

What is a magnetic field?

Does a magnet slow time?

Stephen Hawking explains in his book, *A Brief History Of Time* that virtual photons are the force carrying particles of the electromagnetic field. The 4 forces in nature can be explained by exchanges of particles, but quantum gravity theory has problems and is not complete.

Richard Feynman refers to photons from a magnet in his book, *Q.E.D., The Strange Theory of Light and Matter*. Feynman explains that under certain circumstances, including when a very large number of electrons are all moving in the same way, such as going around in the coils of an electromagnet, a large number of photons are emitted, all of exactly the same kind.

Roger Penrose explains in his book, *The Emperor's New Mind* that the momentum state wave function of a photon is a corkscrew or helix. He also explains that all emitted photons must carry some mass because $E=mc^2$. Think of energy as a highly diluted form of mass or think of mass as a highly concentrated form of energy.

Thus one can visualize magnetic attraction and repulsion as streams of photons with their corkscrew shaped wave functions screwing into (attraction) or screwing out of (repulsion) each other. Now you can visualize that forces do indeed arise from an exchange of particles, or their wave functions. It has been suggested that these streams of virtual photons travel along the magnetic lines of force.

This leads to very interesting questions.

What is the frequency of a permanent magnet's field?

F.A. Wilson explains in his book, *From Atoms To Amperes* (Bernard Babani publishing, London England c 1989) that in the case of the electromagnetic force, the exchange particle is the photon, and that from Einstein's and Planck's formula arises a relationship between the mass of a photon and the frequency of the light (visible or not) it represents.

Planck's formula: $E=hf$ where:

E is the energy of a single photon,
f is the photon's frequency,
h is Planck's constant,

Einstein's formula: $E=mc^2$ where:

E is energy,
m is mass,
 c^2 is the speed of light squared,

hence, $hf=mc^2$

thus showing that the mass of a photon is directly proportional to the frequency of the photon.

$$E=hf \text{ and } E=mc^2 \text{ so } hf=mc^2$$

Because higher frequencies have more energy ($E=hf$), they deliver more mass ($E=mc^2$). Einstein understood that light quanta (photons) are a mass transfer mechanism. The flux quanta (flowing particles) or photon exchange frequency is thus mass in motion and is the force of a magnetic field. The frequency and number of photons exchanged must be extremely high to exert physical attraction or repulsion.

The implication is that the frequency creates a force that is a physical mass connection, $hf=mc^2$. Different magnet compounds should have different frequencies since photons are emitted/absorbed by electrons. If an electron is throwing out a stream of photons while orbiting/spinning, you can visualize a corkscrew or helix stream of photons!

A photon's wavelength is measured as a distance along a line through the center of the helix in one revolution around the helical trajectory. A flat projection side view of a helix looks like a sine wave.

Low frequency photons (such as radio waves) are often described in terms of wavelength (units in meters), while high frequency photons (such as gamma particles) are often described in terms of particle mass energy (units in electron volts). As you increase the energy by increasing the frequency, you wind up with photons of more measurable mass. At the high frequency end of the electromagnetic spectrum are high energy photons known as gamma rays, which are streams of gamma particles. Beta particles are free electrons or positrons. Alpha particles are the nucleus of helium atoms.

In every day life, you can understand that energy is proportional to frequency if you understand a concrete hammer drill will deliver more energy to the drill hole if it hammers at a frequency of 10 strokes per second instead of 1 stroke per second.

Is a magnet losing mass by emitting a field?

Stick a magnet to the bottom of a metal shelf. Watch it defy gravity. If it is defying gravity, it must be expending energy. By $E=mc^2$ it must be losing mass!

One may object to this by stating there is 0 mass displacement, therefore 0 work, and 0 energy loss, but the flux quanta (flowing particles) of the magnetic field is an unobvious mass displacement itself. The April, 1990 issue of Physics Today contains a photo of magnetic vortices labeled "Seeing flux quanta" and states "Where two oppositely directed magnetization streams merge, they produce vortices similar to merging streams of water."

