This magnetic moment

Magnetism, like many forces of nature, baffles scientists and inspires poets. Now, it may set tomorrow’s electronics all a-spin.

By Anita Martin

Magnets have attracted attention since the ancient Greeks, who found strange stones near the city of Magnesia, powerful enough to pull iron. Around the same time, the Chinese fashioned a needle from such materials, and watched as, suspended, it pointed north and south. The magnetic compass soon followed, sending explorers into great, blue waters, and eventually, all over the world.

Then, in 1958, another explorer, Explorer-1, found the Earth’s biggest magnet: the Earth itself. Explorer-1 was an American satellite that discovered the magnetosphere, a region around the Earth streaming with electrically charged particles, where magnetic and electric phenomena reign.

So what’s the world’s smallest magnet? “There’s some debate,” says Saw Hla, an assistant professor of Astronomy and Physics. “But it could be the electron.”

Dr. David P. Stern of the Goddard Space Flight Center agrees. “Imagine (the electron), as people around 1900 imagined it,” Stern says, “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 part acting like a small current, and the result would be that the electron is magnetized along its rotation axis—it has a magnetic moment, in science-speak.”

Stern’s comparison has its limits. Electrons, as fundamental particles, have no practical dimensions: no radius, no axis and therefore, no “rotation” as such.

That said, “the electron behaves as if it had attached to it a magnet,” explains Nancy Sandler, an Ohio University nanoscientist. “And since a magnet can also be created by making circular electric currents, people find useful the association with something that is rotating.”

“Electron spin,” as we call it, was discovered in 1925 by S.A. Goudsmit and George Uehlenbeck. Similar to how the Earth, the world’s largest magnet, revolves around its axis; the nanomagnet electron contains an intrinsic "spinning" quality. When their "spins" align, electrons help determine an atom’s or a molecule’s magnetism, and promise tomorrow’s technological revolution: spintronics.
Less is more

When that revolution hits, the Nanoscale Interdisciplinary Research Team (NIRT) at Ohio University hopes to lead the insurgency, with electrons as their secret weapon.

“Spintronics is still such a new field that’s emerging,” says Muhammad B. Haider, a fifth year Ph.D. “In the 1960s, this field was electronics; now we have spintronics.”

Haider, who plans to follow a professional path into nanotechnology research, has been actively scouting this new field for years. In fact, his current project is three years in the works. Using the Molecular Beam Epitaxy (MBE) device, Haider creates something you can’t find in nature: a magnetic semiconductor.

Although under nature’s recipe, magnets are usually metals, (e.g. iron, cobalt and nickel), Haider can cook up a semiconductor from scratch, with magnetic atoms mixed in.

Haider’s ingredients of choice are nitrogen (N), gallium (Ga) and manganese (Mn) or chromium (Cr) (a magnetic metal), on a sapphire substrate. A carefully constructed GaMnN or GaCrN makes what’s called a diluted magnetic semiconductor.

Diluted magnetic semiconductors attract scientists and engineers because they allow greater control over electron density, which can transform the material from a semiconductor to a metallic material—and back again.

“If you apply enough voltage, you can drive more electrons into these semiconductors,” explains Arthur Smith of the NIRT team. “When the electron density reaches a certain point, the material becomes magnetic. Then, by reversing the polarity of voltage, you can drive the electrons back out.

Electron density can be controlled in a semiconductor using electric fields,” explains Arthur Smith of the NIRT team, “This can then allow control of magnetic fields by simple application of voltage.”

Down the line
One possible function of semiconductor magnets, as Haider points out, lies within the fantastic future of spintronics. While electronics works with the charge and transfer of electrons, spintronics seeks to control the spin. As of now, however, applications of spintronics remain largely speculative.

“You have to really understand before you can apply,” says Hla, who also researches spintronics. “You have to really know what you’re building.”

Hla’s building molecules from cobalt, extracted from human blood, and surrounded by four “carbon legs,” which he lines up as perfectly as he can into rows and columns.

Hla imagines many practical possibilities for his research; including cooling down and possibly speeding up laptop computers. To transfer information through a laptop, electrons must move from point A to point B. But, if we could line up electrons, and transfer information by means of magnetic electron spin...

“Imagine a delivery system,” Hla says, “You can give parcels to people, and let those people run to deliver it. Now, the people have to move. That is electronics—the flow of electrons. Or, we could let many people queue, and they could just pass the parcels down the queue. Now you don’t need to move people, just your hands.”

Likewise, if one electron could shift an adjacent electron’s spin, information could be passed for longer distances with less interference—all without the extra heat.

“Electrons have two important properties that can transfer information: charge and spin,” Sandler says, “now we use charge—we simply transfer the electrons themselves. To manipulate the spin as well is like tapping into an information source that was there but you couldn’t get to it.”

“Spintronics is only a dream now,” Hla says, “but if we keep researching and developing, spintronic devices are very promising.”

Don’t worry if spintronics leaves you feeling a little dizzy. With a science as small as this, uncertainties abound. Not to mention that the precise nature of magnetism remains mysterious. Although new surprises emerge at every turn of the electron, somewhere between the planet Earth and the electron, nanoscientists lay the foundations for tomorrow’s technology.