Origin of magnetic fields may lie in special relativity's spacetime distortions

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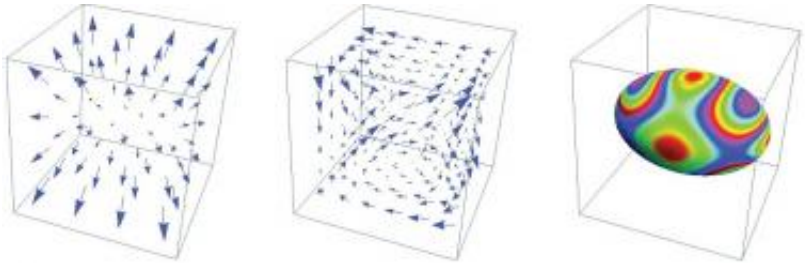

Images of (left) the vector, (middle) the generated vorticity, and (right) the magnitude of the square of the vorticity of the new mechanism for the origin of magnetic fields. Image credit: S. M. Mahajan, et al. © 2010 The American Physical Society.

(PhysOrg.com) -- Magnetic fields play an important role on scales ranging from the sub-atomic to the cosmic, from particle spins to galaxy clusters. Although scientists know how to create and manipulate magnetic fields, as well as use them for a variety of applications from computers to credit cards, they still don't have a universal theory of how magnetic fields initially originated in astrophysical settings. In a new study, two scientists have proposed a new primary generation mechanism for the magnetic field that is based on the spacetime distortions caused by special relativity.

Magnetic fields are invisible fields that exert a vector force, characterized by both strength and direction, and are produced by

magnetic objects or changing electric fields. When described by ideal dynamics, magnetic fields are mathematically and physically equivalent to a vorticity, meaning they have a tendency to rotate. This is what makes it difficult to determine the origin of magnetic fields, since it means that magnetic fields have helicity, which is a kind of "topological charge." However, helicity cannot change under the influence of an ideal force, forbidding the emergence of any vorticity from an initial zero value.

To get around this constraint, scientists have more recently turned to non-ideal dynamics. Researchers have looked at non-ideal mechanisms ranging from something called the baroclinic effect to processes stemming from inflation, quantum chromodynamics phase transitions, and radiation effects. However, while these mechanisms likely play a role in magnetic-field generation at some scales, none of these effects can be considered a universal mechanism that operates at all scales.

In their new study, Swadesh Mahajan from The University of Texas at Austin and Zensho Yoshida from The University of Tokyo have proposed something entirely different. Since all non-ideal mechanisms are too weak and not general enough to explain the origin of magnetic fields, they decided to reexamine the ideal dynamics. They found that vorticity/magnetic fields can be generated in strictly ideal dynamics, as long as the dynamics is embedded in the twisted spacetime described by special relativity. Their mechanism can seed a magnetic field, which can then be amplified by the dynamo mechanism to create larger magnetic fields.

As the physicists demonstrate, special relativity effects can destroy the topological constraints that would otherwise forbid the creation of magnetic fields. Basically, the relativistic distortions of spacetime can modify the way in which inhomogeneous flow fields interact with inhomogeneous entropy. Although other mechanisms can still play a role

in creating magnetic fields, the new relativistic drive emerges as a strong ideal universal origin mechanism for seeding magnetic fields. The new mechanism is especially dominant for highly relativistic flows, such as cosmic particle-antiparticle plasmas, plasmas in the magnetosphere of neutron stars, etc. Even for nonrelativistic plasmas, the relativistic drive can easily overcome damping and remain dominant until the magnetic field reaches values in the range ~1 gauss, which is about twice that of the Earth's magnetic field.

“To generate magnetic fields (a vorticity) from a state of no magnetic field, we must break the topological invariant,” Mahajan told PhysOrg.com. “For that to happen, the effective force has to be so that it cannot be expressed as a perfect gradient. The baroclinic departure could do it, and special relativity does it (in ideal dynamics) by simply demanding that the equations of motion be Lorentz invariant.”

The discovery that special relativity can provide an ideal universal vorticity generation mechanism could help scientists understand the origins of the massive magnetic fields in astrophysical settings. As one of the most challenging unsolved problems in theoretical physics, finding a universal origin of magnetic fields could also shed light on the properties of large physical systems, and possibly even advanced spacetime geometries.

“Magnetic fields are found in all levels of cosmic and astrophysical settings,” Mahajan said. “Most of them are, perhaps, relic fields created at some time in the evolution of the universe. The magnetic fields could have played a very fundamental part in the structure formation. Unless one isolates how and where and perhaps when they are generated, it is hard to put together a satisfactory story of the universe. Unraveling the origin story is a big deal. Magnetic field generation in laboratory systems, especially in the highly relativistic systems, is again a fundamental determinant of the further evolution of such systems and

needs to be understood. We are nowhere near the complete unraveling, but we hope that we may have taken a major step towards creating an eventual story; it will require a lot of computational and modeling effort to develop the story."

More information: S. M. Mahajan and Z. Yoshida. "Twisting Space-Time: Relativistic Origin of Seed Magnetic Field and Vorticity." *Physical Review Letters* 105, 095005 (2010). DOI:10.1103/PhysRevLett.105.095005