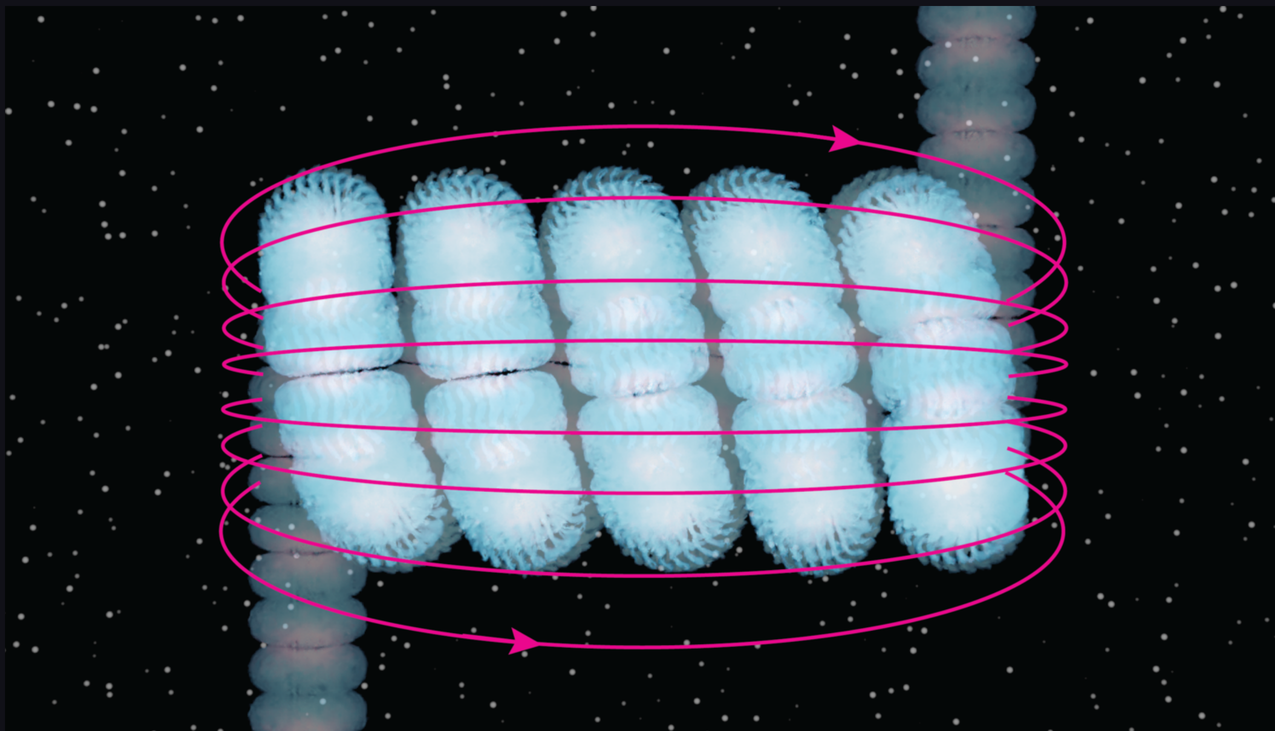
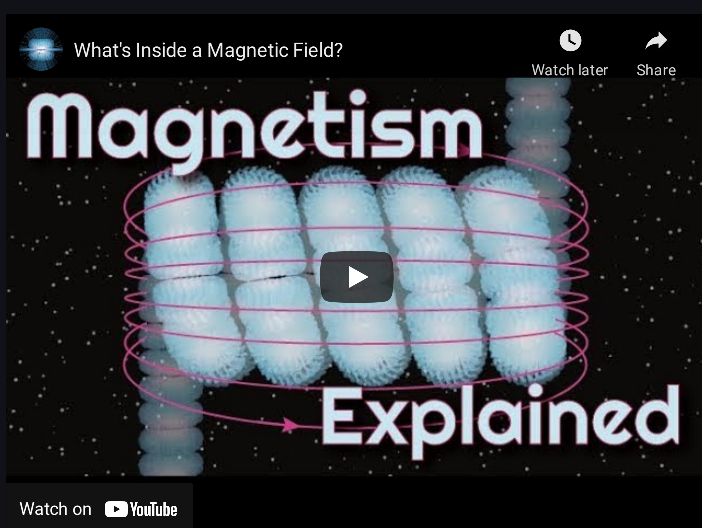


Jul 21

How Do Magnets Work?