Theoretical physicist and Nobel laureate Sheldon Glashow explains for PBS NOVA online (Einstein's Big Idea, October 11, 2005) that, "When an object emits light, say, a flashlight, it gets lighter."

Do magnets evaporate like black holes?

I find it interesting that iron (a strongly magnetic element) is the most massive element that can be produced during the fusion phase of a star's life. It takes a supernova to create all the elements

beyond iron in the periodic table. A star's fusion phase starts with hydrogen and stops at iron which has the most tightly bound and thus most stable nucleus of all the elements. Iron⁵⁶ is at the top of the binding energy curve. On the curve, hydrogen is at the bottom to the left of iron, and the heavy elements such as uranium are at the bottom to the right of iron. I've seen one book that stated nickel is really at the top of the binding energy curve. It is interesting that many meteorites are made of ferromagnetic elements, iron and nickel, blown out by stars that went supernova! Iron and nickel, with their tightly bound nucleus, seem to give virtual photons (flux quanta) a better grip for magnetic attraction when passing through.

A star with enough mass near the end of its fusion phase can go supernova, and may leave behind a neutron star, or a black hole, depending on the mass available. Certain rapidly rotating neutron stars, known as Magnetars, are believed to produce the strongest magnetic fields in the universe. A black hole is an object of such dense mass that it creates a gravitational field so strong that the escape velocity exceeds the speed of light! If black holes have a magnetic field, and it can get out, this seems to imply that virtual photons (flux quanta) can travel faster than the speed of light! Black holes may evaporate by a process known as Hawking radiation, (named after Stephen Hawking who theorized it). Black holes may also evaporate by quantum tunneling. Quantum tunneling is when a particle penetrates a barrier which it ought not have enough energy to penetrate.

Where is the mass of these virtual photons from a magnet?

Force carrying photons are called virtual photons because unlike other real photons, they cannot be directly detected by a particle detector. In Feynman diagrams, virtual photons are symbolized by squiggly lines that never have loose ends. Magnetic lines of force curve back to the magnet and never have loose ends. This topology seems to imply there are no magnetic monopole particles. Virtual photons may be concentrated along magnetic lines of force (flux lines), which may be mass entanglements. Einstein stated, "The particle can only appear as a limited region in space in which the field strength or the energy density are particularly high". The energy density is strongest where the lines of force are around a magnet, so that is where the most virtual photons should be.

The range of electromagnetic force is thought to be infinite. The strength or intensity of an electromagnetic field decreases at a rate of $1/\text{distance}^2$. This equation holds true for light from a point source, but not for force from a magnet which drops off at faster rates. This is probably because virtual photons from a magnet are following the flux lines and not traveling in straight lines like photons from a light bulb. You can measure force from magnets with a ruler and a grocery scale.

Could it be that force carrying virtual photons cannot be detected because they are in another dimension? Could their mass be smeared around the universe in another small dimension, with only force detectable in our normal size visible dimensions? (Magnetism as invisible plumbing behind our reality, non-locality, like Einstein's spooky action at a distance via EPR channels.) The October 12, 1999 Time Travel episode of PBS's NOVA showed photons traveling at 1.7 times the speed of light via quantum tunneling. This faster than light communication may imply travel through another dimension. A short distance traveled at the speed of light in a very small dimension could appear as a large distance traveled faster than the speed of light in our normal size visible dimensions. Quantum tunneling may be direct evidence of the other hidden dimensions in string theory.

Do the lines of force have a physical reality?

The magnetic lines of force have tension, as demonstrated by a magnet being suspended in air below a certain type of superconductor. The conventional explanation for this is flux pinning in the superconductor. The magnet hanging below the superconductor will swing back and forth on the tension of its flux lines (lines of force) which are somehow partly pinned in and partly expelled from the superconductor.

This tension is the basis for proposals and research to use magnetic fields as solar wind sails to propel spacecraft. The force of the solar wind pushes against the magnetic field, and the tension of the flux lines transfers the force back to the spacecraft, dragging it through space like a sailing ship.

Does a magnet slow time?

