Electron spin resonance experiment pdf

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In atomic physics and chemistry, electron spin is a property of an electron that is loosely related to its spin about an axis and its angular momentum. Two electron spin states are allowed, which are described by the quantum number ms, with values of +½ or -½ . The spin of an electron isn't as easily visualized as the spin of an ordinary object, such as a marble. Spin has a definite magnitude and it does have a direction, but quantization makes this more complicated than direction using regular vectors. The SI unit of spin is the Newton meter second (N·m·s). This is the same unit as angular momentum in classical mechanics. However, spin is often calculated as the spin angular momentum divided by the reduced Planck constant $\hbar$, yielding a dimensionless value. There are practical applications of electron spin. These include nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), electron spin resonance spectroscopy, and giant magnetoresistive (GMR) drive head technology. Physicists at the University of California, Riverside have achieved a breakthrough in developing a “spin computer,” based in part on graphene, that could pave the way for machines that never need to boot up—or even just remain on all the time, consuming virtually no power in the process.A computer based on this technology—dubbed tunneling spin injection—utilizes an electron’s spin state as a way to efficiently store and process data. Spin computers generate less heat while running much faster than today’s silicon-based machines.Here’s how it works: physicists can polarize an electron such that it has a directional orientation or “spin.” It means electrons can either spin up or spin down. And since electrons are, well, extremely small, you could store much more data in this fashion than with conventional electronics.The new idea is to use graphene, a single-atom sheet of carbon atoms in a honeycomb pattern, as a heat-resistant conductor for tunneling spin injection. Graphene first shot into the limelight several weeks ago when Andre Geim and Konstantin Novoselov won the 2010 Nobel Prize in Physics for experiments with the two-dimensional material.“Graphene has among the best spin transport characteristics of any material at room temperature,” Roland Kawakami, associate professor of physics and astronomy at UC Riverside, and the research team lead, said in a statement. He added that graphene’s characteristics make it a promising candidate for use in spin computers.There’s a catch, though: electrical spin injection from a ferromagnetic electrode into graphene is inefficient, Kawakami said. “An even greater concern is that the observed spin lifetimes are thousands of times shorter than expected theoretically. We would like longer spin lifetimes because the longer the lifetime, the more computational operations you can do.”To solve the problem, the team inserted a nanometer-thick insulating layer in between the graphene layer and the ferromagnetic electrode. The result: dramatically improved efficiency.Kawakami said that graphene could eventually enable electrons with much longer spin lifetimes than normal. “This lifetime could be microseconds long,” he said. “A long lifetime is a special property of graphene, making it a very attractive material for a spin computer.”So far, tunneling spin injection remains a laboratory-only endeavor. But the implications for future generations of computing could be profound. Next up for Kawakami’s team: a working spin logic device that demonstrates many of the above concepts in action.(Image credit: Kawakami lab, UC Riverside.) An atom is best visualized as a tight, dense nucleus surrounded by buzzing, orbiting electrons. This picture immediately leads to a question: How do electrons keep whirling around the nucleus without ever slowing down? This was a burning question in the early 20th century, and a search for the answer ultimately led to the development of quantum mechanics itself.In the early 20th century, after countless experiments, physicists were just beginning to put together a coherent picture of the atom. They realized that each atom had a dense, heavy, positively charged nucleus surrounded by a cloud of tiny, negatively charged electrons. With that general picture in mind, their next step was to create a more detailed model.Related: Weird 'gravitational molecules' could orbit black holes like electrons swirling around atomsIn the earliest attempts at this model, scientists took their inspiration from the solar system, which has a dense "nucleus" (the sun) surrounded by a "cloud" of smaller particles (the planets). But this model introduced two significant problems. For one, a charged particle that accelerates emits electromagnetic radiation. And because electrons are charged particles and they accelerate during their orbits, they should emit radiation. This emission would cause the electrons to lose energy and quickly spiral in and collide with the nucleus, according to the University of Tennessee at Knoxville (opens in new tab). In the early 1900’s physicists estimated that such an inward spiral would take less than one-trillionth of a second, or a picosecond. Since atoms obviously live longer than a picosecond, this wasn't going to work.A second, more subtle issue had to do with the nature of the radiation. Scientists have known that atoms emit radiation, but they do so at very discrete, specific frequencies. An orbiting electron, if it followed this solar system model, would instead emit all sorts of wavelengths, contrary to observations.The quantum fixFamed Danish physicist Niels Bohr was the first person to propose a solution to this issue. In 1913, he suggested that electrons in an atom couldn't just have any orbit they wanted. Instead, they had to be locked into orbits at very specific distances from the nucleus, according to the Nobel Prize citation entry for his subsequent award (opens in new tab). In addition, he proposed that there was a minimum distance an electron could reach and that it could move no closer to the nucleus.He didn't just pull these ideas out of a hat. A little over a decade before, German physicist Max Planck had proposed that the emission of radiation might be "quantized," meaning an object could only absorb or emit radiation in discrete chunks, and not have any value it wanted, according to the HyperPhysics reference page at Georgia State University (opens in new tab). But the smallest size of these discrete chunks was a constant, which came to be known as Planck's constant. Prior to this, scientists thought such emissions were continuous, meaning particles could radiate at any frequency. Planck's constant has the same units as angular momentum, or the momentum of an object moving in a circle. So Bohr imported this idea to electrons orbiting a nucleus, saying that the smallest possible orbit of an electron would equal the angular momentum of exactly one Planck constant. Higher orbits could have twice that value, or three times, or any other integer multiple of the Planck constant, but never any fraction of it (so not 1.3 or 2.6 and so forth).Planck's constant written out. (Image credit: ragsac via Getty Images)It would take the full development of quantum mechanics to understand why electrons had such a minimum orbit and clearly defined higher orbits. Electrons, like all matter particles, behave as both particles and waves. While we might imagine an electron as a tiny planet orbiting the nucleus, we can just as easily imagine it as a wave wrapping around that nucleus.Waves in a confined space have to obey special rules. They can't just have any wavelength; they must be made out of standing waves that fit inside the space. It's just like when someone plays a musical instrument: If you pin down the ends of a guitar string, for example, only certain wavelengths will fit, giving you the separate notes. Similarly, the electron wave around a nucleus has to fit, and the nearest orbit for an electron to a nucleus is given by the first standing wave of that electron.Future developments in quantum mechanics would continue to refine this picture, but the basic point remains: An electron can't get any closer to a nucleus because its quantum mechanical nature won't let it take up any less space.Adding up the energiesBut there's a completely different way to examine the situation that doesn't rely on quantum mechanics at all: Just look at all the energies involved. An electron orbiting a nucleus is electrically attracted to the nucleus; it's always being pulled closer. But the electron also has kinetic energy, which works to send the electron flying away.For a stable atom, these two are in balance. In fact, the total energy of an electron in orbit, which is a combination of its kinetic and potential energies, is negative. That means you have to add energy to the atom if you want to remove the electron. It's the same situation with the planets in orbit around the sun: To remove a planet from the solar system, you'd have to add energy to the system.One way to view this situation is to imagine an electron "falling" toward a nucleus, attracted by its opposite electric charge. But because of the rules of quantum mechanics, it can't ever reach the nucleus. So it gets stuck, forever orbiting. But this scenario is allowed by physics, because the total energy of the system is negative, meaning it's stable and bound together, forming a long-lasting atom. Originally published on Live Science on Jan. 21, 2011 and rewritten on June 22, 2022.

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