Science, Technology, Astrophysics & Cosmology, Material Science



Visualizing Magnetism

Magnetism is a common phenomenon for all, yet poorly understood by most. We become acquainted with magnetism from a very early age, maybe noticing that they're used to pin photos and documents to the refrigerator by our parents or maybe we experience them as toys. Maybe we were lucky enough to experience magnetic sand at a science

museum. If we were born in Japan, Germany, or Russia, we may have had first-hand experience with magnetically levitat[illegible] trains. In any ev[illegible] were each al[illegible]st certainly astounded by our first enco[illegible] a-distance between two otherwise ordinary looking objects. If you can't remember the feeling, watch this kid.

But action-at-a-distance is not a matter of magic, it is a matter of physics. Our sense of wonder for magnets may turn to an inquiry into the science behind the familiar phenomenon. Perhaps that is what led you to this page. Unfortunately, as of this publication, the overwhelming majority of explanations for magnetic action terminate in one of two dead-ends. First, you will learn that atoms are each tiny magnets and so composite materials simply behave depending on the coordination of their subunits. This obviously punts the question of what makes the tiny magnets attract? For that line of inquiry, we are generally met with the second fatal roadblock: atoms interact magnetically due to magnetic fields. Of course, this explanation, however deep one dives into the mathematical descriptions of fields, begs the question: what *is* a magnetic field?

The magnetic field of physics is a dynamic description — that is, it has both a shape and motion. This is evident from the basic unit of magnetic field strength, the ampere/m. The ampere signifies charge per time and is the basic unit of current. Hence, a magnetic field is dynamic: it what some*thing* is doing. Therefore, in alternative to traditional visualizations, our explanation of magnetism begins not with an activity like a field but with an actor: the atom.

Magnetism Begins with Atoms

Magnetism is presently understood as one side of a double-headed atomic phenomenon called electromagnetism. Electricity being the simpler of the two faces, it is all but imperative that you go back and read our work-up and watch the animation for visualizing electricity before proceeding here.

If you are short on time, I'll provide you with an extremely brief re-cap. We integrate contemporary mathematical descriptions of electricity into an explanation that we believe improves upon traditional hydraulic and electron-bead-flow models. In brief, we illustrate the concept of charge through the rotation of atomic surfaces. These surfaces, called electron shells (e-shell) or orbitals, behave per quantum mechanical electron wave functions. Surface-to-surface transmission of e-shell rotation between aligned shells of atoms constitutes electricity. Although there are never electron beads moving along in our wire, our visualization of electricity is entirely consistent with modern mathematical representations. Current flow is merely reimagined as propagation of *in situ* e-shell surface rotation.

This is an updated way to visualize electricity. We hope to improve upon the old text-book style "electron-bead-flow" and "hydrodynamic" analogies.

We utilize the simplest and most abundant atom, hydrogen, for our explanation of both electricity and magnetism, since it has only a single electron forming one e-shell orbital. We fashion a simple, hypothetical single-atom-thick wire from ionized hydrogen. The ionization indicates that the atoms electron surface is not localized by enmeshed with its

In the Lab...

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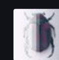

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neighbors. We can extend the electromagnetic principles applied to hydrogen across other more complex elements and molecules by the careful addition of orbital surfaces, recognizing that new e-shells may pa[illegible] others may rotate freely and separately contribute to magnetism.

Visualizing the Invisible

Magnetic action is next explained as a natural extension of the aligned rotation of conducting electron surfaces in a current-carrying wire. Through the vertical transmission of rotational momentum between atoms through polar surface contact, a horizontal interaction is also introduced toward their equators. The magnetic field, B, of the atom describes this surface motion, which occurs 90 degrees orthogonal to current, I (see **Fig 1A**).

The reason that magnetic action extends beyond the current-carrying wire's apparent surface is that while 99.999% of the electron exists within 430 pm of the nucleus, there is a small chance of finding that surface extended to incredible distances. In fact, under Quantum Mechanics, the radial distribution function for the electron has no limit on reach. For our model, we represent this unusual quality of the atom as rarefied extensions of the electron shell: incredibly thin filaments, radially organized about the atom (**Fig 1B)**.