Nobel prize winner Richard Feynman explains in his sum over histories interpretation of Quantum Mechanics that photons go where time is least. They follow the path of least time. Generally, this is a straight line, from point A to point B, if the effects of gravity and small constrictions are excluded. Einstein showed that gravity slows time, and that acceleration produces the same effects as gravity. Astronomers have observed that gravity bends light. Physicists have proven with atomic clocks and airplanes that gravity slows time. Clocks run slower at lower altitudes where gravity is stronger. Time is least (flows more slowly) where gravity is most. Gravity bends light because the photons are seeking or are pulled toward a path of least time, which is a path of more gravity! This space time curvature is the essence of General Relativity. Because we are talking about photons, this is also a link between Quantum Mechanics and General Relativity.

If one falls into a black hole, time slows as one accelerates toward the event horizon. Time stops at the event horizon. This is the point where you have accelerated to the speed of light and the escape velocity from the black hole's gravity equals the speed of light. At the speed of light, length shrinks to zero and time stands still. Think of it this way: If you leave the face of a clock at the speed of light, the light that leaves after you can never catch up with you, therefore time has stopped. Also, if something has a length, it must take time to pass.

Below the event horizon, escape velocity exceeds the speed of light, hence light cannot escape, and the name black hole came to be. A black hole's gravity should bend light (photons) into orbit near the event horizon. The earth orbiting the sun has momentum which keeps it in orbit. If the earth's momentum were to stop, the earth would seek the path of least time, and plunge straight into the sun! Photons, and everything else, like planets, try to go where time is least. This is a part of space time curvature, which is gravity.

Could it be that virtual photons from a magnet follow the magnetic lines of force because this is their path of least time? Could it be that a magnet slows time by accelerating photons? Einstein asked himself the question: If gravity and acceleration feel the same, perhaps they are the same.

Kip Thorne explains in his book, *Black Holes and Time Warps* that the electromagnetic field of an object contributes to the gravity of the object, because mass and energy are equivalent. Brian Greene explains in his book, *The Elegant Universe* (a 3 part PBS NOVA, Oct. 28, Nov. 4, 2003) that Maxwell's equations for the electromagnetic field are relativistic. This implies that an electromagnetic or magnetic field changes the rate at which time flows. The combined ideas of fields, quantum particles, and relativity produce what is known as relativistic quantum field theory.

Since all photons must carry some mass, the emission of a photon is by definition the acceleration of a small amount of mass to the speed of light. Some people call this a conversion to energy. If a magnet is emitting massive numbers of virtual photons, then a small but significant amount of mass is being accelerated to the speed of light, and this should slow time. Thus the lines of force may indeed be a path of least time for the virtual photons emitted by the magnet.

The magnetic field in a CRT (cathode ray tube) can be seen as controlling the path of an electron by controlling the rate at which time flows in the CRT. The electron is seeking or being pulled to a path of least time on it's way to the screen!

All mass objects have gravity that slows time to some degree, depending on the mass of the object. The electromagnetic field contributes to the gravity of an object, thus it also affects the rate at which time flows. The magnetic field around a magnet can thus be seen as a curvature of space time.

Do clocks run slower in a magnetic field?

The September 2004 issue of Scientific American (Beyond Einstein special issue) has a small article on Clock Comparison Experiments on page 100. It states: "The typical basic "clock" is an atom in a magnetic field, and the ticking rate is the frequency of a transition between two of the atom's energy levels that depends on the strength of the magnetic field."

Why does a magnet emit virtual photons?

Perhaps, the alignment of atomic spins in a magnet somehow creates a quantum mechanical photon pump! Remember, the spin angular momentum of electrons, protons and neutrons, plus the orbital motion of electrons, are all moving charges that constitute electric currents, and thus gives rise to a magnetic field!

I hope you have enjoyed this intuitive exploration of relativistic quantum magnetism.

[David Sligar](#), August 1999, revised April 6, 2000, Dec. 16, 2003, Oct. 11, 2005, Jan. 24, 2006, March 23, 2008

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