, nothing promises a spherical shape..

The most logical definition of the sun's magnetosphere is as the region of space **connected to the sun by magnetic field lines** which originate at the sun. A similar definition works for the Earth and for planets. For the sun, that is also the definition of **the heliosphere**--see

http://www.phy6.org/Education/wtermin.html

All we know now is that it is huge, that even Voyager 1 has not yet crossed its boundary, although it did cross the first transition associated with the approach of that boundary, the "termination shock" at 94 times the average sun-earth distance, and more recently, so did Voyager 2.

Why is the heliosphere so big? Because on one hand, the solar wind helps stretch out the sun's magnetic field, as described in

http://www.phy6.org/Education/wimfproj.html

and on the other hand, the outer boundary is where whatever lies beyond **stops** this expansion. For the heliosphere, what lies outside it is the very rarefied **interstellar** ("between the stars") **plasma** and the extremely weak **interstellar magnetic field**. Only when the expanding solar wind has spread itself (and its magnetic field) very, very thin does its pressure match the weak counterpressure.

The boundary itself is not likely to be a sphere. The **solar system is moving** relative to its galactic neighborhood, so the front will be compressed and the "tail" stretched out.

The heliosphere resembles the magnetospheres of Earth and planets, but its dimensions do not, because with Earth, what lies outside is the solar wind--nearer the sun and therefore denser--and the interplanetary magnetic field, also many times stronger than the interstellar field. And again, it's **not at all symmetrical**. On the side facing the Sun the Earth's magnetosphere is fairly well defined at a distance of about 11 Earth radii; but it is very much stretched out on the side facing away. Spacecraft have sampled it about 20 times further and it is still going strong there--it might well extend 10 or more times further. As for size to the sunward boundary of some planetary magnetosphere, , see last line of the table in

http://www.phy6.org/earthmag/mill_8.htm

The line above it gives the typical density of the solar wind.

Asking questions is easy, answering them is harder. I hope what is here satisfies you.

116. Project to show that Iron rusts faster in Fresh Water

Hi! Can you help me with a science fair experiment to show that iron rusts faster in fresh water than in salt water?

Reply

I regret to inform you that **your hypothesis disagrees with observations**: salt water is **much more corrosive** than fresh water, because the salt molecules dissolved in water tend to **split apart into electrically charged parts** and these help the chemical reaction which corrode metals. See:

http://www.phy6.org/Education/whposion.html

If you had asked around, you would have found that the navy and shipping companies prefer placing their ships (in particular, ships intended for long term storage) in river inlets, because there corrosion is reduced, For instance, the US Navy in California has a large reserve fleet in the Sacramento river, rather than around nearby San Francisco, which would have been more convenient.

Similarly, merchant ships used to be kept for emergencies in the Hudson (maybe still are), and it is a well-known fact that steamships on the Great Lakes last much longer than the ones that sail the salty oceans.

It is similar for aluminum, by the way. Before WW-II there existed various kinds of "flying boat" seaplanes, e.g. the "clippers" which flew across the oceans, and in the war the US navy widely used the "Catalina" flying boat. I believe that one had folding wheels and could taxi onto a beach or apron, ending on solid land where it was hosed down with fresh water. Still, seaplanes are now rare. Most fly in places like Alaska, Canada and Minnesota, where they always land on salt-free water.

117. Fluorescent lightbulbs

I am an 8th grade science teacher. My students are currently debating current issues concerning various types of radiation. One of my students would like to ask you the questions below. Would you be able to take the time to answer the student's questions? Thank you!!

And from the student:

I am a student of a middle school in Wisconsin. I would like to know what your view of fluorescent bulbs vs. incandescent bulbs is. I am interested in you opinions for a debate I will be participating in. More specifically, I would like to know the advantages of fluorescent bulbs. Any information you can provide would be helpful.

Reply

Fluorescent bulbs produce much more light for a given amount of electric power. Light emitting diodes, now just creeping into use, are even better. In a society where energy conservation is an important issue, these are likely to displace incandescent bulbs, even though they cost quite a bit more to manufacture. In part the cost of incandescent lightbulbs is low because their production has become rather automated. Maybe the new devices will also become cheaper when mass-produced.

Incandescent bulbs use tungsten, whose supply is limited, though right now no shortage exists. Fluorescent bulbs contain mercury in small amounts, so their disposal may add mercury to the environment, and it is a toxic substance. Their lifetime is long, but frequent switching on and off shortens it appreciably. I am not sure about diodes, but they are probably OK.

Postscript: An article on p. 98-99 of "**The Scientific American**", March 2008, compares the merits of the three light sources.

118. More about the Year 2012

Hello Dr. Stern.

My most recent concern is the prophecy of a "doomsday" for Earth in 2012. This prophecy states that the polar reversal and polar shift of the Earth will occur, causing destruction. Is the Earth due for another polar reversal in the near future? Or is this just a big myth? Also, I've heard about the Planet X, tenth planet of our solar system. Does this planet have an elliptical orbit that would collide with our Earth in 2012? Or is this Planet X a big myth? What are your thoughts on the Mayan Calendar ending in Dec 21 2012?