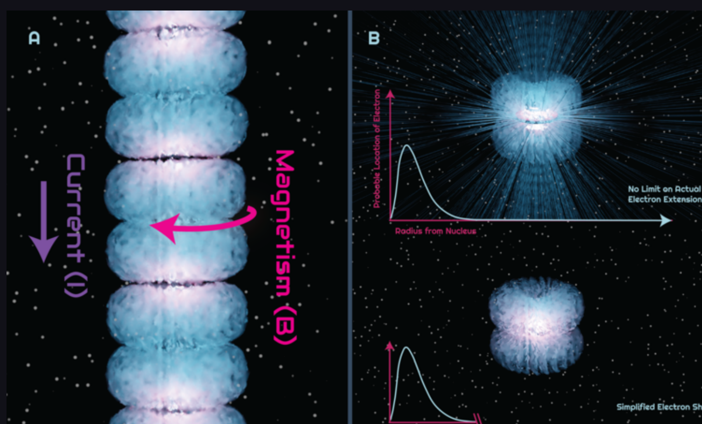
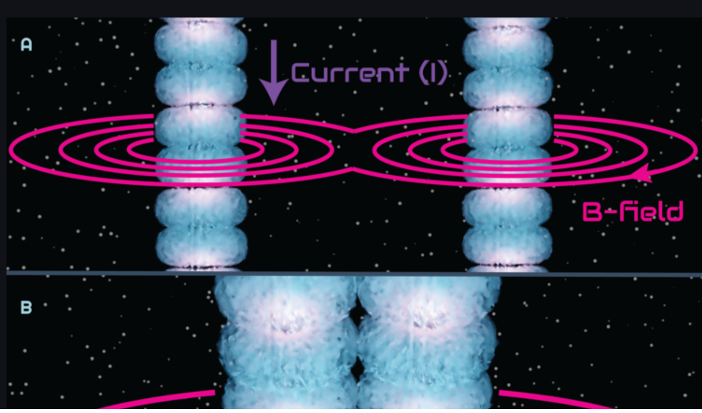


Fig. 1 Magnetism is visualized at the atomic level as the lateral interaction between aligned orbital surfaces of atoms. Magnetic field is orthogonal to current as shown in (A). The transmission of lateral interactions beyond the apparent surface of the wire is made possible because of the thinned extensions of the atom's e-shell (panel B top), as described by the electron wave function of quantum mechanics. We omit these extensions throughout the visualization (panel B bottom) for clarity but they are always assumed present and responsible for transmission of invisible action.

We imagine the physical extensions of the atomic surface are responsible for the action-at-a-distance. Lateral magnetic motion of conductive rotating e-shells thus synergizes between current-aligned wires, pulling them together as shown in **Figure 2** below (panels **A** and **B**). This illustrates the basic principle of magnetic attraction. By inverting one of the wires, we find that currents are now opposed, as are the magnetic actions of each column's atoms (**Fig 2C**). The clash of opposing effort between e-shells in each column drives the wires apart and illustrates magnetic repulsion.



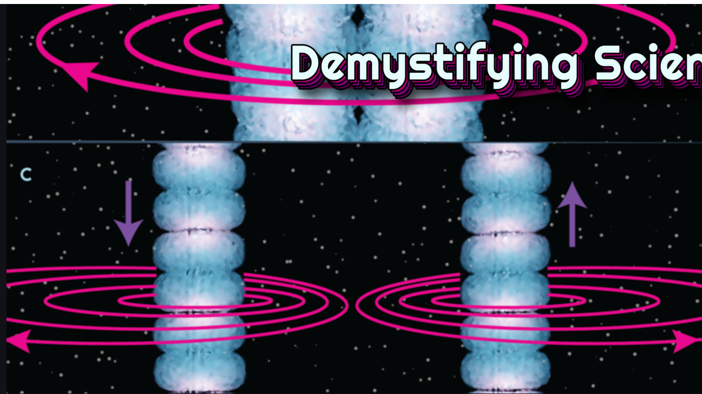


Fig. 2 Magnetic attraction is understood as synergistic effort by current aligned and in-contact e-shells in (A). The combined magnetic field, also called induction, results from the combined motion of these aligned atomic surfaces (B). If one current is inverted, the lateral action of each wire pushes opposite the other, resulting in a repulsive effect (C).

The Electromagnetic Coil

To construct the most basic magnet imaginable, we coil up our single-file hydrogen wire as shown in below in **Figure 3**. Coiling of the wire aligns the lateral motion of all e-shells on the surface of the composite cylinder (**Fig 3B**). The combined flow of the coil's composite surface appears to track out from one end of the coil and into the other. The composite magnetic field describes this pole-to-pole flow of the coil's atomic surfaces.

It is now easy to understand how the magnetic attraction between current-aligned wires multiplies through the coil's architecture, since lateral efforts align and combine. If we bring the North pole of one coil near the South pole of another, the radial extensions of the e-shell enmesh laterally and pull the coils together magnetically (**Fig 3C**). Inverting one coil and pitting South vs. South or North vs. North poles has the opposite effect, where the conflicting effort of each coil's atoms push them apart (**Fig 3D**).

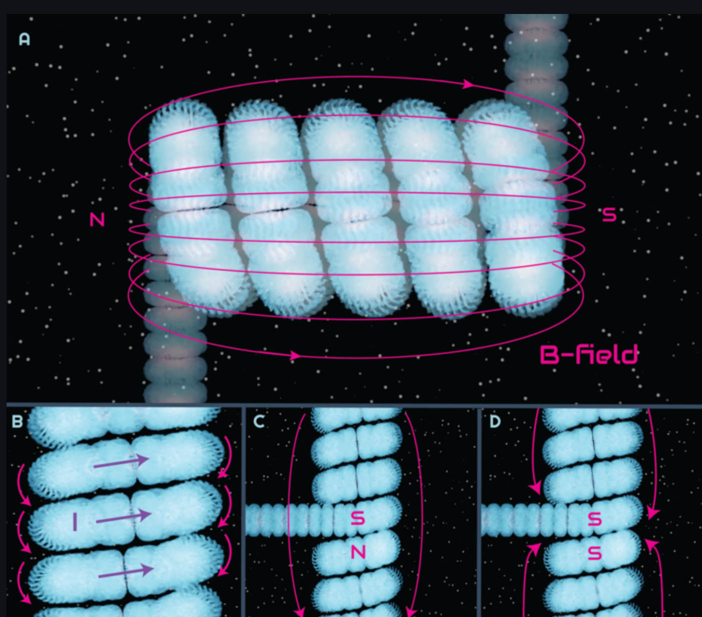


Fig. 3 The simplest magnet, a solenoid (A), is fashioned by coiling our single-file hydrogen wire so that on all surfaces current and magnetism are aligned (B). The result is cohesive surface motion of all atoms on the composite cylinder. If we bring two coils together with similar orientation, an attractive synergism is observed between their e-shells (C). If we invert one coil and bring them together we observe the clashing of oppositely oriented e-shells pushes them apart (D).

Extrapolating This Simplified Explanation

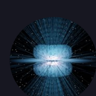
Again, any visualization of intricate physical processes inherently necessitates simplification. Here, we have utilize[illegible] single-atom-th[illegible] [illegible]onized h[illegible] for our demonstration and readily ackno[illegible] wire exists naturally, its likeness is probably only found in the deep reaches of outer space. In our every-day reality, we only encounter synthetic electromagnets comprised of more complex atoms. This means those metals have additional surfaces. In common conducting materials, such as copper, there may be several polar contacts available for electromagnetic interaction.

Even more complex metals, like those found in a bar magnet, appear to utilize separate orbitals for bonding and conduction than those involved in magnetism. We would visualize distinct magnetized e-shells as freely rotating, and spatially isolated from the conductive bonding lattice. This is why "permanently" magnetized materials do not exhibit a current. Furthermore, the relevant magnetic e-shell surfaces in bar magnets still retain the essential pattern of the spiraled coil from our depiction. We are working toward an animation of these complex atoms and will present an appropriate visualization in a future post/video.

One final note is that often the strongest magnet is a combination of a magnetizable metal with a coil. A magnetizable metal has unencumbered e-shells distinct from bonding and these surfaces are readily incited to magnetic cohesion through contact with coil's extended atomic surfaces. Often, cores of electromagnets utilize iron or nickel for the very reason that these elements are highly susceptible to the magnetic behaviors (moment) of proximally excited atoms in the coil. By contributing aligned e-shells to lateral rotatory action, the iron/nickel atoms amplify the strength of the coil's electromagnetism.

Note: The fiber-based atomic model for magnetism presented here was inspired by the ideas of Descarte, Faraday, innumerable mathematical physicists, and especially the ideas of Bill Gaede.

magnetism



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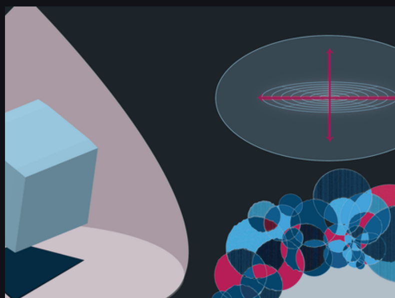

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