Reply

I wrote about 2012 in replies to letters, linked from the bottom of

http://www.phy6.org/stargaze/Scalend.htm

The answers there note that the rotation of Earth cannot shift significantly (conservation of angular momentum) and that the Earth's reversal of magnetism, by all past observations--if it comes, it will be very gradual, and in any case won't affect life on Earth. **The Maya** were keen observers of the sky, and their calendar was good (though the Babylonians, 2000 years before them, devised a good calendar too); but they had no telescopes, had no concept of the solar system (as far as I know) and certainly none of magnetic fields.

"Planet X" was much discussed in the early days, when Percival Lovell searched for it, basing his search on supposed deviations in the motion of Neptune. No new major planet was found--just Pluto, too small to have an effect, though many other minor planets (**"Kuiper belt objects"**) were later added at similar distances. To the best of my knowledge, the subsequent motion of Voyager showed no influence of "Planet X," though the one of Pioneer 10 and maybe 11 (I think) deviates slightly.

119. Can Space Plasma help Spacecraft Propulsion?

With space filled with plasma (charged particles from suns) is it feasible to create electromagnetic space propulsion systems ?

Would these be similar to the solar sails already in use by several space agencies ? Or could they be similar to the electromagnetic propulsion systems created for water vessels (I think back in the early 90's) ?

Reply

I cannot guess all possible applications, but my first guess would be, it is probably not feasible. To create a force forward, **something else needs to be pushed back**, or at least something moving needs to be stopped.

A **solar sail** stops sunlight, or reflects it back, which doubles the force (and actually it's best to deflect it by 90 degrees, to increase the orbital velocity around the Sun). The solar wind also can be stopped--I don't know how its pressure compares, I suspect it's less than that of sunlight.

But to make use of the surrounding plasma, you need some electric circuit which **pushes the plasma back**. You could propel a ship by electric currents through the ocean, creating a water jet directed backwards (it would still take a lot of energy). However water is fairly massive, while the plasma of space is usually much more rarefied than the best laboratory vacuum.

Ion rockets indeed push back plasma, but the plasma is **generated in the spacecraft itself**, where its motion can be controlled before it is pushed away. The energy then comes from solar cells, and the acceleration is very gradual. See

http://www.phy6.org/stargaze/Sionrock.htm

120. When is Earth an Insulator and when a Conductor?

Why is it that Earth some times behaves like a conductor and some times behaves like a dielectric (=insulator)? Please answer this question..

I am a student of telecommunication, from Pakistan.

Reply

My work experience is with the magnetic field of Earth in space, so please check what I write with someone more experienced! Also, your question is not very specific--one must guess **what you mean each time you write "sometimes."** Still, let me try.

Sometimes the Earth is like a **conductor**--for instance, when you ground an instrument by running a wire from it to pipes in the ground. That is probably **ionic conductivity**--caused because earth usually has SOME water in it, coating its grains of clay or sand. That water is never pure (like distilled water) but always has at least some salt dissolved in it, and maybe other "electrolytes" as well.

Such dissolved molecules break up into electrically charged components, which can conduct electric charge (see http://www.phy6.org/Education/whposion.html) The current may consist of many branches, but the ground is so big that it can easily conduct even large currents.

But **at other times** you have radio signals, and the ions in the ground cannot oscillate fast enough to follow the voltage changes of such signals. In that case, Earth is **like a dielectric**. If you sit inside a concrete house during a rainstorm (and concrete is like earth, it also absorbs water), you can still listen to the radio inside. Put the radio inside a closed metal pot and the sound stops, because metal is a different kind of conductor and blocks radio waves from reaching the receiver.

That, anyway, is my guess

Good luck in your studies!

121. Can atmospheric atoms join the solar wind?

When atmospheric molecules of any type are dissociated from their home planet, for example Venus, are those molecules then blown outward by the solar wind? If so, could they be captured by other planets?

Could ice blocks on the Moon, or material on Earth, come this way from closer to the Sun?

Reply

Any atmospheric molecule removed from the gravity of its planet needs **two additional steps** before it can be caught up by the solar wind: it must **become ionized** (lose at least one electron, so that it responds to electric and magnetic forces), and **be detached** from whatever **magnetic field** it is produced in, so that it can attach itself to the interplanetary field which permeates the solar wind (see
http://www.phy6.org/Education/wimfproj.html
about attachments of ions to magnetic field lines).

That's what seems to happen to many atoms and molecules evaporated off **comets**. They easily escape the comet's weak gravity, and since comets have no magnetic field of their own, when atoms become ions (by sunlight detaching an electron) they are already in the interplanetary magnetic field and are therefore easily "picked up." The same happened with the "**artificial comet**" of the AMPTE mission (late 1984 or early 1985), where the experimenters waited for the spacecraft to enter interplanetary space, then blew an explosive charge which scattered barium vapor. Barium atoms are easily ionized by sunlight and are promptly picked up by the solar wind.

It is very unlikely for ions from a planet to do so, except maybe from the outer atmosphere of Mars and Venus, where planetary magnetic forces are weak or absent. I know of no ice blocks on the Moon: any ice there would probably come from comet impact.

And once an ion is in the solar wind, its chances of hitting a planet are negligible.